A STUDY ON THE APPLICATIONS OF GEOSPATIAL ENGINEERING TECHNIQUES IN MINERAL MAPPING AND GEOTOXICOLOGICAL RISK ASSESSMENT OF MINING LAND CONTAMINATION IN ULU JOHAN, KINTA VALLEY TINFIELD

OSAMA AHMAD MUSTAFA ABU-LIBDA

UNIVERSITI SAINS MALAYSIA

2008

ACKNOWLEDGEMENTS

This work is proudly dedicated in almost every respect to my dear mother, Sara, who instilled in me a reverence for learning, and to my brothers and lovely sister who were behind the first inspiration for conducting a postgraduate research overseas. Their continuous encouragement and prayers to the Almighty and every care they put have made my mission a success. Heartfelt gratitude I express also to my dears and relatives in the occupied Holy Land - Palestine whom their endless openhanded and openhearted sacrifices were the driving engines to achieve crème-de la-crème in my studies. I am all indebted to a considerable number of individuals and organizations for support, guidance and collaboration and without whom; this work would not have been possible. In this connection, I am very much indeed thankful to my research supervisors: Assoc. Prof. Dr. Md Azlin Md Said, GIS & Remote Sensing Research Group, USM School of Aerospace Engineering; Mr. Tuan Besar Tuan Sarif, USM School of Material & Mineral Resources Engineering; and Mr. Azli Kamil Bin Napiah, Malaysian Center for Remote Sensing (MACRES) for their invaluable supervision, consultation and generosity they gifted throughout the project cycle. Extended thanks are due to geology consultant Mr. Tan Teong Heng for his constructive tips and comments on geochemical exploration aspects in tropical Malaysia.

Appreciation and special thanks additionally go to those organizations, information centers and science laboratories which nurtured this research by providing a positive environment and delightful welcome to access their available database and laboratory utilities per needed. In this avenue, I should acknowledge the services of Analytical Chemistry Lab of USM School of Chemical Engineering, Geotechnical Lab of USM School of Civil Engineering, USM School of Material & Mineral Resources Engineering; Malaysian

Center for Remote Sensing, Department of Mineral & Geoscience Malaysia and Malaysian Forestry Institute for the great response in providing assistance and information pertaining to the research study area. I am also obliged to many lecturers and professors who instructed me in many courses of wide spectrum of engineering topics, whilst progressing in my research assignment, by which I experienced further knowledge polishing, research excellence and career professionalism. It was enjoyable as well as educational. Not to mention, the wonderful sociality and sincere sympathy demonstrated by many Malaysian and international staff, friends, colleagues and classmates have in all added enthusiasm and loving atmosphere to the learning process. Finally, but not the least, I would like to express my sincere gratitude to the great couple Mr. Mohammad Ibrahim Abu Qao'd and Mrs. Siti Hajar Binti Hassan Azhari for their personal unending support and welcome. They have been always considering me one of their family members during my stay in Malaysia - may Allah bless them.

TABLE OF CONTENTS

CHAPTER FOUR: RESEARCH METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

f	:	Light Frequency
c	:	Speed of Light
λ	:	Wavelength
Geotox I	:	Geotoxicological Index
C	:	Concentration Level
$\gamma(h)$	:	Function of Correlation in Semivariogram Model
h	:	Lag
Z	:	Data Point Value of A Random Variable
N	:	Sample Size
$\sum$	:	Mathematical Summation
Γ	:	Gamma Matrix
g	:	Vector in Space
i , j	:	Coordinates in x,y Space
R	:	Ratio of Pixels
a , b	:	Constants
DN	:	Digital Number in Pixels
SR	:	Spectral Reflectance
$NDVI$	:	Normalized Difference Vegetation Index
$TNDVI$	:	Transformed Normalized Difference Vegetation Index
u	:	Pixel Vector of Transformed Value
x	:	Pixel Vector of Original Value
σ	:	Standard Deviation
μ	:	Moment or Constant Mean
p	:	Order
C	:	Parameter in Semivariogram Model
λ_N	:	Weighting Function
$Z(s)$	:	Function of Value Predicting of Data Point s
$\varepsilon(s)$	:	Function of Residual Error of Data Point s

LIST OF ABBREVIATION

AMD	:	Acid Mine Drainage
ARAR	:	Applicable, Relevant and Appropriate Requirements (USA)
ARE	:	Asian Rare Earth Sdn Bhd
BL	:	The Background Limit (Reference)
BLUE	:	Best Linear Unbiased Estimate
COPH	:	Contaminant of Potential Hazard
DL	:	The Detection Limit (Analytical)
EIA	:	Environmental Impact Assessment
EIV	:	Ecological Intervention Value
EMR	:	Electromagnetic Radiation
ERA	:	Ecological Risk Assessment
ERDAS	:	Earth Resources Data Analysis System
ESA	:	Environmental Site Assessment
ESA	:	European Space Agency
ESDA	:	Exploratory Spatial Data Analysis
ESRI	:	Environmental Systems Research Institute
GIS	:	Geoinformation System
GPS	:	Global Positioning System
GVI	:	Green Vegetation Index
HHRA	:	Human Health Risk Assessment
HTIV	:	Human Toxicological Intervention Value
ICP-OES	:	Inductively Coupled Plasma-Optical Emission Spectrometry
ICRCL	:	Inter-departmental Committee on the Redevelopment of Contaminated Land (UK)
ISO	:	International Organization for Standardization
IV	:	Intervention Value
LCA	:	Land Contamination Assessment
LRO	:	Landuse-Dependent Remediation Objective
MACRES	:	Malaysian Center for Remote Sensing
MAREC	:	Malaysian Rare Earth Corporation
MPC	:	Maximum Permissible Concentration
MPR	:	Maximum Permitted Risk Level

MTC	:	Malayan Titanium Corporation
NIR	:	Near Infra Red
ODBMS	:	Object-Oriented Database Management System
ppm	:	Part Per Million (Concentration)
PPE	:	Personal Protection Equipments
PVC	:	Polyvinyl Chloride
QA/QC	:	Quality Assurance/Quality Control
QQ Plot	:	Quantile-Quantile Plot
RA	:	Risk Assessment
RDBMS	:	Relational Database Management System
REE	:	Rare Earth Elements
RGB	:	Red Green Blue
SBI	:	Soil Brightness Index
SEK	:	Societe des Etains de Kinta
SMEK	:	Société de Mines d'Etain de Perak
S/N	:	Signal-to-Noise Ratio
SPA	:	Soil Protection Act (The Netherlands)
SPSS	:	Statistical Package for the Social Sciences
SRC	:	Serious Risk Concentration
SWIR	:	Short Wave Infra Red
TC	:	Tasseled Cap
TV	:	Target Value
VI	:	Vegetation Index
VNIR	:	Visible-Near Infra Red
WI	:	Wetness Index

KAJIAN PENGGUNAAN TEKNIK KEJURUTERAAN GEORUANG DALAM PEMETAAN MINERAL DAN PENILAIAN RISIKO GEOTOKSIKOLOGI PEMALAAN TANAH LOMBONG DI ULU JOHAN, LEMBAH TIMAH, ULU KINTA

ABSTRAK

Pemineralan semulajadi dan kegiatan perlombongan yang berterusan telah menghasilkan banyak bahan pemala yang berpotensi memberi kesan terhadap persekitaran yang mungkin boleh menyebabkan pencemaran tanah dan risiko kepada kesihatan manusia dan ekosistem. Pencirian geoenviromen dan penilaian pemalaan tanah (seperti yang dirancang dalam Penilaian Tapak Enviromen Fasa I dan II) telah dilakukan dalam kajian ini dengan menggabungkan teknik terkini perlombongan dan kejuruteraan georuang. Kajian awal menunjukkan kualiti tanah yang kurang memuaskan disebabkan gangguan secara semulajadi dan kegiatan manusia. Dalam fasa kajian risiko, prosedur geokimia carigali telah dilakukan dengan mengambil 25 sampel tanah, GPS dirujuk, pada kedalaman kurang daripada 40 sm secara rambang. Kepekatan unsur As, Zn, Mn, Pb, Te, Sb dan Zr di dalam sampel (saiz 10 mesh) telah dianalisis menggunakan ICP-OES. Kandungan ini kemudiannya dilakarkan menggunakan Kaedah Pemodelan Kriging Interpolasi Ruang Geostatistik dan memaparkan menggunakan GIS. Kajian menunjukkan terdapat pola taburan yang memanjangi arah timur laut-Barat Daya, selari dengan zon pemineralan dan kegiatan perlombongan. Paras kepekatan melebihi nilai latar menggambarkan kemerosotan paras pencemaran di dalam tanah. Kajian pemetaan GIS menggunakan Pemodelan Kriging Interpolasi Ruang Geostatistik indek bahan pemalaan menunjukkan As, Zn, Mn, dan Pb berpotensi berisiko tinggi melebihi 80 % berlaku berdekatan dengan kawasan titik panas ekologi. As berpotensi menghasilkan pemalaan melebihi 65% dan Pb melebibihi 85% yang berlaku berdekatan dengan perkampungan. Inferens tentang geotoksik disokong oleh pemprosesan imej multispektrum Landsat TM5 dan IKONOS, dan juga oleh penyakit kulit yang dialami oleh manusia. Data geobotani

inframerah telah membolehkan tumbuh-tumbuhan yang sihat dan kurang sihat dibezakan. Begitu juga dengan tanah yang tercemar dan tidak tercemar dapat dibezajelaskan. Pemodelan Indeks Tumbuhan TNDVI menunjukkan tumbuhan yang tidak sihat berkait rapat dengan tanah yang tercemar. Pemodelan 'Taseeled Cap' menunjukkan tumbuhan yang tidak sihat di dalam kawasan yang tercemar dicirikan oleh Indeks Kecerahan Tanah dan Indeks Kehijauan yang rendah. Penyakit kulit dikesan di tempat yang berdekatan dengan kawasan yang tercemar; mencadangkan dengan itu satu rangkaian tersembunyi antara geologi tempatan dan kejadian-kejadian kesihatan manusia. Hasil pemetaan georuang dan analisis risiko membolehkan keputusan dibuat untuk mentakrifkan kawasan yang benar-benar memerlukan kajian dilakukan untuk memantau risiko pencemaran ke tahap yang boleh diterima sebelum membangunkan semula kawasan Ulu Johan. Dengan memetakan keputusan kajian seperti ini akan membolehkan risiko dimaklumkan kepada semua pihak yang terlibat. Hasil daripada kajian ini, dicadangkan kajian susulan dibuat dalam fasa III Penilaian Tapak Enviromen.

A STUDY ON THE APPLICATIONS OF GEOSPATIAL ENGINEERING TECHNIQUES IN MINERAL MAPPING AND GEOTOXICOLOGICAL RISK ASSESSMENT OF MINING LAND CONTAMINATION IN ULU JOHAN, KINTA VALLEY TINFIELD

ABSTRACT

Natural mineralization and intermittent mining operations in Ulu Johan, Kinta Valley tinfield have resulted in generating enormous quantities of contaminants of potential hazard in the environment, thereby contaminating the land asset and imposing significant risk to human health and ecosystem. A geoenvironmental characterization and assessment of soil contamination planned in Environmental Site Assessment Phase I and Phase II, had been carried out in this study by the integration of state-of-the-art techniques of mining geoscience and geospatial engineering. The preliminary risk assessment phase revealed deterioration of land quality due to natural and anthropogenic disturbances of regolith materials. In the quantitative risk assessment phase, a geochemical exploration procedure was undertaken to collect, prepare and analyze a total of 25 GPS-georeferenced soil samples extracted at average depth <40 cm by random sampling. The 10-mesh-sized samples were analyzed by ICP-OES for elements As, Zn, Mn, Pb, Tl, Sb and Zr then mapped-out using geostatistical spatial interpolation modeling by kriging and geovisulaized thematically in GIS. Geochemical mapping showed generally a spatial distribution pattern extending NNE-SSW, parallel to the zone of mineralization and mining activities. The anomalous environmental concentration levels above the global background values implied to the extent and severity of pollution levels on the contaminated land. GIS hazard mapping using geostatistical spatial interpolation modeling by kriging of geotoxicological indices of target contaminants of potential hazard revealed that As, Zn, Mn and Pb impose high potential to hazard exposure probabilities exceeding 80% to occur in ecological receptors located at/near hot spot sites, and that As and Pb impose high

potential to hazard exposure probabilities exceeding 65% and 80%, respectively, to occur in human receptors located at/near hot spot sites. Geomedical inference of geotoxicity was supported by geobotanical remote sensing image processing of Landsat TM 5 and IKONOS multispectral data and a ground truth study, as a spatial qualitative approach supporting the GIS-quantitative ecological risk assessment. Geomedical inference of geotoxicity was also supported by environmental epidemiology study of human disease etiology as a spatial qualitative approach supporting the GIS-quantitative human health risk assessment. False-color composite infrared geobotanical data enabled distinguishing between stressed and healthy vegetation, and therefore identifying contaminated and non-contaminated lands. Modeling vegetation index of TNDVI revealed information on stressed vegetation was associated with contaminated land areas by increasing grades of pixel darkness. Tasseled Cap modeling showed the stressed vegetation cover associated with contaminated land areas characterized by high Soil Brightness Index and low Greenness Index. Epidemiological disorders were detected in inhabiting centers spatially proximal to contaminated areas; suggesting thereby a concealed linkage between local geology conditions and human health incidents. The geospatial results of geochemical mapping and geotoxicological risk analysis suggested the decision to the need for applying urgency methodology at defined contaminated sites as priority to manage the contamination risk to an acceptable level before re-developing Ulu Johan's land asset. Geovisualizing these results cartographically in thematic maps will enable communicating risk to different concerned parties. The study suggested further the need to go on for conducting the Environmental Site Assessment Phase III in future.

CHAPTER ONE
INTRODUCTION

1.0 Background

Land is a finite valuable resource. Degradation and contamination of land can be caused by natural and anthropogenic forces. Metallogenesis conceals a huge amount of mineral accumulations in the environment, naturally contaminating thereby different Earth systems (Siegel, 2002). On the other hand, excessive human exploitation of mine resources on an industrial mining scale have polluted mine environment and surrounding environment in a fast-pace mode (UNEP-DTIE, 2007), inducing thereby many geological hazards and severe environmental damage long after the mine has closed (Da Rosa, 1997). In particular, surface mining methods generate enormous quantities of waste which diffuse many potentially hazardous elements from ore deposit (Siegel, 2002; Selinus, 2004) that are causing or could cause significant harm or pollution of surface waters and groundwater (NetRegs, 2007). These hazards often reside in the mine geological environment, embarking thereby many on-going challenges in terms of land development, public health, environmental protection, stakeholder demands and policy making, and impeding greatly the development of national economy. Identifying and dealing with such contaminated land is important in order to support increased quality of life for communities and conservation of biodiversity and to sideline economic and property damage (EA and NHBC, 2000). Unfortunately, much contaminated land is neither yet identified nor adequately described (Kibblewhite, 2001).

Solutions to environmental problems of contaminated land are many and varied, be they technological, personal, corporate, and governmental or other measures (e.g., Chiras and Reganold, 2005; Bell and Donnelly, 2006). But all these solutions depend largely on the quality of land contamination assessment (Kibblewhite, 2001) to estimate the risk of adverse effects of potential chemical exposure, and in order to attend a sensible risk management decision to mitigate the hazard (Gerba, 2004). Apart from providing potential targets for mineral exploration and georesource evaluation, mining and economic geologists are invited more than ever to use their geological knowledge in diverse issues of contaminated land (e.g., Katsumi, 2003). Their geo-investigations are essential to unveil varied information on land condition. Fortunately, the powerful capabilities of geospatial engineering tools derived from modern aerospace-related technologies, and their applications in environmental surveillance, resource survey and health-related issues, play a welcome mat for these geoprofessionals to attain best solutions and optimization mechanisms for analyzing and synthesizing site's geoinformation (e.g., CHAART, 2006; Boham-Carter, 1994; Bell, 2004). This will reflect on maximizing the revenue of knowledge that is coherent and necessary to serve the decision-making process pertaining to managing mining environmental hazards and protecting human health and ecosystem.

1.1 The Hypothesis and Need for the Study

The pioneering work of developing Malaysia has carried out through tin mining since the 1880s. In Kinta Valley, mining is a crucial activity and has played a central role in the very district's economy as the main provider of foreign exchange. In the district, surface mining was the common mining method applied for tin extraction from ground (e.g., Sani, 1998; Khoo and Lubis, 2005). It is the production and disposal of waste which can cause the most extensive and long-lasting disturbance to land (Cooke, 1999). Hazardous, radioactive and other toxic substances have routinely been generated and subsequently disposed of in the shallow subsurface during and after mining activities in Kinta Valley (e.g., SAM, 1984). As the district has long history of mining over a century of time, the relics of mines and exposed tailing soils are heavily rich in contaminants of potential hazard (COPHs) that resulted from mineralization and intermittent mining of tin deposits. In the past, most mining operations did not seek to minimize the potential negative effects to the environment and society but were carried out in a manner that often resulted in significant harm to the environment (UNEP-DTIE, 2007). In addition, many of today's waste management techniques do not eliminate the problem, but rather only concentrate or contain the hazardous contaminants. Residual hazards remains on-site following active operations of mineral extraction or the completion of mineland reclamation. These residual hazards pose continued risk to human and the environment and represent a significant problem that requires continuous long-term management, i.e. >1000 years (Kostelnik et al., 2004).

The physicochemical landscape of mining lands in Kinta Valley has been largely disturbed since the downturn of mining business in the late decades of the last century. Human involvement in re-inhabiting these derelict lands has resulted in developing land resource for many purposes (e.g., Sani, 1998). Many of these purposes are now operating extensively on historical and yet-active mining lands, such as Ulu Johan, west Kinta tinfield, which is surrounded by the historical mega-mining towns of Bukit Merah, Papan and Lahat. Ulu Johan is a watershed catchment area facing an increasing expansion of urbanization and industrialization centers, e.g. Bukit Merah Industrial Zone and Lahat Industrial Zone, besides the current agricultural, fishery, mining and recreational uses of land resource. However, shortage of building land (particularly for industrial concerns) means that developers are re-using more and more land in areas distinct with a history of mining, and by which, Ulu Johan's land and water resources will naturally expect a soon invasion by this fast national development wheel.

The land overlying mine workings often cannot be redeveloped without treatment (Lee and Yeap, 2002), but the time required for a treatment program is limited in the face of the current great expansion of development in Kinta Valley. Although some mined-out lands in the district have their soils been reclaimed to reduce the visual landscape impact (Lee and Yeap, 2002), there is no comprehensive characterization of these lands on a large scale (Muhd Razali et al., 1993; Mohamad and Hassan, 1997). In addition, the geochemical threats of residual hazardous elements in the reclaimed tailings are still giving precedence of unsafe conditions to human and the environment. They should be viewed as serious redline in the environmental plan and stakeholders' interest prior redeveloping, restoring and management of such sites. These contaminated assets need also to be quickly assessed, rehabilitated and cleansed up from residual hazards, and their ecosystems to be restored to their natural state of health in order to be appropriate for redevelopment. The concern over soil contamination stems primarily from health risks, both of direct contact and from secondary contamination of water supplies (Cross and Taylor, 1996). The harm also affects on ecological systems and organisms, buildings and property, including produce, livestock, owned or domesticated animals and wild animals which are the subject of shooting or fishing rights (NetRegs, 2007). Uncertainties about remediation requirements and liability for contaminated lands can also cause blight, deterring development of land; adding to pressures on greenfield sites, and affecting urban regeneration (UTF, 1999).

People living on or near a mining contaminated site will often be concerned about potential effects on their health (a geohealth issue). To determine the need for intervention and to avoid future liabilities, hidden costs and work's delay, the risk from a contaminated site needs to be assessed. Mapping is one of many inputs to environmental assessment procedure of contaminated sites; but it is time consuming and expensive task, requiring extensive amounts of geology, hydrology, chemistry and computer modeling skills (Cross and Taylor, 1996). Unfortunately, the non-availability of good baseline geochemical data in tropical countries has become a major constraint in risk management of contaminated lands. Detailed geochemical maps are rare in tropical areas and there is an urgent need for high resolution geochemical data as necessitated by environmental and epidemiological studies (Plant et al., 1996).

It is obvious that many challenges conceal in dealing with mining contaminated land asset, and are awaited to be accomplished by highly skilful Malaysian geoprofessionals and risk engineers to ensure integrated value judgments and science-based practice to manage the hazard. In the face of the abovementioned challenges, it is necessary to carry out a quick characterization and pilot assessment of the residual hazards of mining contaminated lands in Ulu Johan, and a seriously continuous monitoring plan if these lands were to be re-developed in the near future. As economic and mining geologists' activities in the past included tasks of mapping, recording and compiling geological data in and around the mine (e.g., Arogyaswamy, 1973; Peters, 1987), their knowledge in mining research is now globally called upon to extend beyond conventional boarders to reveal much about contaminated lands. They can contribute in developing advanced solutions and techniques of assessment; management and monitoring land contamination (e.g., Hale and Kühnel, 1997; Katsumi, 2003).

It is the current study to be directed to employ the modern aerospace-related technologies used worldwide in surveying, characterizing and assessing mining impacts – geospatial engineering techniques as the apple of our debate. The use of geospatial technology in environmental-health issues is the subject of widespread interest and heated debate as the public become more involved with environmental discussions and demand greater access to information. Using understandable geospatial maps that handle risk information on land contamination and the environment in organized style of themes will promote better communication between public, planners, decision-makers, land developers as well as research personnel. Ultimately, achieving this collaboration will cast in attaining successful disaster response management applicable at all levels of organization, leading thereby to save life and property from hazard impacts (Smith, 2001).

1.2 Problem Statement

The spatial residual geochemical hazards laden in metallogenic and mining contaminated lands of Ulu Johan, Kinta Valley tinfield impose geomedical/geotoxicological risk to human health and ecosystem. The risk needs to be scientifically characterized, technically visualized and professionally communicated in order to support a rapid science-based decision-making system relating to managing land contamination hazard.

1.3 Objectives of the Study

The study aims at employing an integration of the state-of-the art techniques of mining geoscience and geospatial engineering to facilitate a rapid, reliable assessment system and risk analysis of land contamination aimed at:

1. Configuring the spatial dispersion structure of pedogeochemical species in the site's geospace (the land quality aspect).
2. Identifying locations where observed levels of mineral contaminants of potential hazard (COPHs) are likely to pose unacceptable risk to human health and ecosystem now or in future, i.e. geotoxic, hot spot sites (the geoepidemiological or geohealth aspect).
3. Deciding whether the geospatial analysis-derived risk requires applying the urgency methodology or taking measures/actions to manage the environmental geochemical hazard to an acceptable level (the risk decision aspect).

1.4 Scope and Limitations of the Study

The work in this thesis relies basically on the mere soil geochemistry (analytes) as a principal toxicity indicator the baseline geoenvironmental assessment derives from. This is because the time, costly chemical tests and financial allocations set for the current project limit the researcher's capability to cover other interrelating factors worth investigation (e.g. ecotoxicity, soil biogeodynamics, environmental chemodynamics, intoxication mechanisms, quantitative risk exposure or dose-response analysis, etc.). In spite of these limitations, the geochemical aspect of soil has been long proving to be an essential environmental element most toxicity risk studies of contaminated sites pay attention to (e.g., Boularbah et al., 2006; Naidu et al., 2003; Ahlf et al., 2002; Förstner, 2002; Thomas, 2003; Vallero, 2004; Vallero and Peirce, 2003; Wright and Welbourn, 2002; Woolley, 2003; Walker et al., 1996; Yu, 2005; Schuiling and Zijlstra, 2001; Singh et al., 1997; Abrahams and Thornton, 1994; Dunn and Irvine, 1993; Bascietto et al., 1990; Irvine et al., 1988; Nriagu, 1988; Rosen et al., 1978).

Without any readily available maps of geochemical provinces or any geochemical atlas in Malaysia, and the non-availability of reference studies regarding risk-based standards and thresholds of maximum permissible concentrations in Southeast Asia so far, tremendous obstacles stand firmly before the work. Therefore, the analysis in this thesis had resorted to rely on the personally collected field data and on the recognized Dutch risk standards of soil, in replace to the shortcomings.

The work was divided into two phases of assessment. The initial phase was to set a desk study to bring about the initial information on site geoenvironmental and ecological conditions – Environmental Site Assessment (ESA) Phase I. This was essential input information for preliminary risk assessment of land contamination. Following ESA Phase I procedure, the powerful data analysis, data management, mapping and geocomputation capabilities attributable to geospatial engineering techniques were applied for demarcating and unveiling the spatial structure of soil mineral contaminants in the study area. This stage is referred to as the Environmental Site Assessment (ESA) Phase II. Once the geodatabase was generated, the aim was extended to categorize the quality conditions of the contaminated surface environment based on generic risk criteria – generic quantitative risk assessment. Here, the need had highlighted the importance of adopting the Dutch risk standards of soil exceedance and safe thresholds for human and ecosystem endpoints. From these standards, geotoxicological risk indices were generated in intention to model the spatial extension of hazard probability and then to classify the site into mappable hazard grades. The quantitative risk assessment pool included two GIS-generated types of geo-mapping to categorize the site, they were:

1. Pedogeochemical maps visualizing the spatial extension of mineral contaminants in the study area – communicable to risk specialists; and
2. Geotoxicological hazard exposure (probability) maps, assigning locations of 'hot spot' areas for human health and ecosystem - communicable to specialists and non-specialists.

The quantitative information on risks of pedogeochemical contamination was amalgamated with qualitative information on health status of human site-users and ecosystem, observed from ground-truth and remote-sensing studies (i.e., geomedical inference). For this application, two qualitative approaches of land contamination assessment were employed:

1. The technique of prospecting geobotanical remote sensing was used as support for ecological risk assessment (ERA) of land contamination

2. The technique of environmental epidemiology was used as support for human health risk assessment (HHRA) of land contamination.

Locations where high concentrations of contaminants of potential hazard (COPHs) had exceeded the permissible levels were diagnosed as 'hot spot' locations (geotoxic sites). These sites were visualized by thematic cartographic maps in which risk mapping had played a supporting tool for judging on and communicating the risk to different concerned parties. Suggestions and recommendations regarding further investigation exuded as fruitful outcomes of this geospatial-based risk analysis.

1.5 Organization of the Thesis

Chapter 2 provides an overview survey of literature on the latest developments in mining geosciences and the state-of-the-art applications of geospatial engineering techniques in risk assessment of land contamination. The focus of the discussion is directed to show the success of geospatial technology when hybridized with earth science tools used by mining geoprofessionals, and the great revenue of this hybridization in the mission of land contamination assessment (LCA).

Chapter 3 aims at describing the characteristics of the study area and the background aspects of the locale, required as input information for the site investigation program. The strategic characteristics of the study area are discussed in detail. Specific observations of human and natural processes that have been playing as significant drivers in deteriorating the site quality are emphasized elaborately.

Chapter 4 outlines the general methodology adopted in the research project. Discussion on the research road map and methods employed in the detailed investigation are given in detail. Field, lab and office procedures on sampling, data collection, geodatabase management and data geoprocessing used in data treatment for synthesizing geoscientific information are all discussed thoroughly.

Chapter 5 addresses the results and findings of geospatial-based risk analysis. The statistical measurements and spatial modeling of soil contamination, together with thematic risk maps were presented numerically as well as graphically. The results of image processing and ground-truth studies, verifying the numerical geoprocessed spatial models, were also co-synthesized as integrated qualitative techniques for understanding the imposed damage of soil contamination on the total environment of the study area.

Finally, chapter 6 highlights the recommendations pertaining to the use of aerospace-related techniques of geospatial engineering in the geological investigations and environmental risk assessment studies of metal pollution in mining areas of Kinta Valley. Future work and proposed developments, as optimum, fruitful end-points out of the current work, were also projected for prospective research candidates and interested personnel.

CHAPTER TWO
LITERATURE SURVEY

2.0 Background

Space visionaries in the early 20th century recognized that putting satellites into orbit could furnish direct and tangible benefits to people on Earth (Encyclopedia Britannica Online, 2007). In the next fifty years, space promises to become a new arena of intense economic competition; increasingly important to communication, manufacturing, mining and other commercial activities. This is as a fruit of 40 years investing in space programs and raising technologies to new levels of performance and capability, and transferring these technologies back to applications on Earth (ESA, 2007).

Tremendous achievements have been already scored in the field of aerospace survey in real-world applications, as a result of adopting modern strategies on how to benefit from space for human's prosperity and lifeway improvement. Among the common space segment component technologies, aerospace development trends show that satellite industry is the largest and fastest growing segment. Accompanying this segment, there is a host of other emerging aerospace-related technologies that have begun to generate revenue and interest as new satellite-based commercial outputs have rapidly evolved and spoken for themselves (Dasch, 2002). Geospatial technologies, in particular, have dazzlingly expanded and involved profoundly in a multidisciplinary and interdisciplinary pivot to hybridize the knowledge of various science, engineering and technology domains. Spans satellite technologies and appliances of geoinformation systems (GIS), Earth imaging, remote sensing and positioning systems have stridden the arc and trends of geospatial engineering science to reach wide applications including environmental and natural resources management, national security, public health, location-based services, transportation and emergency management. Recently, tremendous use of these smart aerospace-related technologies has been valuably evident in Earth and environmental related investigations; from which, their information disseminated finds its best description as "Environmental Intelligence" designated by Kraselsky and Gravatt (1989). In recent times, the ever-increasing involvement of geologists in long-term research projects to evaluate the risk potentials of environmental change has been evident in many regulatory and governmental agencies round the globe (Lundgren, 1999). As our world's most precious natural resources are in shorter supply than ever, geologists and software engineers are currently rethinking how geospatial technologies can lead to better asset management (Lake and Farley, 2006).

The purpose underlying this chapter is to review the literature on pioneering works addressing the use of geospatial engineering techniques in mining geology and environmental investigation, particularly for mining pollution and environmental risk characterization. The chapter also demonstrates a space for the main geospatial engineering techniques of remote sensing and GIS and their potentials in risk studies of geospheric pollution, where geoscientific data analysis is crucial and the needs for such type of data are increasingly important. In order to produce a risk assessment model, and, therefore, a resource management plan and effective decision-making, certain geospatial information technologies can be of great assistance to accomplish these tasks.

2.1 Recent Trends in Implications of Mining Geosciences to Mine Geoenvironmental Studies

The 'geoenvironment' is a specific compartment of the environment and, as such, concerns itself with the various elements and interactions occurring in the domain defined by the dry solid land mass identified as 'terra firma'. These include a significant portion of the geosphere and portions of both the hydrosphere and the biosphere (Yong et al., 2007).

Since the lithosphere is the base of biosphere on the Earth (its material base), monitoring of the geological environment is the major and necessary part of the global ecological monitoring of the Earth (Munn, 1973).

Investigating resource mineralization and its mining aspects in the environment is a norm for economic and mining geologists (e.g., Erickson et al., 1984) and a fundamental requirement in many aspects of mining engineering (Daemen, 2002). Preceding and during mine operations, geological activities, such as exploration and site characterization, are necessary to provide detailed information on the mine environment, feasibility and development. Current methods of mining geology employ refine geochemical, geophysical, geobiological and geocomputational data analysis techniques (e.g., Moon, 1995; Daemen, 2002; Green, 1991; Peters, 1987; Reedman, 1979; Arogyaswamy, 1973).

While the traditional aim from using these geotechnologies was intimately directed for economical discoveries, momentum has been building in recent years on studying mine geoenvironment and its interaction with the environment and health (e.g., Aswathanarayana, 1995; Bell and Donnelly, 2006). This is because the processes of natural mineralization and resource extraction commonly raise public concern about potential environmental impacts to air, water and land, especially for communities allocated in or nearby these geo-processes (e.g., Yong et al., 2007; Selinus et al., 2005; Selinus, 2004). The recent call for the importance of mining geosciences research to work on environmental assessment of mining pollution can be realized from tracking the following developments:

1- The increasing dilemma of mine geoenvironment problematic consequences and its interaction with landuse, public health and resource development in the modern society (e.g., Dorr, 1987; CIGEM, 2003). This has driven forth the importance of adopting a proper environmental management plan for the mining industry per se (Hartman and Mutmansky, 2002). Satisfactory resolution requires recognition that both minerals and a healthy environment are essential to society, i.e. environmental responsibilities (e.g. Demetriades et al. 1997).

2- The close interrelationships between environmental geochemistry and exploration geochemistry disciplines encouraged the collaboration in areas where exploration and environmental geochemical interests overlap (Hall, 1995). In the past, anomalous accumulations of metals are the focus of mineral exploration; today the background concentrations of metals are of greater significance to the total metal loading in the environment. This had enabled for the toxicologist to realize potential contributions of each activity type contributing in the loading process (Selinus, 2004). The experimental works of regolith geochemical exploration and geo-mapping programs for ore deposits (e.g., Lett et al., 1998) have been extended to environmental-health applications and risk studies on the effects of mining on the geoenvironment and health (e.g., Selinus and Esbensen, 1995; Fletcher, 1996; Cocker, 1999; Garcia-Sanchez and Alvarez-Ayuso, 2002; Mesilio et al., 2003; Reimann and de Caritat, 2005; Lech et al., 2004). This extended geo-knowledge arc has enabled exploration geochemists working on environmental assessment to perform the following tasks (Siegel, 1995):

a. To assess the quality of geochemical data;
b. To determine the natural background variation in contaminant elements against which the degree of anthropogenic pollution can be estimated;
c. To predict potential pollution problems;
d. To resolve newly identified contamination problems and to minimize their impact on the living ecosystem; and

e. To evaluate remediation proposals in the light of the practical and future impacts on the environment

3- Ecological systems used in mineral research have been recently involved profoundly in multi-issues of mining land contamination. Phytomining studies and prospecting programs using biological indicators of mineralization (geobotany) and their ecophysiological response to natural soil contamination, such as flora (e.g., Brooks, 1972; Brummer and Woodward, 1998; Akçay et al., 1998; McInnes et al., 1996; Özdemir and Sağiroğlu, 2000; Arne et al, 1999; Hulme and Hill, 2003; Fernandez-Turiel et al., 2003; Paton and Brooks, 1996; Nagaraju and Karimulla, 2001; Raju and Nagaraju, 1999; Malaisse et al., 1999; Lintern, 2005) and soil geozoology e.g., termite mound (e.g., Kebede, 2004), have all emphasized the use of these biosystems in environmental assessment, monitoring, geoepidemiology and risk mitigation/rehabilitation of land contamination (e.g., Warren, 1984; Ma et al., 2003; Ginocchio and Baker, 2004; Tahir Shah et al., 2004; Kfayatullah et al., 2001; Raghu, 2001; Kim et al., 2003; Gongalsky et al., 2004; Pratas et al., 2005; Bech et al., 1997; Mkandawire and Dudel, 2005; Stoltz and Greger, 2002; Dickinson and Wong, 2002; Boularbah et al., 2006; Odhiambo and Howarth, 2002; Ma, 2004).

4- Economic geologists are recently directed to develop refine geoenvironmental techniques for: mapping of natural levels of toxic heavy metals in soils; clarifying whether soil have high toxic metal concentration or high leachabilities caused by anthropogenic or natural processes; determining chemical interactions between toxic metals and soil materials for fixing toxic metals in soil; and develop on-site chemical analytical techniques for surveying contaminated sites (Katsumi, 2003). In this avenue, geoscience's tools are to complement the skills of biomedical and environmental professionals to more serve public health and disease prevention domains, i.e. geomedicine (Bunnell, 2004). Geopractitioners of these tools are entitled to (Finkelman et al., 2005):

a. Identify the environmental causes of known health problems and seek solutions to prevent or minimize these problems;
b. Identify geochemical anomalies in the geoenvironment that may impact on health
c. Reassure the public when there are unwarranted environmental health concerns deriving from geologic materials or processes; and
d. Evaluate the beneficial health effects of geologic materials and processes.

5- With the introduction of computer geology and geospatial engineering techniques of remote sensing/GPS/GIS/geostatistics in mining and environmental research arenas, geospatial environmental applications have become far extensive to be employed in mining geoscience studies concerning risk assessment of mining environmental impacts (e.g., MINEO, 1999). Geospatial technologies have also recently providing powerful tools for spatial decision support system (SDSS) to protect property and life from various types of environmental hazards (Lavakare, 2001). Extensive use of such geotechnologies has been evident in the production of pollution-risk maps around mining areas, in assessing mining land contamination and to develop models for understanding pollution dissemination. This has far improved the optimization of data geoprocessing and, in turn, enriching of geoscientific knowledge on such damaged environments (MINEO, 2003).

2.2 Contaminated Land

Beckett and Simms (1984) and ICE (1994) defined contaminated land as that land which, because of its former uses, now contains substances that give rise to the principal hazards likely to affect the proposed form of development and which requires an assessment (called land contamination assessment LCA) to decide whether the chosen development may proceed safely, or whether it requires some form of remedial action. The potential for contamination is not confined to the direct use of a site; it may reflect the impact of neighboring uses or activities adjacent to the contaminated site.

2.3 Risk, Exposure and Hazard

The National Research Council (1996), Crosby (1998), Woolley (2003), Levitan (2004) and Yu (2005) asserted that hazard is defined as the potential for harm and adverse effect posed by a source (contaminant of potential hazard 'COPH' or hazardous situation) and its magnitude is equated with the severity of the expected consequences. Risk is a function or measurement of the magnitude of the hazard by the probability and likelihood of its occurrence and consequence. Thus, risk in terms of likelihood as a probability function (f) can be expressed as (Levitan, 2004):

$$[\text{Risk} = f\,(\text{Exposure} + \text{Hazard})] \quad (2\text{-}1)$$

Given geochemical environment, McBean and Rovers (1998) and Gebra (2004) stated that there are three components of pollutant linkages must exist for risk to occur: a contaminating source, a migration pathway and an exposed receptor (see Figure 2.1). Exposure could be acute, exerting toxicity due to high dose of metal over short period of time, or chronic, exerting toxicity due to long-term exposure to low levels of some metals, causing gradual development of health symptoms.

Fig. 2.1 The Essential Components of Risk Scenario (McBean and Rovers, 1998)

2.4 Environmental Geotoxicology

Environmental geochemical and geological systems involve the variant segments of the ground, water, air and biota of our globe. Geochemistry is responsible for studies of all these segments and may be applied in investigation and solution of several environmental problems (Dangić, 1996). Geological knowledge is an essential line in environmental toxicological studies as it plays a requirement for investigating the chemical behavior and the quality of geo-materials that prompt toxicity in the environment and organism's health (Guidotti, 2005). Yong (2001), Yong et al. (2007) and Pierzynski, et al. (2000) discussed that the term of 'toxic' or 'hazardous' implies to the sense of chemistry as of health adverse effect becomes more appreciable over the 'pollution' term in terms of mortality or serious illness or presenting a significant hazard condition of a substance. Siegel (2002) related toxicity hazard as a function of many environmental and biological parameters that determine the speciation of a metal which affect metal's tendency to ionize in solution and ultimately its toxicity. The abovementioned authors concluded that geomedical adverse health effects related basically to mineralogical-chemical stress in geosphere (i.e. geo-stressors) are likely well-studied if viewed from toxicological point of view, regardless to the current or intended land application, activity or process.

2.5 Environmental Risk Assessment of Land Contamination

The process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences of probabilities of occurrence is known as 'risk management'. The main elements of risk management are: risk assessment and risk reduction (ICE, 1994). Traditionally, 'risk assessment' (RA) is the organized process of appraisal used to describe and estimate the likelihood/significance of an adverse outcome from environmental exposures to chemicals or observed levels of contamination on a site (Connell, 2005; ICE, 1994). Risk assessment procedure consists of hazard identification and assessment, risk estimation and risk evaluation; while risk reduction procedure is meant for setting risk control measures/actions.

Realizing that ecosystem receptors are acknowledged in recent times to show sometimes more sensitivity than humans, the modern risk studies of ground contamination have been refined to consider both human and ecosystem as two independent, but dynamically integrated, components of the total environment. Risks threatening human health are not necessarily doing the same to wildlife and vice versa (Bascietto et al., 1990). From the literature, e.g. Connell (2005), Woolley (2003) and Vallero (2004), two principal areas of risk assessment (RA) are recognized:

1. Human health risk assessment (HHRA), addressed by medico-experts
2. Ecological risk assessment (ERA), addressed by natural scientists

In view of contaminated sites, ICE (1994) indicated that 'hazard identification and assessment' step deals with comparing the observed level of contamination with generic reference data indicative of specific types and levels of risk (measuring the potential for harm to occur); while site-specific 'risk estimation and evaluation' step estimates the probability that harm will occur (qualitative or quantitative estimates). Sharma and Eddy (2004), Pichtel (2000) and Lerche and Paleologos (2001) emphasized that a systematic risk assessment (RA) must be preceded by a complete Environmental Site Assessment (ESA) procedure to confirm the contamination at the site, to compare with regulatory requirements, to determine the compliance and to avoid the liability for and costs associated with the clean-up of a site. A final decision will then be taken as to the disposition of the property. Generally, there are three ESA phases are projected by the abovementioned authors:

1. Preliminary risk assessment (known also as ESA Phase I or desk study or liability assessment stage to generally identify potential areas of contamination),
2. Generic quantitative risk assessment (known also as ESA Phase II or site investigation or confirmation sampling assessment stage to confirm or deny the presence of suspected contamination identified during ESA Phase I), and
3. Detailed quantitative risk assessment (known also as ESA Phase III or site characterization or fate and transport modeling stage where a proper clean-up management/land-use action is identified).

2.6 Risk Guidance Values

The international regulatory and statutory guidance pertaining to assessing the risk of contaminated sites relied on the development of environmental assessment criteria for soils and groundwaters against which analytically determined site concentrations can be assessed. The analytical detection limits (DL) and background concentrations (BL) were taken into account in establishing such criteria to help in assessing the possibility of significant harm to receptors from site-based contaminants, provided such values meet certain requirements. The objective was to categorize the site based on guidance values to estimate the type and magnitude of exposures from the chemicals of potential concern that are present at or migrating from a site/facility (Sarsby, 2000; RAIS, 2005). Based on the criteria of concentration limits, three approaches have been dominantly projected and globally applied in the literature (e.g., Beckett, 1993; Young et al., 1997; Sarsby, 2000; Quint, 2001; Moen et al., 1986; Swartjes, 1999; RIVM, 2001):

1. The 'ABC' guideline values for soil and groundwater which represent: 'A' values set for BL or close to DL values which implies the soil is clean; 'B' values for intermediate contamination level and where additional investigation of the site is required (renamed lately to target value (TV); and 'C' values for heavy contamination level and where

remedial action is essential (re-named lately to intervention value (IV). This approach was formed and enforced by the Dutch Soil Protection Act (SPA) and later by Ontario Ministry of Environment.

2. The 'trigger' and 'action' guideline concentrations. Here, two tiers of intervention are used (Figure 2.2): the 'trigger' value (lower) indicating the site is 'uncontaminated' but further investigation is necessary, and the 'action' value (upper) indicating the site is contaminated and where some form of remedial action is likely for the proposed end-use of the site. This approach was enforced by UK's Inter-departmental Committee on the Redevelopment of Contaminated Land (ICRCL).
3. The health risk assessment approach to site remediation which sets individual criteria as 'applicable, relevant and appropriate requirements (ARAR)' determined on the basis of a site-specific RA and adopted as site-specific clean-up requirements. Enforced by USEPA under the 'Superfund' legislation.

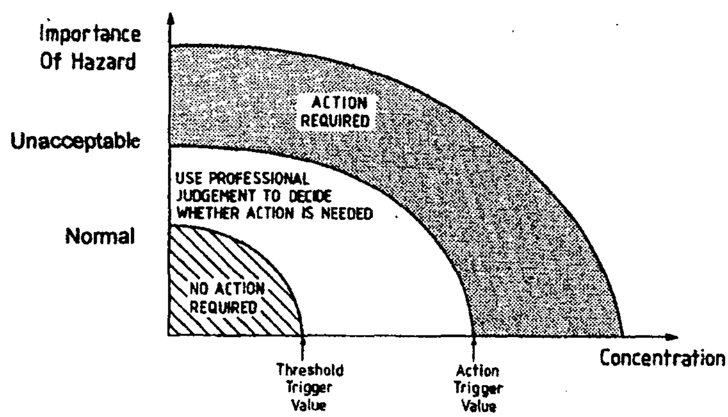

Fig. 2.2 Trigger Concentration Zones and Their Interpretation (Beckett, 1993)

2.7 Geospatial Engineering Techniques

Hooper et al. (2001) defined 'geospatial engineering science' as the development, dissemination, and analysis of terrain information that is accurately referenced to precise locations on the Earth's surface (i.e. spatial reference). It includes all geospatial information services for collection, information extraction, storage, dissemination, and exploitation of geodetic, geomagnetic, imagery, gravimetric, aeronautical, topographic, hydrographic, littoral, cultural, and toponymic data. These services base extensively on the application of computer technology to spatial problems, including problems of collecting, storing, visualizing, and analyzing spatial data, and of modeling spatial system dynamics (ESRI, 2007). Brimicombe (2003), Brimicombe and Tsui (2000) and Macmillan (1997) discussed that spatial geocomputation tools are used as a means of solving applied problems and contributing to the development of theory. According to Couclelis (1998) and Armstrong (2000), these geo-tools include: geoinformation systems (GIS), spreadsheets, statistical packages, data mining and knowledge discovery, remote sensing packages, neural networks, artificial intelligence, heuristics, geostatistics, fuzzy computation, fractals, genetic algorithms, cellular automata, simulated annealing and parallel computing. The next discussion deals only with two geospatial engineering techniques: remote sensing technology and geoinformation systems in parallel to the thesis's main interest.

2.7.1 Remote Sensing

Remote sensing commonly represents one of the first stages of land assessment (Bell, 2004; Bell and Donnelly, 2006). According to Sabins (1999) 'remote sensing' is defined as the science of acquiring, processing and interpreting images and related data, acquired from aircraft and satellites that record the interaction between matter and electromagnetic energy (EMR)". The information that can be extracted from remotely sensed data depends on the type of EMR energy the remote sensing system detects. The energy moves with the velocity of light in a harmonic pattern consisting of sinusoidal waves where it has both electrical and magnetic field components lie in perpendicular position. EMR travels at the same speed (c) of light. If wavelength (λ) is the distance between any point on one wave to its same position on the next wave, expressed in micrometer (µm) or nanometer (nm), and frequency (f) is the number of cycles completed in one second, expressed in megahertz (MHz) or gigahertz (GHz), then the relation between these parameters is Lillesand and Kiefer (2000):

$$c = \lambda f \tag{2-2}$$

Aronoff (2005), Lillesand and Kiefer (2000) and Jensen (2000) discussed that the interaction of EMR waves with natural surfaces and atmospheres is strongly dependent on the frequency of the waves. EMR spectrum is divided into a number of sub-energy fields called spectral regions (X-ray, ultraviolet, visible, infrared and microwave). Each spectral region is characterized by specific wavelengths. Waves in different spectral bands tend to excite different interaction mechanisms such as electronic, molecular, or conductive mechanisms. Energy from the sun may be scattered, reflected, or absorbed by the Earth's surfaces. The wavelength ranges in which the atmosphere is particularly transmissive of energy are referred to as 'atmospheric windows'. These windows of the spectrum are used for their applicability to a particular remote sensing system/application. Instruments capable of measuring EMR are called sensors. Operationally, sensors can operate in two forms: passive (utilize reflected sunlight or the emitted energy by an earthy object) and active (utilize own system's built-in source of generated radiation). The remote sensing of Earth involves two basic processes: data acquisition and data analysis (Figure 2.3). The data acquisition process consists of:

1. Energy sources, maybe from the sun or the platform (a),
2. Propagation of energy through the atmosphere (b),
3. Energy interactions with Earth surface features (c),

4. Re-transmission of energy through the atmosphere (d),

5. Detecting sensor systems (e) , and

6. Sensor's data in pictorial and/or digital form (f).

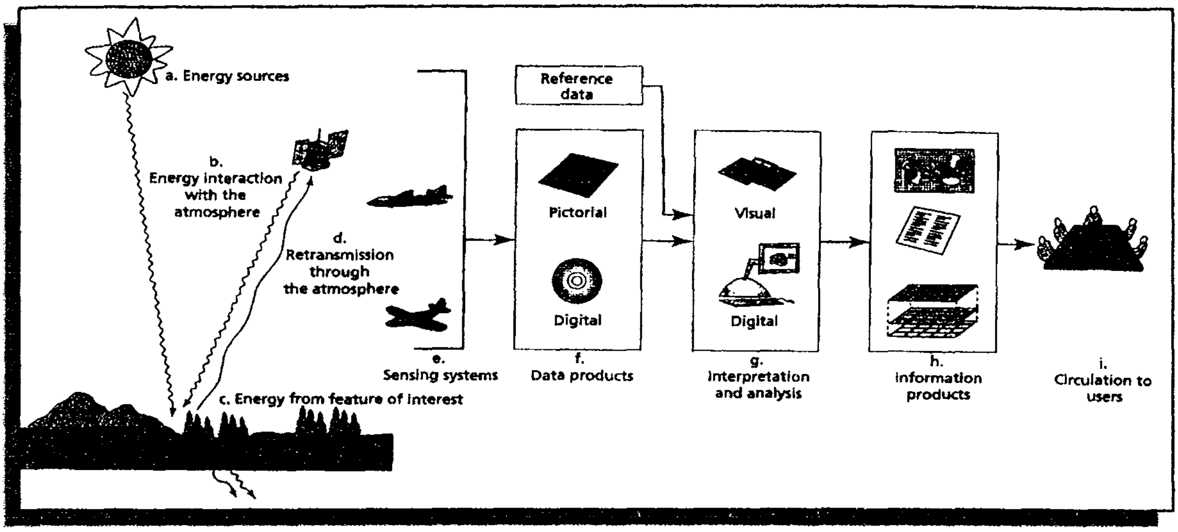

Fig. 2.3 The Remote Sensing Process (Aronoff, 2005)

The data analysis process consists of:

1. Viewing and interpreting devices for pictorial data (visual), and a computer (automated) to analyze digital sensor data and derive information (g),

2. Compilation of information in the form of hard-copy maps and tables, or as computer files (h) suitable to the application of a user, and

3. Presentation and circulation of the information to the users who apply it to their decision-making process (i).

2.7.1.1 Spectral Signature

Objects selectively absorb and reflect EMR as different way as their molecular composition of their surfaces and by that observing the properties of the returned radiation leads to the characterization of the Earth surface feature. The reflectance characteristics of Earth surface features may be quantified by measuring the portion of incident energy