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Application of Remotely Sensed Data and GIS in Assessing the Impact of Mining Activities on the Environment

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ABSTRACT: Primary industries such as mining form the backbone of developing economies throughout much of the world. A century of production driven, environmentally insensitive policies however, are leading to massive soil degradation and contamination, toxic vegetation, groundwater {surface and subsurface) pollution, mine dump disposal and landscape defacement around the mining areas. A systematic and multi-disciplinary approach of mapping, monitoring and controlling the impact caused by the mining activities is necessary so as to understand the character and magnitude of these hazardous events in an area. This paper first addresses the issues concerning mining and its impact on the environment and on goes to assess the various remotely sensed geo-İnformatioo tools available nowadays for capturing up-to-date and detailed earth observation data, processing and interpretation in mining induced environmental problems.

1 INTRODUCTION

Any actual mine site is just one point in a long line of activity before and after the digging starts. Unlike the days when mining was a low-tech 'pick and shovel' enterprise, with perhaps a bit of dynamite thrown in, today's mining and mineral extraction industry is high-tech and often chemically intensive.

It is a transitory land use that takes many forms; e.g., dredging, placer area mountaintop removal and contour operations. It requires an extensive network of industrial infrastructure that can disrupt the surrounding land and stretch far beyond the comparatively small footprint of the mine or exploration site. In spite of its great economic benefit therefore, *it* creates many environmental problems İn which the chemical and physical properties of the spoil change to create a hostile environment (Poulin & Sinding, 1993). While it is easy to believe they are not there, in many countries of the world, mining activities is resulting in disastrous impacts on the basic life-support systems such as clean air and water, productive soil and the Earth's rich biotic diversity by:

- Destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes,
- Causing erosion, sedimentation, subsidence and landslides,
- Contributing to floods,
- Pollutant loading to groundwater and surface water from acid mine drainage,
- Process solution leaks, spills, and surface subsidence,
- Destroying or altering fish and wildlife habitats,
- Impairing natural beauty,
- Damaging the property of citizens,
- Creating hazards dangerous to life and property
- Degrading the quality of life in local communities, and
- Counteracting governmental programs and efforts to conserve soil, water, and other.

Precautionary measures must be taken to stabilize these areas and/or proper planning be taken prior to mining so as to avoid serious pollution and degradation of the environment. Remote sensing from aircraft and satellites, is a powerful tool used in Earth resources mapping which can be adapted for environmental monitoring of mining induced activities. The large number of satellites orbiting the Earth allows for frequent downloading of images of any particular area. Combining such data with other ancillary data types in a Geographic Information System (GIS) allows decision-makers and planners with adequate and understandable information to assessing the impact within a relatively short period of time.

2 MINING AND THE ENVIRONMENT

2.1 *Mining Issues*

Mining involves several stages; namely, site development, mining, mineral extraction/ benefication/processing and mine closure. Each of diese stages of the mining process has the potential for different impacts of various degrees depending on the sensitivity of local terrain, the type of technology employed the skill and knowledge of the company and its ability to monitor and enforce compliance with environmental regulations.

Site development starts with the discovery of a potential mineral deposit. The next problem is devising a way to get all the necessary equipment and manpower to the site in order to begin the extraction process. Quite often, mine sites are situated in out of the way areas that require the construction of a road network (roads/ railways/air access routes), making deleterious road impacts one of this phase's biggest environmental problems. New access roads and townships often initiate unplanned development and squatting. The construction of road access to the area concerned causes disturbance of the surface, and has negative effects on vegetation, wildlife, deforestation and residents İn me area.

Mining involves three categories: surface mining, underground mining and in situ mining. Initial preparation of surface mine involves removing the vegetation, topsoil, blasting, gross sizing of ores and extensive modification of the topography of the entire area (see Fig.1). Such activity brings local air quality problems because of the amount of dust raised from the exposed earth. The surrounding area is littered with waste rock dumps, tailings and slime dams, creating a zone of residues. These are mostly earthy in nature and hazardous to health if the mineral extracted is dangerous (such as uranium and/or thorium bearing ore or asbestos), or if it has been washed with toxic or harsh substances (e.g., cyanide, mercury and sulphuric acid) to separate the valuable materials from waste products. The waste rock and soil dug up during ore extraction, called overburden, are mostly piled in dumps, which take up good land and pollute soil and water. Surface waters draining the dumps of waste rock carry pollutants to agricultural land and drinking water supplies. In most cases, the combination of the physical and chemical characteristic often renders steep, barren and unproductive land - a sterile landscape indeed. In many omer countries, the residues during the drier seasons often cvumble to a fine dust from which even a wind of moderate force can produce a miniature sandstorm. When it rains, the sodden dumps revert to amorphous slurry, which spreads to the nearby-cultivated land and water supplies.

All subsurface mining results in the transfer of material from beneath the surface to the surface itself. Abstraction of groundwater is often required. Like surface mining, underground operation cause surface disturbance by requiring land for waste rock disposal, storage of ore and low-grade material and siting of ancillary facilities. Removal of rock and subsurface water frequentiy results in surface subsidence and collapse. Subsurface mining creates the potential for mine effluent - acid mine drainage and heavy metal concentrations. These effluents can wreak havoc on watersheds and aquatic ecosystems. This acid mine waste quite often leaches into ground water, streams, and lakes causing pollution to entire streams and rivers. It can lead to fish kills and sterilisation of biologically rich areasr

Figure 1 Fiion Norte open pit mine in Tharsis, southwest Spain.

Finally, in situ leaching is probably the least known mining method and the process basically involves drilling smaller holes in the site, and using water based chemical solvents to flush out the desired mineral in a solvent state. At first glance, the rninimalization of waste represents one of the most environmentally beneficial aspects of this method. On the other hand, the injection of toxic substances directly into the earth both in and near the water table represents one of the least environmentally beneficial aspects of the method.

Mineral Processing. Once extracted, the mineral in question needs to be processed or cleansed of its impurities. This stage, also known as benefication commonly involves chemically intensive activities. Benefication/ processing may include mechanical, gravitational, magnetic, chemical, electrochemical, and/or thermal methods of separating target minerals from wastes and concentrating values prior to sale. Contaminants build up in the soils near smelters, some finding their way into food crops. Air pollution from smelters might release poisonous particles and noxious gases into the atmosphere. This, when not controlled, fine their way into the water, soil and vegetation usually causing severe health hazard to the miners and the community close to the mine site.

Airborne pollution from rubble dumps, slimes dams, open pits and overburden heaps in the form of dust İs potentially a serious hazard.

Waste disposal methods vary from site to site. They can be left İn piles next to the site, or backhoed into the mine, in either case, the issue of acid mine drainage remains a potential environmental problem. Waste is also stored in containing ponds or dams to minimise the acid mine drainage. These however, are not always stable. The chemically intensive nature of the benefication stage increases the possibility of an accidental spill, and human nature being imperfect means that spills are a common occurrence.

Mine closure. The closure of a mine often involves severe and devastating environmental and socio-economic impacts. The dramatic loss of employment and the faltering of many small enterprises in the area are a major blow to die population involved. With surface and underground mines, the main hazard revolves around erosion, weathering, seepage, impairing of natural beauty, damage to property of citizens and total failure of steep pit walls and waste pile slopes. Acid pH-values and hazardous mineral content may hamper revegetation, while dust from wind erosion of tailings, ponds and waste rock piles may cause air pollution. The sort of hazard and risk evolving from those abandoned mines may vary. There are those that we can see and those, which we don't. The problems that uranium, radium and other radioactive mines deliver are there to stay for centuries to come. Besides, abandoned and unguarded excavations including prospect pits, open pits, shafts and audits of which there are more than hundreds are hazardous to the reckless, the unwary, or the uninitiated. Closed plants, workshops, houses and infrastructure (roads, railways, etc.) are unsightly and may become safety hazards.

Site restoration projects are always problematic in many countries. Legal requirements for site restoration do not exist and hence, the adverse impact of such neglected mines is evident. First there is the issue of money. Nearly all have enacted various degrees of less than stringent environmental regulations in the hope ofdrawing İn foreign capital. Site restoration requirements as a result, get lost in the shuffle always. In the mean time, environmentally hazard continues at an alarmingly consistent rate.

2.2 *Mining Stages*

The types of mines vivid in many countries fall into:

Abandoned mines. Those, which were exploited in the past but, are in some way or other discontinued and not functioning anymore. Some of mem are pre-historical in nature or were reactivated at different periods and times in their history. In most countries, the active mines of today might have been the abandoned mines of the past. Whatever they are, the unregulated mines of the past typically dispose mine wastes without any environmental controls or constraints. In many settings, this old mine wastes remain vulnerable to wind and water erosion. They still release pollutants many years after the mines or enterprises have shut down. Where restoration laws are intact, their implementation can be highly problematic. Cleaning these mines and industrial sites nowadays is extremely costly and non-affordable by any government standard. Furthermore, cleaning up the sites may not result İn appreciable improvements in human health or the environment. Consider the case of environmental restoration of uranium mines in Namibia. Firstly, the volumes of the accumulated radioactive waste are far too high to be removed at a reasonable cost. Secondly, safer alternative disposal sites are either not available or else are impractical. Given resource constraints, what decision rules should guide activities for remediation? Which sites should be addressed first? These issues are hard to answer.

Reactivated and active mines. These have also their stories to tell. During their operating periods, many have not kept any environmental standards and have maintained no sparkling compliance records. Environmental studies even if they exist, are often incomplete, widespread or are in the form of uncontrolled mosaics and reconnaissance sketches.

The impact of mining is often not a W:al phenomenon. On the contrary, the effect that this hazard has might involve air, water and soil pollution, which might have a national, regional, and international character. To effectively map and apply environmental control methods, the potential hazards of each mining phase and their impact on the environment have to be understood.

Generally, each mining has its own local features, impacts and unique settings. Although it is always possible and easy to describe a generalised situation, each mine (whatever its status) has variable impact on the environment that requires differing mapping and monitonng approaches. Studying me impact of radioactive mines in general is not restricted to local situation alone. It can sometimes inflict larger area and health-wise anyone living in its surroundings (even when not using water, soil, etc.) contrary to sulphide mine which can sometimes involve local phenomena and where its impact on health is felt upon using the contaminant which is associated with it. Again, in most abandoned mines, original scenarios (before the mining starts) are hard to establish. For one thing there is no literature or maps available and no environmental impact assessment (EIA) was done prior to the activity. What went on İs therefore hard to establish.

In another situation, a reactivated mine might trigger the removal of old waste to another locality or pile İt İn the same area resulting in toxic chemicals polluting not only the rivers but also the soil. The landscape defacement might have gone unnoticed. Besides, the origins of the waste dumps created are hard to establish making it impossible to analyse the pollutant involved. The old contamination and those deposits outside the known mining sites are especially interesting since they might have already been covered by soil and vegetation and occasionally difficult to map.

3 REMOTE SENSING AND GIS TOOLS

Rational management of the natural resources and of the environment depends not only upon the wisdom of decision-makers but particularly upon the availability to them of necessary information. Traditional methods of storing information about resources and the environment and of retrieving it depend upon the use of maps. With most mining sites (abandoned, reactivated or active) İn the world: baseline datasets regarding the mine, mine operation, impact on soil, water, vegetation, flora and fauna, etc., is either missing or totally absent. When available are rather incomplete, inadequate or inaccurate for this purpose. Any study regarding past mining activities, extent and their current impact on the environment therefore has to start from zero. Remote sensing (e.g., airborne or satellite borne) is one of the best tool we have nowadays which can provide a matching spatial coverage. Nearly all are obtained in digital format. Even if they are not (e.g., standard aerial photographs) they can easily be scanned and incorporated as a tool into the interpretation processes. Modern image processing techniques of digitally formatted data are available m market nowadays, which can be used to enhance, manipulate, classify and subsequently interpret the data.

3.1 *Optical Remote Sensing*

Aerial photographs has been used since the early 20^th century to provide spatial data for a wide range of applications. It is the oldest, yet most commonly applied remote sensing technique. *Nowadays,* almost all topographic maps are based on aerial photographs. The latter (taken either İn black & white or colour), because of its high resolution, also provide the accurate data required for many cadastral surveys, Earth resource and geo environmental surveys. Figure 2 represent the aerial photo of the Tharsis sulphide mine in Southwest Spain. Woldai & Fabbri (1998), using such photographs taken from different periods and at different scales were able to map the various land use, land cover, soil, vegetation, urban and infrastructure in the area in detail. Landslides, subsidence, mining waste dumps and other activities associated with mining hazard can easily and successfully be delineated and monitored.

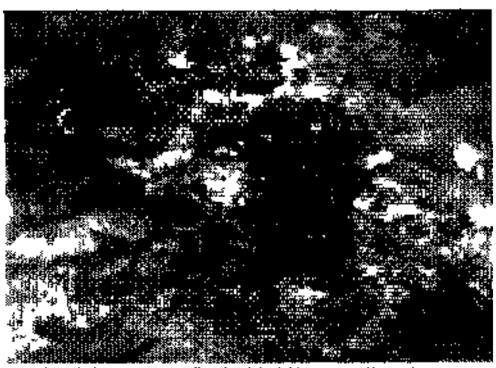
Aerial photographs are taken in stereo, in which successive photos have a degree of overlap to enable stereo-interpretation and stereo measurements. Apparently, most mines are situated İn remote areas and aerial photograph covering such area is usually absent in many countries. Besides, running repetitive aerial photographic coverage of such area is always expensive to allow change detection mapping.

There has been phenomenal growth in the field of satellite remote sensing over *the last* two decades (refer to http '/«uelliies Melius se/ for further reading). While the importance of all existing Earth Observation Satellite (EOS) systems in mapping and zoning the impact of mining on the environment is acknowledged and can not be denied, in this paper, only the most widely used images are discussed.

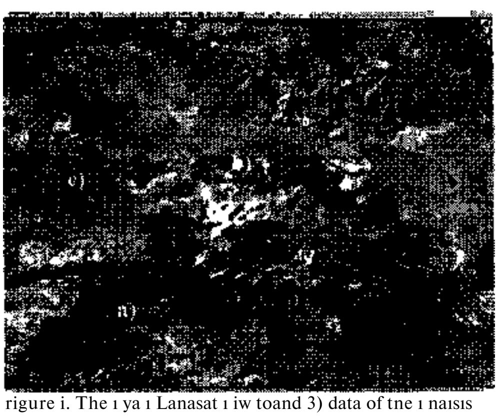
Figure 2 Aerial photo coverage of the Tharsis sulphide mine in Southwest Spain The mine site for some years now is not in operation

Almost 30 years after the first EOS went to orbit, *Landsat MSS and TM* still remain the most popular and the most widely used remotely sensed data applied in many scientific researches and productions. Landsat MSS with its 80 m resolution comprise of four bands ranging from the visible to the near infrared region. Mining induced activities may affect large areas and in this respect Landsat MSS can be used to map such area. As is shown in Figure 3 however, the resolution been coarse, details might be absent.

Landsat TM on the other hand, has 30 m resolution and six broad spectral bands in the Visible, Near Infrared - NIR and Short Wave Infrared - SWIR region and a Thermal band of 120m resolution. The better resolution of TM (Fig.4) implies that better delineation and assessment of the features in mining induced activities is possible than with Landsat MSS. Besides, the compilation of resources and environmental maps up to a scale of 1:100 000 can be achieved with high reliability (Woldai & Fabbri, 1998).



__„_!__.!_'__________"._^ı„Ljıd4)ı n -li • In • a in Southwest Spain. The very dark area correspond to mining dumps, open-pit mine and polluted lakes; dark grey to bushy vegetation (known as 'Jara' in Spain; grey corresponds to grass and white bare soil



rigure i. The ı ya ı Lanasat ı iw toand 3) data of tne ı naısıs area. Southwest Spain. The mining activities are much betler represented in this image than Figure 3. The change in land use is ma) where eucalyptus is growing as part of the afforestation programme in the area, b) represented the polluted lake showing different spectral signature than was possible m Figure 3 c) represents the bushy vegetation ('jara').

Woldai & Limptlaw (2000) used Landsat TM/MSS and aerial photographs taken at different time to monitor the changes inflicted by many years of mining activities in the Ndola mining area İn Zambia. By applying various image processing techniques including the Normalised Difference Vegetation Index (NDVI) to the images taken in 1989, 1993 and 1997, they were able to measure the presence of green vegetation, tailing dams and barren rock/soil including waterbodies and infrastructure (Limptlaw & Woldai, 2000). Besides, by including aerial photograph • of 1968 to the datasets, they were able to demonstrate the changes that have taken place in this area in the last thirty years (Woldai & Limptlaw, 2000). The degree to which spectral information derived from remotely sensed data (Landsat TM, MSS and aerial photos taken at different times) can be used to' extract land cover changes and contamination- from mining activities was also assessed by Woldai & Fabbri (1998) in the Tharsis mine area in Southwest part of Spain. By using Landsat MSS/TM and aerial photographs, all taken at different periods, it was possible to analyse:

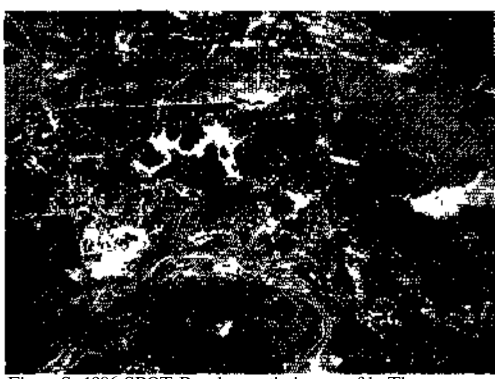
- Land uses changes associated with opencast mining.
- Evolution of dumping grounds.
- Delineation of the exact location of mine works, waste tips and land cover and land use changes.
- Landscape defacement as a result of mining activities.
- Barren wasteland.

The Thermal band, designated as TM6 can successfully depict higher temperatures related to underground coal fires (Prakash et al., 1995, 1999). Surface fires are nigh temperature phenomena, which show up also on short-wave InfraRed bands. By using a false colour composite generated by combining TM bands 7, 5 and 3 İn red, green and blue, respectively, they were also able to map surface fires and depict their aerial extent in the Jharia coalfield of India and North-west China. In an area like the Jharia coalfield (JCF), where extensive and rapid underground and opencast mining is going on continuously, land-use studies are of paramount importance. Prakash & Gupta (1998), on the basis image processed Landsat TM image data FCC of bands 4/3/2, 7/5/3, 5/4/2 (in RGB order) and ratio images was able to discriminate dense vegetation, sparse vegetation, fire, opencast mining (coal), overburden dump, subsidence and barren wasteland, settlement, transport network, river and water pond. Currently Landsat 7 ETM plus is added into the list with the same specifications as its predecessor, exception been, the introduction of an additional panchromatic band at 15 m resolution and an improvement of TM band 6 (thermal band) from 120 m to 60 m resolution.

Equally, various environmental analysts have used the *SPOT systems* (SPOT 1 and 2) for some years. The Panchromatic mode acquired in the visible region of the electromagnetic spectrum has a resolution of 10 m (Fig.5) while the M ulti-Spectral

(XS) has three bands in the visible to Near Infra-Red region.

SPOT 4, which is operational since March 24, 1998 offers a number of improvements over its predecessors; including the addition of a short wave infrared (i.e. mid IR) band. In order to allow on-board registration of all bands, the 10 metre panchromatic band on SPOT 1-2 has been replaced on SPOT 4 by 10 and 20 metre sampling of band 2 (red). The spectral bands measured by the HRVIR instruments have been carefully selected to match the SPOT missions requirements, particularly for: monitoring of crop and plant health, land use and land cover mapping, forestry, natural hazard and pollution monitoring, water resources evaluation, topographic and relief mapping, ecosystem monitoring, etc. In addition to the two high-resolution HRVIR instruments (each offering resolutions of 10 and 20 metres), SPOT 4 also carries the "Vegetation" wide-angle, medium-resolution payload offering a swath width of 2,250 km and a resolution of 1 km offering analysts with vegetation's excellent revisit capability. The stereo capability of SPOT panchromatic allows for precision mapping of various terrain features. It can assist in verifying the accuracy of existing maps and databases, updating other mapping information (e.g., vegetation, soil, hydrologie, settlement, etc.), serve as an up-to-date map for poorly mapped or unmapped areas and create highly accurate derived databases, such as land use or land cover maps



FigureS. 1986 SPOT Panchromatic image oftheTharsrs area (covering a window of Figure 3) showing the various mine dumps, open-pit mine, polluted lake and infrastructure

Chevrel & Coetzee (2000), using SPOT image and other data derived from various sources (e.g., digital elevation models, geology, airborne radiometry, data on water quality, etc.), were able to identify pollution, assess the environmental impact of mining activities and develop methods for assessing the risk and sensitivity analysis of surface and groundwater of the West Rand area - Gauteng Province, South Africa. Particularly by using digitally supervised classification of SPOT and Landsat TM images, they were able to classify the land-cover map, later recorded as an infiltration potential map. Accurate classification of the mining activity areas provided them with a map of potential pollution sources. Tailings dams were also easily identified and inventoried through a visual interpretation of SPOT image. The suitability of Landsat TM and SPOT Panchromatic data for assessing and representing changes in land cover (from 1986 to 1995) due to gold mining activities is also noted from the work of Ardanza (1999) working in the BOSAWAS Biosphere Reserve in Nicaragua. Ardanza İn his work was able to delineate several illegal mining. His research using SPOT and TM data revealed, the lost of 220 hectares of forest to illegal mining in about 10 years period.

In the list of Earth observation satellites used for mapping nowadays are the ***Indian Remote Sensing Satellites:*** IRS-1A (launched m 1988) and its identical follow-up 1RS-IB (launched in 1991). India's latest satellites IRS-1C and IRS-1D were launched in 1995 and 1996. In particular, the IRS-IC and IRS-ID introduced a heavier (1,350 kg), more capable Earth observation platform. The spacecraft bus is similar to those of IRS-1A and IRS-IB, but a slightly larger solar array generates more than 800 W. Both IRS-1C and ID produce 5.8-meter panchromatic (0.50.75 u.m - black and white) imagery, which is resampled to five-meter pixel detail, an improved spatial resolution than the SPOT panchromatic with 10 m resolution. The multispectral data acquired are comparable with Landsat's MSS and TM. These satellites are also equipped with two-band Wide Field Sensors (WiFS) that cover a 774-square-kilometer (481-square-mile) area in a single image, as well as LISS-3 4-band (0.52-0.59, 0.62-0.68, 0.77-0.86, and 1.55-1.70 urn) multispectral sensors that provide 23.5-meter resolution multispectral coverage. The 23.5-meter resolution imagery is resampled to produce 20-meter pixel detail. The spacecraft also carry a 2-channel (0.62-0.68 and 0.77-0.86 urn) wide-field sensor (190 m resolution).

3.2 *Microwave Remote Sensing*

For parts of the world, including some developing areas, that is habitually covered with cloud, the advent of airborne radar (Fig.6) and spaceborne radar (eg. Radarsat-1, ERS-1, JERS-1) has also provided excellent new tools for earth resources mapping, Unimpeded by haze and most cloud conditions and equally suitable İn day- and night-time, SAR could be used to survey, map and monitor various landuse and land cover activities relate to mining activities. A large archive of SAR data has been constructed since the launch of the European Remote Sensing Satellites _ERS-1 and 2_ in July 1991 and April 1995, respectively, and this database is continually being updated now by ERS-2 with new acquisition. Colour composite created by combining ERSİ and ERS2 data acquired at different periods; may allow for delineating mine waste dumps, polluted tailings and hydrographie networks (Fig. 7).

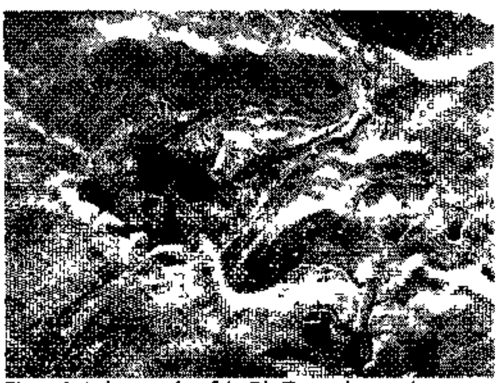


Figure 6 Airborne radar of the Rio Tinto mine area in Southwest Spain showing the different mine dumps.

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Similarly, the Canadian _RADARSAT_ satellite launched on Nov. 4, 1995, is a powerful microwave instrument that can obtain high quality images of the Earth in all weather at any time. This provides significant advantages in viewing under conditions that preclude observation by aircraft and optical satellites. Using a smgle frequency, C-Band, the RADARSAT SAR has the unique ability to shape and steer its radar beam over a swath ranging from 35 to 500 kilometres with resolutions from 10 metres to 100 metres respectively. Incidence angles range from less than 20 degrees to more than 50 degrees The satellite's orbit is repeated every 24 days.

To protect but also exploit the forest areas in a sustainable manner during mining operations, radar surveillance is necessary. Radarsat data has assisted in mapping degraded and deforested areas around illegal mining activities from the Amazon in Brazil with success. It allowed spotting already rather small clearcuts. In this way every logging or deforestation activity can be controlled.

Pioneering studies so far carried out using SAR interferometry (InSAR) have already being earmarked as a new development in understanding our earth and its dynamics. InSAR can provide with unprecedented precision, high-resolution topographic data (DTM's using stereopairs of radar images with differing viewing angles). Differential interferometry allows one to measure surface movements with sensitivity of the order of a few centimetres over large surfaces (Massonnet et al., 1993). This technique has proven its importance in subsidence monitoring and landslides -- typical hazards often associated with mining activities. The ability to make these measurements from space without ground control is a fundamental advance in the management of natural disasters arising from mining activities.

3.3 *New Development*

Potential applications for one-meter satellite imagery in a GIS environment are limitless. Among the new development in Earth observation satellite data is the _IKONOS data_. The latter acquires panchromatic imagery with one-meter spatial resolution and multispectral imagery at four meters. With ground control, the imagery boasts a two-meter horizontal and three-meter vertical accuracy, equivalent to 1:2,400-scale map standards. The satellite's ability to swivel in orbit enables it to collect imagery anywhere on earth with a revisit frequency of just one-and-a-hal f days.

The imagery received from IKONOS can serve as an incredibly detailed basemap upon which other layers are laid, or it can be used as an up-to-date data source from which various land cover, soil degradation, mine wastes and other activities related to mining impact and elevation features are extracted to populate multiple GIS layers. IKONOS and aerial photography can complement the data sources that have traditionally served as sources of land cover and digital elevation models (e.g., Landsat, SPOT, and 1RS data).

Shuttle Radar Topographic Mapping (SRTM). In most developing and some developed countries accurate topographic and digital terrain model (DTM) of the area under investigation is missing. An exciting development towards solving this acute problem in GIS İs envisaged from the new SRTM acquired by Space Shuttle Endeavour in February of this year. The SRTM instrument will allow one to create very detailed topographic maps of the Earth's surface using interferomeöy. This radar system gathered data that will result İn the most accurate and complete topographic map of the Earth's surface that has ever been assembled. Once processed, the SRTM radar data will allow to obtain accurate knowledge of the shape and height of the land, and to assess: flood, soil degradation, deforestation and reforestation, landscape changes (due to mining activities), subsidence, landslides and most of all in monitoring land use and land-cover changes due to mining activities with high precision.

SRTM was launched into an orbit with an inclination of 57 degrees. This allowed most the Earth's land surface that lies between 60 degrees north and 56 degrees south latitude to be covered by the SRTM radar. This is about 80 percent of the Earth's landmass.

The *Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)* is an imaging instrument, which was built for the Ministry of International Trade and Industry of Japan İs flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER will be used to obtain detailed maps of land surface temperature, emissivity, reflectance and elevation. The EOS platforms are part of NASA's Earth Science Enterprise, whose goal is to obtain a better understanding of the interactions between the biosphere, hydrosphere, lithosphère and atmosphere.

ASTER is the only high spatial resolution instrument on the Terra platform. It will be used with MODIS, MOPITT, MISR and CERES, which monitor the Earth at moderate to coarse spatial resolutions. ASTER's ability to serve as a 'zoom' lens for the other instruments will be particularly important for change detection, calibration/ validation and land surface studies.

The coming years will bring particularly exciting new, space-dependent, technologies to the service of the mineral exploration and mining industry. These will allow us to map the entire earth in more detail than ever before. Major new development in satellite remote sensing will be the products of *imaging spectroscopy or hyperspectral sensing*. The latter would employ from 100 to 300 contiguous spectral bands to record a "complete" and continuous reflectance spectrum for every pixel in the scene. This will allow one to determine the mineralogical composition of rocks and soils and some vegetation types as well as monitoring environmental processes and remediation and to locate waste products, such as sulphate minerals, causing acid mine run-off from mine tailings (Swayze et al., 2000). Hyperspectral sensing will bring the exciting new possibility of not just discriminating the material (possible with some current sensors) but actually identifying it and putting a name to the major mineral components present in every pixel of an image.

4 CONCLUSION

1. 30 years after the first Landsat went to orbit, remarkable advancement in spatial-, spectral- and temporal resolutions of the satellite data has been achieved. Spatial resolution has increased from a resolution of 80 m İn 1972 Landsat images to 10 m or 5 m of SPOT or 1RS panchromatic images and subsequently 4 m multispectral to 1 m panchromatic resolution of IKONOS-2 - the latter almost comparable to conventional aerial photograph. Such images with high spatial resolution represent a powerful Geo Information System (GIS) as they are, provided that there is sufficient good ground information with which to interpret them. In the case of IKONOS for example, the details and the amount of information that can be extracted has no limit making mining activities easy to monitor and timely assess wim high accuracy.

2. In most Developing Countries, topographic base maps and other maps related to environmental hazard are either missing or when available rather incomplete, inadequate or inaccurate for this purpose. Most of all, environmental maps are collected at different scales and wi± different legends by several actors making it impossible to reconcile and complement one another. Manual plotting of data on maps that exists lead to inaccuracies, inconsistencies between different organisations that plot the same data, and frequently this can lead to legal problems relating to such thing as the position of boundaries. The increasingly detailed digital elevation models (DEMs) coming from SRTM is at previously unheard of resolutions (e.g., I-5m) and something to look at to overcome this obstacles.

3. On the other hand, spectral resolution has allowed broadband spectral images to be reduced to hundreds of narrow bands in hyperspectral bands allowing for the first time an easy screening technique for potential acid mine drainage, for the discrimination of mineral types and chemicals often difficult to map using the other remotely sensed data (e.g., Landsat TM). Already the United States Bureau of Reclamation and the Environmental Protection Agency are using hyperspectral technology to guide them in their site characterisation and remediation activities.

4. In addition the improved temporal resolution of the satellite data has allowed for an increased frequency of observation and a better ability to observe changes at a point of measurements.

5. Satellite images and aerial photos, allow one to monitor mining event during the time of occurrence while the forces are İn full swing. The vantage position of satellite images and aerial photos makes it ideal to evaluate areas of historical mining operations as well as active mine sites to the extent of providing more sensitive, cost effective, and timely monitoring potential. Satellite images offer multispectral approach, synoptic overview and repetitive coverage. They provide very useful environmental information, on a wide variety of terrain parameters and range of scales.

6. Remote sensing data should generally be linked or calibrated with other types of data, derived from mapping, measurement networks or sampling points, to derive at parameters, which are useful in the study of mining hazards. The linkage is done in two ways, either via visual interpretation of via digital processing, manipulation and classification of the datasets. Modern image processing techniques are highly advanced and the software available to do that are readily available in the market nowadays.

7. The data required to understand the impact of mining from the environment is coming from different disciplines, which need integration in order to arrive at hazard map zonation. Data integration is the strongest element of Geo-Information System (GIS). The zonation of hazard might serve as the basis for impact assessment measures and should supply planners and decision-makers with adequate and understandable information within a relatively short period of time.

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