DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEMS BASELINE GEODATABASE TEMPLATE AND SPATIAL ANALYSIS METHODS FOR EVALUATING POTENTIAL AND PREDICTED ENVIRONMENTAL IMPACTS FOR SUSTAINABLE ENVIRONMENTAL IMPACT ASSESSMENT OF MINING IN SIERRA LEONE

A thesis submitted to Selinus University of Sciences and Literature,

Faculty of Life and Heart Sciences in partial fulfillment of the requirements for the award of the degree of

Doctor of Philosophy in

Sustainable Development & Geographic Information Systems

By

Samuel Mohamed Kamara

JULY, 2020

DECLARATION

"I do hereby attest that I am the sole author of this thesis and that its contents are only the result of the readings and research I have done. The Thesis titled of "Development of a Geographic Information Systems Baseline Geodatabase Template and Spatial Analysis Methods for evaluation potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra Leone" Submitted for the Award of Doctor of Philosophy in Sustainable Development and Geographic Information Systems, is my original work and the thesis has not formed the basis for the award of any degree, associateship, fellowship or any other. The material borrowed from similar titles other sources and incorporated in the thesis has been duly acknowledged. The research papers published based on the research conducted out of the course of the study are also based on the study and not borrowed from other sources.

Date: July 2020

Student Signature

Student ID: **UNISE0800IT**

Acknowledgment

I will, first of all, express my sincere thanks and appreciation to the Almighty Allah for his countless blessings and guidance I received throughout this course. I am deeply grateful for the love and support of my late parents, and my entire family. I am thankful to the University of Selinus Faculty of Life and Heart Sciences for allowing me to pursue a Doctorate in Sustainable Development & Geographic Information Systems. I would also like to thank my guide and my faculty's source of inspiration for their valuable mentoring and inputs. Their constant support and invaluable advice have always guided me in the right direction. They helped me to know various phenomena related to the research practices which further gave an impetus to channelize my study appropriately. I sincerely thank them for their treasured guidance without which this thesis would have never been possible. Lastly, I express my deep sense of gratitude to the almighty, my family members especially my wife Mrs. Ramatu Kamara your unconditional support and love and my kids; Samuel, Sarah, and Samuella, thank you for making me proud to be your father.

Student Signature

Student ID: UNISE0800IT

DEDICATION

This thesis is dedicated to my beloved late parents,

Mr. Unisa Kamara, Mrs. Makallay Kamara, and Madam Sarah Kandeh,

who answered the call of the Almighty ALLAH when I was still in the

academic struggle. Your love, patience, support has been a source of

inspiration and encouragement throughout my life. May Almighty ALLAH

grant you, Heaven.

Ameen

ABSTRACT

As the stress on the exploitations and exploration of environmental natural resources in Sierra Leone continues to increase as a result of excessive development pressures, integration of Geographic Information Systems into environmental impact assessment considerations become even more important in the EIA process. It has been felt, therefore, that, without incorporating Geographic Information Systems into environmental planning, monitoring, and management, it would be impossible to move towards sustainable development. The EIA process involves the consideration of many different variables and phenomena, which often have complex interrelationships that vary in space and time, and GIS can be an important tool in modelling such variables.

Spatial analysis of EIAs in mining involves the use of GIS integrated submodels. Such models use mathematical, statistical, and algorithmic methods to predict the spatial and temporal distribution of different environmental impacts on environmental parameters. GIS-based spatial analysis techniques like; overlay analysis, buffering analysis, proximity analysis, spatial interpolation analysis, least-cost path analysis, geostatistical methods, uncertainty analysis, and sensitivity analysis, are used in the spatial and temporal simulation of environmental impacts assessment studies. Data visualization, in the form of 3D visualization, TIN, thematic maps, symbolic maps, tables, and charts are used in the communication and decision-making of EIA of mining reports. Although Environmental Impact Assessments (EIAs) are dependent on geo-spatial information to make an assessment, there are no rules set on how to conduct an environmental assessment on mining activities in Sierra Leone. Environmental Impact Assessment (EIA) was formally adopted in Sierra Leone in 2010 as a measure to protect the environment and to reduce environmental degradation associated with major developmental projects. However, application of GIS in mining EIA in Sierra Leone is constrained by the availability of an

appropriate digital electronic baseline geodatabase on environmental parameters and datasets, such as base maps on Land use/land cover, soil, geology, topography, population density, socio-economic levels, road accessibility, air quality, water quality, noise level, biological content, historical value, archaeological, climate change to name a few. Although very significant work has been done in environmental impact assessment and sophisticated Geographic Information Systems has been developed to determine the location of mineral deposit and ore bodies, no complete GIS spatial data collection and spatial analysis methods and database model appear to have been developed to date to provide an integrated sustainable spatial analysis and modelling tool for EIA and environmental management of mining in Sierra Leone. Some possible reasons are; (i) the absence of comprehensive understanding of interrelated environment impacts caused by the mining of different minerals, (ii) the environmental uniqueness of each mine, which make it difficult to develop general tools of EIA analysis and models (iii) the availability of adequate spatial data, information and appropriate GIS technics (iv) because of the dynamic characteristics and multivariate nature of the environment, it has often been difficult to collate, analyze and interpret its datasets (v) lack of appropriate temporal and spatial resolution of remotely sensed imageries and accurate geospatial data can be a major limitation on spatial modelling (vi) Finally, the availability of GIS professionals and affordability of GIS software and related hardware is a major constraint on EIA. Most EIA studies of mining projects have focused only on one or a limited set of impacts of the project on the physical, ecological, or social environment. Thereby, such studies have not provided a holistic picture of the entire environmental impact scenario. However, this great complexity can be overcome, with the innovation and application of a system of computer tools such as geographic information systems. Therefore, the development of a Geographic Information Systems Baseline Geodatabase Template and Spatial Analysis Methods for evaluation potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra

Leone will help to provided a holistic picture of the entire environmental impact scenario of mining in Sierra Leone that can support the data acquisition process of environmental impact assessment and offers a concept for developing analysis methods for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development in Sierra Leone. It is expected that the environmental databases from mining companies have uniformity in data collection procedure, field measurement procedure, results classification, coding and data management, analysis method, and reporting data system to the environmental agency. The study emphasized the application of GIS technology and software such as ArcGIS Desktop, ArcCatalog. ArcMap.

The expected output is an application in the ArcGIS software environment where the no GIS expert and the environmentalist can easily use the templates and the spatial analysis methods to analyze the data and get a comprehensive analysis and results for EIAs of mining reporting. This study will add a more meaningful contribution to studies already done by other researchers in the integration of GIS and GIS software to solve the environmental problems of mining. Thus, this thesis offers a tempting avenue for further research.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF TERMS

CEIA	–	Cumulative Environmental Impact Assessment
DEM	–	Digital Elevation Model
EPA	–	Environment Protection Agency
EPA–SL	–	Environment Protection Agency Sierra Leone
EMP	–	Environmental Management Plan
EIA	–	Environmental Impact Assessment
ESHIA	–	Environmental Social Health Impact Assessment
EIS	–	Environmental Impact Statement
ESRI	–	Environmental Systems Research Institute
GIS	–	Geographic Information Systems
GPS	–	Global Positioning System
NA	–	Network Analyst
LP	–	Linear Programming
ISO	–	International Organisation for Standardisation
SA	–	Spatial Analysis
SEA	–	Strategic Environmental Assessment
SL	–	Sierra Leone
TIN	–	Triangular Irregular Network
UTM	–	Universal T

Chapter 1: Introduction

1.1. Background of the research

Since its introduction more than 45 years ago, environmental impact assessment (EIA) has gradually developed into a powerful planning and decision-making tool. EIA studies the environmental consequences of a proposed project so that corrective actions can be taken to ameliorate the adverse impacts. It is one of the environmental management tools that have been established in different countries to ensure environmental protection (Jay et al., 2007). Generally, an impact study is an information collection and analysis process; thus, up-to-date, available, and relevant data are needed to attain useful results (Bulla et al. 2004). The importance and necessity of data are emphasized in the basic principles of an environmental impact assessment; the realization of an EIA is only possible if the appropriate quantity and quality of data are available. Fortunately, when it comes to environmental impact studies, a rise in the number of studies conducted has also led to a rise in quality (Barker – Wood 1999). Because of the dynamic characteristics and multivariate nature of the environment, it has often been difficult to collate, analyze, and interpret its datasets. The EIA process involves the consideration of many different variables and phenomena, which often have complex interrelationships that vary in space and time, and GIS can be an important tool in modelling such variables.

This great complexity can be overcome, however, with the innovation and application of a system of computer tools such as the Geographic Information System (GIS) and related technology. GIS is applied in all EIA stages: from the acquisition, storage, and display of thematic information relative to the vulnerability of the affected resources, to

impact prediction and qualification, evaluation, and finally, presentation. GIS also offers a graphical presentation of Environmental Impact Assessment (EIA) for easy analysis during the decision- making processes. Because GIS is proficient in data collection and collation, it has become an appropriate mechanism for creating an environmental information system database. This storage facility makes environmental data easier to upgrade, update, and retrieve as desired.

Although Environmental Impact Assessments (EIAs) are dependent on geo-spatial information to make an assessment, there are no rules set on how to conduct an environmental assessment on mining activities in Sierra Leone. Environmental Impact Assessment (EIA) was formally adopted in Sierra Leone in 2010 as a measure to protect the environment and to reduce environmental degradation associated with major developmental projects.

As the stress on the exploitations and exploration of environmental resources in Sierra Leone continues to increase as a result of excessive development pressures, integration of Geographic Information Systems into environmental impact assessment considerations become even more important in the EIA process. It has been felt, therefore, that, without incorporating Geographic Information Systems into environmental planning and management, it would be impossible to move towards sustainable development.

However, incorporation of these considerations in EIA studies of mining projects in Sierra Leone has been minimal in practice because of confusion over appropriate spatial and temporal boundaries in impact studies, lack of emphasis by the project proponents and the government agencies, and more importantly, the absence of structured methodologies (Canter and Kamath, 1995). In recent years, though, studies have

increasingly started to address this issue and have shown that the existing EIA methodologies and assessment tools can often be combined effectively to address EIA studies of mining projects.

Nevertheless, the concepts and guidelines developed for data collection, processing, and analyses thus far are somewhat generic and it is important to develop sector-specific methodologies.

The main objective of this thesis is to develop a Geographic Information Systems Baseline Geodatabase Template and Spatial Analysis Methods for evaluation potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra Leone. How some of the critical data collection activities and analyses within the EIA process of mining could be carried out to address the impacts is discussed. The methodology presented in the development of the database template and analysis methods can be replicated into other EIAs studies for different sectors in Sierra Leone.

1.2. Scope and significance of the research

The problem of how to effectively handle a large volume of environmental spatial and non-spatial data is not new. Although very significant work has been done in environmental impact assessment and sophisticated Geological Information Systems has been developed to determine the location of mineral deposit and ore bodies, no complete GIS spatial data collection and spatial analysis methods and database model appear to have been developed to date to provide an integrated sustainable spatial analysis and modelling tool for EIA and environmental management of mining in Sierra Leone. Some possible reasons are; (i) the

absence of comprehensive understanding of interrelated environment impacts caused by the mining of different minerals, (ii) the environmental uniqueness of each mine, which make it difficult to develop general tools of EIA analysis and models (iii) the availability of adequate spatial data, information and appropriate GIS techniques (iv) because of the dynamic characteristics and multivariate nature of the environment, it has often been difficult to collate, analyze and interpret its datasets (v) lack of appropriate temporal and spatial resolution of remotely sensed imageries and accurate geospatial data can be a major limitation on spatial modelling (vi) Finally, the availability of GIS professionals and affordability of GIS software and related hardware is a major constraint on EIA. Most EIA studies of mining projects have focused only on one or a limited set of impacts of the project on the physical, ecological, or social environment. Thereby, such studies have not provided a holistic picture of the entire environmental impact scenario. However, this great complexity can be overcome, with the innovation and application of a system of computer tools such as geographic information systems. Therefore, the objective of this present research is to develop a Geographic Information Systems baseline geodatabase template and spatial analysis methods for the evaluation of the potential and predicted environmental impact for sustainable impact assessment of mining in Sierra Leone which will help to provide a holistic picture of the entire environmental impact scenario of mining in Sierra Leone that can support the data acquisition process of environmental impact assessment and offers a concept for developing analysis methods for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development in Sierra Leone. This can then be used to develop an integrated spatial analysis model tools for baseline EIA studies of mining in Sierra Leone. The study emphasized the application of GIS technology and software such as ArcGIS Desktop, ArcCatalog.

ArcMap.

1.3. Aim and objectives of the research

This research aims to develop a Geographic Information Systems baseline geodatabase template and spatial analysis methods for the evaluation of potential and predicted environmental impact for sustainable impact assessment of mining in Sierra Leone that can support the data acquisition process of environmental impact assessment and offers a concept for developing analysis methods for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development in Sierra Leone. To develop such a database template and analysis methods, comprehensive knowledge, and understanding of the complexity of the various process involved in mining as well as GIS technical capacity, analysis, and applications must be combined. The main assumption for this research is that the use of GIS enhances better communication between the mining operator, government ministries, departments and agencies and the general public to make better decisions on mining activities for the attainment of sustainable development in the mining sector. Secondly, the use of GIS improves environmental impact assessment and management in the mining industry. It is expected that the environmental databases from mining companies have uniformity in data collection procedure, field measurement procedure, results classification, coding and data management, analysis method, and reporting data system to the environmental agency. The expected output is an application in the ArcGIS software environment where the no GIS expert and the environmentalist can easily use the templates and the spatial analysis methods to analyze the data and get a comprehensive analysis and results for EIAs of mining reporting. This study will add a more meaningful contribution to studies already done by other researchers in the integration of GIS and GIS software to solve the environmental problems of mining in Sierra Leone. The study

emphasized the application of GIS technology and software such as ArcGIS Desktop, ArcCatalog. ArcMap.

1.4. Research Contributions

As stated earlier, the purpose of this research is to develop a Geographic Information Systems Baseline Geodatabase Template and Spatial Analysis Methods for evaluation potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra Leone. that can support the data acquisition process of environmental impact assessment and offers a concept for developing analysis methods for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of the mining industry in attaining sustainable development in Sierra Leone. The expected output is an application in the ArcGIS software environment where the no GIS expert and the environmentalist can easily use the templates and the spatial analysis methods to analyze the data and get a comprehensive analysis and results for EIAs of mining reporting. This study will add a more meaningful contribution to studies already done by other researchers in the integration of GIS and GIS software to solve the environmental problems of mining. It will also aid environmental practitioners, Environmental planners and engineers, and environmental scientists, by providing an environmental database spatial data collection for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development.

1.5. Limitations of Research

This study focused on the thesis is to develop a Geographic Information Systems baseline geodatabase template and spatial analysis methods for evaluating potential and predicted environmental impact for sustainable impact assessment of mining in Sierra Leone. The study emphasized the application of GIS technology and software such as ArcGIS Desktop, ArcCatalog. ArcMap. The approach is to help environmental practitioners, Environmental planners, engineers, and environmental scientist by providing an environmental database template for data collection and analysis for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development and employed the use of GIS to solve environmental problems faced in the impact assessment studies of mining. Due to the limited available data, a conceptual GIS database template has been developed rather than a databased case study of a mining site. No site investigation and data collection were undertaken. The literature review revealed that no complete GIS spatial data collection and spatial analysis methods and database model appear to have been developed to date to provide an integrated sustainable spatial analysis and modelling tool for EIA and environmental management of mining in Sierra Leone. Therefore, it is expected that the environmental databases from mining companies have uniformity in data collection procedure, field measurement procedure, results classification, coding and data management, analysis method, and reporting data system to the environmental agency. The study emphasized the application of GIS technology and software such as ArcGIS Desktop, ArcCatalog. ArcMap.

1.6. Thesis Outline

A summary of the structure of this research is as follows;

In **Chapter 1**, we start by giving the background of the study followed by the scope and significance of the research, aim, and objective of the research, research contributions, thesis outline and the limitation of the research

Chapters 2, gave an overview of policy, legal instruments, and processes of the environmental impact assessment system of mining in Sierra Leone from which the baseline datasets are derived.

Chapter 3, focus on the literature reviews obtained by previous researchers in the field of GIS and the integration of GIS as a tool into environmental impact assessment studies in general and the solution to the environmental impact assessment of mining in Sierra Leone. It followed by an overview of methods and principles of EIA for sustainable development and provide a summary of the environmental impacts of mining. It further explains how the use of GIS software together with the other software's can be used to solve environmental problems in the mining environment and its potentials as a core part of an Environment Database management system.

Chapter 4, focus on the development of the baseline spatial geodatabase template. This chapter also includes a description of the basic steps of the methodology that are used and an explanation of the data structure, characteristics, and the database template design process.

Chapter 5, deals with the development of the baseline Spatial Analysis Methods for Evaluating Potential and Predicted Environmental Impacts of mining. A more detailed explanation of these methods was given and a clear description of the datasets required and GIS spatial analysis techniques were recommended to carry out the analysis in a GIS platform, finally; **Chapter 6**, the Conclusion and Future Research chapter, gives a complete summary of our research and state which added further research to be done.

Chapter 2: An Overview of Policy, Legal Instruments, and Processes of the Environmental Impact Assessment System of mining in Sierra Leone

2.1. Introduction

Environmental Impact Assessment (EIA) is one of the major instruments integrated to make economic development projects, environmentally sound, and sustainable in Sierra Leone. The Sierra Leone government has established an EIA system for developmental projects with the formulation of the Environmental Protection Act of 2008 as well as sectoral policies, laws, and guidelines. Based on the formulated Act, regulations, and guidelines, criteria for EIA has established that the development projects certainly require environmental impact assessment study as per the nature of the projects unless they cross the given threshold for the disruption of the environmentally sensitive areas and their natural environment. However, ongoing EIA systems have big challenges towards environmental data management and biodiversity conservation for sustainable development. To overcome the environmental problems that may result from mining activities, the Government of Sierra Leone has issued several policies, legislation guidelines, and regulations. The following sections give a detailed overview of the policy, legal Instruments, and processes of the environmental impact assessment system of mining in Sierra Leone.

2.2. EIA policies in Sierra Leone

The main legal instrument for EIA in Sierra Leone is the Environment Protection Act of 2008 which was signed as a legal document in September 2008 and amended in July 2010. Following the enactment of this Act, an Environmental Impact Assessment Report (EIA) is demanded certain types of project activities. A potential project requested to carry out EIA studies would be mandated to commence its operations, by the issue of an EIA license, on approval of the submitted EIA report. National requirements for public participation and consultation as part of the conduct of EIA are further outlined in the EIA procedural guidelines that contained a systematic and comprehensive approach to the conduct of EIA and details about the stages of the EIA process, including the categorization of projects into classes A, B, and C (EPA Act, 2008). The EPA Act of 2008, made the preparation of Environmental Impact Assessments mandatory for all planning new projects. This involves the assessment of environmental, socio-economic, health aspects (ESHIA) of the project area, and production of a report. As already discussed EIA is a process and practice which provides information to the local authority, authorized bodies, other interested parties about intended development at a particular locality. EIA is furthermore, the complete process of retrieving and analyzing information for the determination of the application for any development. The general aim of the EIA study is to ensure not only a cohesive impact assessment but also ensuring that all the involved and relevant parties are successfully aware of the overall environmental implications, impacts, and mitigations and provide a technical and non-technical summary, to represent the overall environmental finding and recommendations.

2.3. Laws related to Environmental impact assessment process in Sierra Leone

Several Sierra Leone laws touch mining projects in Sierra Leone. These laws and regulations cover environmental, mining, and industrial activities. Legislation governing environmental issues are found as Acts enacted by parliament. In addition to these, some regulations give an

effect on the Acts. The pieces of legislation of the various government line ministries or institutions include:

The Constitution of Sierra Leone (Act No. 6 of 1991)

Section 15 of the Constitution states that: "… every person in Sierra Leone is entitled to the fundamental human rights and freedoms of the individual." This includes protection from deprivation of property without compensation. Section 21(1) further stipulates that no property of any description shall be compulsorily taken possession of, and no interest in or right over property of any description shall be compulsorily acquired, except where land is required by the GoSL in the public interest.

The Environmental Protection Agency Act, 2008 (Act 11 of 2008)

The Environment Protection Agency Act, 2008 (Act 11 of 2008) was enacted to establish the Environment Protection Agency Sierra Leone (EPA-SL) and to provide effective measures for the management and protection of the environment. The Act repeals the Environment Protection Act, 2000 (Act 2 of 2000). In terms of Section 24 of the Act, any person who wishes to undertake any of the projects set out in the First Schedule of the Act must apply to EPASL for an EIA license. The projects or activities in the First Schedule of the Act that require an EIA license include extractive industries, e.g. mining, quarrying, extraction of sand, gravel, silt, peat, oil, and gas. The application for an EIA Licence must be accompanied by a description of the proposed to be undertaken. EPA-SL must within 14 days of receiving an application decide whether an EIA is required for the project or not. Section 25(2) requires EPA-SL to take the matters set out in the Second Schedule to the Act into consideration when deciding on whether an EIA is required in respect of the project. The factors for determining whether a project requires an environmental impact assessment includes the following: Environmental impact on the community; Location of the project; Whether the project transforms the locality; Whether the project has or is likely to have a

substantial impact on the ecosystem of the locality; Whether the project results in the diminution of the aesthetic, recreational, scientific, historical, cultural or other environmental quality of the locality; Whether the project will endanger any species of flora or fauna or the habitat of the flora or fauna; Scale of the project; Extent of the degradation of the quality of the environment; Whether the project will increase demand for natural resources in the locality; and Cumulative impact of the project together with other activities or projects, on the environment. The applicant will be advised in writing where a decision has been taken that an EIA is not necessary for the project. In instances where projects require an EIA Licence, the applicant will be requested to prepare and submit an ESIA in respect to the proposed project. The content of the ESIA is included in the Third Schedule to the Act. Section 27 of the Act provides that EPA-SL must after receiving an ESIA, circulate it to professional bodies or associations, Government Ministries and NGOs for their comments. The ESIA must also be made available for public review and comments. Notice of the public review must be given in two consecutive issues of the Government Gazette and two issues in a newspaper. In respect of the newspaper published at least seven days must be afforded between the first and second publications. Public comments on the ESIA must be submitted to EPA-SL within 14 days of the last publication in the Gazette or newspaper. Failure to comply with the EPA Act of 2008 is a punishable offense. The Environment Protection Agency Act (EPAA), 2008, is prepared based on facts that development activities have the risk to generate pollution and environmental damage that can lead to the reduction of carrying capacity, productivity, and capacity of the environment. Obligation to provide correctly, accurately, open, and regular information related to environmental protection and management; maintain the sustainability of the environment, and comply with the environmental quality standards and or standard criteria of environmental damage.

The Mines and Minerals Act of 2009

The issues and provisions dealing with the protection and management of the environment form an integral part of the Mines and Minerals Act 2009 and are substantially covered in part XV of the Act. The Act makes it a strict requirement for all small-scale and large-scale mining license holders to acquire environmental impact assessment licenses, by the Environmental Protection Act 2008. Beyond complying with the EPAA, 2008, and a general duty to protect the environment, it further specifies the following requirements, environmental baseline assessment, including detailed measurements; details on the operations, reclamation and closure; including resource requirements, emissions, impacts, immitigable impacts, mitigation measures, timetables, budgets, human resource capacity, monitoring methodology and mechanisms, and an overall environmental management plan; Requirement to consult the public and verify possible impacts; Annual environmental report, covering progress against the environmental management plan; and requiring any water diversion to be approved within an environmental management plan and concerning the prevention and remedy of environmental damage and environmental pollution in business activity of general mining, obliges mining company to submit annual environmental management plan include land use plan, techniques and methods of environmental management, schedule of work and completion of reclamation phase, the area to be reclaimed, the crop type to be planted and environmental management estimation cost. Mining companies are also obliged to submit annual environmental monitoring plans include environmental parameters to be monitored, location of monitoring point, frequency of monitoring, and monitoring estimation cost.

The National Minerals Agency Act, 2012

This is an Act to establish the National Minerals Agency to promote the development of the minerals sector by effectively and efficiently managing the administration and regulation of mineral rights and minerals trading in Sierra Leone. This includes geological survey and

data collection activities to establish a National Minerals Agency Board to provide technical and other support to the agency and to provide for other related matters.

The Forestry Act, 1988

This Act came into operation on 1st July 1988 and the Chief Conservator of Forest, with the directives of the Minister, is responsible for the implementation of its regulations. He, therefore, has the role of preserving the forest environment, promoting the practice of forestry in all use of forestland, to ensure the sustainability of forest products, and the protection of the soil and water resources that constitute the environment.

The Explosives Ordinance of 1955

The Ordinance provides for the licensing of the importation of explosives by the Chief Inspector of the Police Force. Also, the Ordinance states in section 8 that "Subject to the provisions of the Arms and Ammunition Ordinance of 1955, any person who imports or exports any explosive into or from Sierra Leone except by sea at a prescribed port or by air at a prescribed aerodrome shall be guilty of an offense."

The Ordinance also makes provision for the licensing of the Purchase of explosives; Transportation of explosives within the country; Storage facilities for explosives. Despite the provisions of the Ordinance, the importation and transportation of explosives into the country involve several arms of the government who all have to be informed and must individually issue clearance certificates. These include The Sierra Leone Police Force; The National Security Coordinator; The National Revenue Authority; The Ministry of Defence; The Republic of Sierra Leone Armed Forces, Engineering Regiment.

2.4. National Regulations related to EIA in Sierra Leone

Some of the regulations in Sierra Leone also provide an opportunity to conduct environmental assessment studies for example;

The Environmental and Social Regulations for the Minerals Sector, 2011

These regulations state that "All mining activities shall be carried out sustainably by minimizing or eliminating negative environmental and social adverse impacts by the provisions relating to environmental impacts contained in Section 132 (1) of the Mines and Minerals Act 2009 and those relating to social impacts contained in Section 133 (1) (b) (xii) and (xiii) of the same." The regulations outline the environmental and legal responsibilities of a mining license holder. The following are among the listed responsibilities: The holder of a mineral right shall be responsible for the environmental and social impacts of their activities, as well as for managing these impacts. Every holder of a mineral right shall carry on its operations in a manner that is reasonably practicable in such a manner as to prevent, minimize, manage and mitigate any adverse environmental impact including but not limited to pollution resulting from such operations and any adverse social impact. The holder of a mineral right shall be subject to the legal obligation to keep emissions and effluents resulting from its operations under the maximum level of pollutant concentration permitted by these Regulations and they shall manage and control residues, wastes, toxic substances, and other contaminants to ensure that they will not cause adverse effects on the environment and public health.

Sierra Leone Operational Mining Regulations.

These regulations outline the operational requirements of mining license holders in the following aspects: Administration responsibilities; Reporting methods for resources and reserves; mine design of open-pit mines; Occupational health and safety; Workplace Standards; Waste disposal and containment of tailings; Explosives and Blasting; Reclamation and Land Closure. The following are some of the main obligations for mining license holders: Mining Right Holders shall, as far as reasonably practicable, ensure that the mine is designed, constructed and equipped:

(a) To provide conditions for safe operation and a healthy working environment;

(b) With a communication system and with electrical, mechanical, and other equipment as necessary to achieve a safe working environment. Mining Right Holders shall ensure, as far as reasonably practicable, that the mine is commissioned, operated, maintained, and decommissioned in such a way that employees can perform their work without endangering the health and safety of themselves or any other person. Mining Right Holders shall compile monthly health and safety statistics at the mine which must be kept under the terms of these Regulations and if the employer is a body corporate which employs more than 50 employees, the Mining Right Holder shall publish and make available the report in an appropriate form to shareholders or members on an annual basis. The Chief Executive Officer shall appoint a Health and Safety Officer who is suitably qualified to manage and supervise the health and safety operations in the mine. Right Holders shall pay the costs of all clinical examinations and medical tests performed by the terms of these Regulations.

Part XII- of the Operational Regulations for the Mineral Sector, 2011 stipulates specific requirements to be fulfilled whilst undertaking Underground Mining operations.

Some of the specific requirements from the regulations focus on: Underground mine plans, Ventilation in underground mines, Underground mine safety Lighting in underground mines Mine safety planning and precautions Underground Outlets, Ladder ways and Travelling Ways, Underground Emergency Preparedness and Response, Reporting of accidents or dangerous occurrences in an underground mine, Underground operations and safety of trackless transport machinery and Earth Moving Equipment, Underground Mine Ventilation, Prevention of Flooding, Testing for flammable gas.

The Forestry Regulation –1989

These regulations are deemed to have come into force on the 1st of July, 1990. The Chief Conservator holds the same responsibilities as he does for the Act of 1988. Generally,

community forests are managed by the Forestry Division or by agreement with the Division; it could be managed by the local government, or Community Forest Association. Based on this responsibility of the Division, no protected forest shall be tampered with in any way as is stated in section 21, subsection (2) of the Forestry Act – 1988, without written permission from the Chief Conservator of the forest.

The Draft Wildlife Regulation, 1997

The Wildlife Regulation came in to force in 1997. It describes Wildlife Conservation Estate as areas described under the 1972 Wildlife Conservation Act as a National Park, Game Reserve, Strict Natural Reserve, Game Sanctuary, or Non-hunting Forest Reserve. The regulation prohibits all unlicensed hunting with a Wildlife Conservation Estate to include the removal of honey. It prohibits the hunting of young and immature wild animals or birds; female wild animals accompanied by its young; and birds which are breeding. It also prohibits the dazzling of birds and animals.

2.5. EIA Policies Related to Different Sector

To overcome the environmental problems that may result from mining activities, The Government of Sierra Leone has issued several policies including the following;

The National Environmental Policy, 1994: This National Environmental Policy seeks to achieve sustainable development in Sierra Leone through the implementation of sound environmental management systems which will encourage productivity and harmony between man and his environment. It also promotes efforts that will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of people

and serves to enrich the understanding of ecological systems and natural resources important to the nation.

The Core Minerals Policy, 2004: The Core Minerals Policy (CMP) aims to balance the conflicting interests of the industry's stakeholders, effectively deal with environmental and human rights protections, and enable inward investment. The CMP is a comprehensive document that clearly states the Ministry of Mineral Resources' vision and priorities for the mining sector.

The Draft National Lands Policy, 2012: The Land Policy of Sierra Leone aims at the judicious use of the nation's land and all its natural resources by all sections of the Sierra Leone society in support of various socio-economic activities undertaken by sustainable resource management principles and in maintaining viable ecosystems

The National Water and Sanitation Policy, 2011: The policy contains the ambitious targets of extending national water supply and sanitation coverage to 74% and 66% respectively, aligned to the Millennium Development Goals (MDGs). The objective of this policy is to increase the political prioritization for Water, Sanitation, and Hygiene in Sierra Leone, accelerate access to safe, reliable, affordable and sustainable water and sanitation services throughout the country.

The National Biodiversity and Strategic Action Plan, 2003: The action plan intended to conserve and promote the sustainable use of the different components of the country's biodiversity. Several key thematic areas are covered: terrestrial biodiversity, inland water ecosystems, forest biodiversity, marine, and coastal biodiversity and agricultural biodiversity. Also, actions are proposed for key cross-cutting issues affecting the sustainable utilization of biodiversity, including policy, legislation and institutional review, capacity building, identification and monitoring, sustainable use, incentive

measures, research and training, public education and awareness, regulation of access to genetic resources, protection of indigenous knowledge and intellectual property rights of local communities, technology transfer and handling of biotechnology and exchange of information and technical cooperation.

The Draft Forestry and Wildlife Sector Policy for Sierra Leone, 2003

This document is still under review and awaiting parliament approval. The goal of the document is to support the development and exploitation of forests and wildlife of Sierra Leone sustainably for the material, cultural and aesthetic benefit of the people of Sierra Leone in particular and mankind in general.

Chapter 3: The Integration of GIS into Environmental Impact Assessment Studies

3.1. Introduction

Attunes et al. (1996) attempts to employ GIS in EIA which have demonstrated that "GIS can have a wide application in all EIA stages, acting as an integrative framework for the whole process, from the generation, storage, and display of the thematic information relative to the vulnerability and sensitivity of the affected resources, to impact prediction and finally for their evaluation for decision making. The capability of geographic information systems (GIS) to store, integrate, analyze, and display spatial attributes of socioeconomic and environmental data has clearly shown that they are increasingly applied to environmental impact assessments (EIA) studies.

The GIS is a tool that assists in the development of sustainable mining and decision-making processes through the input, spatial analysis, and modelling and the output of relevant information. Integrating GIS within the EIA process of mining will improve different processes and features mainly related to data storage and access, to the analytical capabilities and the communicability of the results. GIS brings to the EIA process of mining a new way of communicating the results of the analysis, which can be of great importance during the public disclosure process where the results from the public consultation and socio-economic surveys can be integrated into a GIS for spatial and non-spatial analysis, and display in a format that is easily understood by both technical and nontechnical stakeholders. Therefore, the development of a Geographic Information Systems Baseline Geodatabase Data Collection template and spatial analysis models for sustainable

environmental impact assessment of mining in Sierra Leone will enhance the effective management of the country mineral resources. The development of such a system will allow a more realistic approach to the environmental impact assessment study.

3.2. Environmental Impact Assessment (EIA)

According to Yousefi (2004), EIA is a process for identifying, predicting, evaluating and mitigating the biophysical, biological, hydrological, ecological, meteorological, noise, economic, social, and other relevant effects before development, then using the conclusions as a tool in planning and decision-making. In other words, impact assessment, simply defined as the process of identifying the future consequences of the current or proposed action. Its primary objective is to encourage the inclusion of environmental concerns in planning and decision making and to ultimately arrive at actions that are more environmentally attuned. The International Association for Impact Assessment adopts the following steps as being part of an EIA process: screening, scoping, the examination of alternatives, impact analysis, mitigation and impact management, evaluation of significance, preparation of environmental impact statement report, review of the environmental impact statement, decision making and follow up. To elaborate further Muthusamy and Ramalingam (2003) agree that an ideal

EIA system would

1) Apply to all projects that are expected to have a significant environmental impact and address all impacts that are expected to be significant.

2) Compare alternatives to a proposed project (including the possibility if not developing sites) management technique and mitigation measure.

3) Result in a clear environmental impact statement that conveys the importance of the likely impacts and their specific characteristics to non-experts as well as experts in the field.

4) Include broad public participation and significant administrative review procedure.

5) To be timed to provide information for decision- making

6) Be enforceable

7)Include monitoring and feedback procedures

In all of these steps mentioned, Geographical Information Systems play a pivotal role in ensuring that the steps are timely, efficient, and as accurate as possible.

3.3. Geographic Information Systems (GIS)

Geographic Information Systems are a set of tools for collecting, storing, retrieving as well as, transforming, and displaying spatial data from the world for a particular set of purposes (Burrough, 1986). The application of GIS is coherent with the discipline of the end-users and has become applicable to nearly all human endeavors ranging from the simple task of finding the best solutions or complex data analysis and information extraction for best policy formulations. In environmental impact assessment of mining, GIS is used as a software to collect, compute, store, analyze, manage, and present all types of physical, biological, environmental, ecological, and geological data. It integrates all statistical data and analysis with the Information Management utilization and database management (Eta J. B., Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A., 2014). Geographic Information System is essentially a marriage between computerized mapping and database management systems (Yousefi, 2004). GIS is entrenched in intellectual practices, populated by data and driven by mathematical analysis (Eta J. B.,

Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A., 2014). GIS uses layers also known as "themes" to overlay different forms of information, with each theme representing categories of information, such as population, roads, vegetation, settlements, forest cover, land use, etc. A single map generally contains a lot of information that is used in different ways by different individuals and organizations (Eta J. B., Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A., 2014). It represents a means of locating ourselves about the world around us (Yousefi, 2004). Yousefi (2004) stated that, with GIS hardware and software, maps usually display and analyze spatial data which most often have attributes that are tied to a database or databases. GIS databases include a wide variety of information including geographic, social, political, environmental, and demographic (Eta J. B., Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A., 2014)

3.4. GIS Integration in Environmental Impact Assessment Studies

Given the spatial geographic nature of many environmental impacts assessment studies, Geographical Information Systems can have a wider application in all EIA stages, acting as an integrated framework for the entire process, from the generation, storage, and display of the thematic information relative to the vulnerability and sensitivity of the affected natural resources, to impact identification and finally their evaluation for decision support (Antunes et al., 1996). Using Geographic Information System (GIS), will not only improve the overall process of the EIA but also provides valuable mapping methodologies, including spatial analysis and modelling for a holistic environmental system approach. It can be used to model the sensitivity of the environment and its components to proposed mining projects. It also has the capability of carrying out various analyses on both spatial and non–spatial(attributes) data. GIS analyses include buffering, distance analysis, cost analysis statistical analysis, spatial analysis, trend analysis, overlays, etc. In the application of GIS in EIA studies, GIS is a software used to collect, analyze, manipulate, store, manage and

present all types of physical, biological, environmental, ecological and geological data and environmental impact assessment study is the complete process of collecting, processing, analyzing information and the determination of the application for development approval, which could be accessible by the stakeholder, concerned communities and organizations.

Yousefi et al (2003) stated that EIA is a decision process, which aims to both identify and predict impacts on the natural environment. GIS is integrated within the EIA process to improve different features, mainly related to data storage and access, to the analytical capabilities and the visualization of the results. GIS brings to the EIA process a new way of analyzing and manipulating spatial data and an improved way of communicating the results of the analysis, which can be of great importance during the public disclosure and participation process where the results from the public consultation and socio-economic surveys can be imported into a GIS for spatial and non-spatial analysis, and display in a format that is easily understood by both technical and nontechnical stakeholders. Furthermore, Eedy (1995) stresses some of the advantages of the use of GIS in EIA, namely for data management, overlay, and analysis, trend analysis, as sources of data sets for mathematical impact models.

Erickson (1994) identified four methodologies associated with impact assessment, each with its strengths and weaknesses. The four methodologies are Checklist, Matrix Overlay, and Network.

The **Overlay method** of impact assessment requires physical or computerized overlays of individual maps of social and physical attributes of the project area. This method thrives on a graphical display of data, but it is limited in that it lacks analytical capabilities. GIS is the ultimate tool for overlay EIA (Ramesh P. Bhatt, 1999). The data it uses include topological data, air dispersal patterns, land and resource use data, wildlife, surface, and

groundwater intakes. Such data may be obtained from aerial photography and satellite remote sensing or other sources.

The **Checklist method,** this method varies from simple or complex list of environmental components, attributes, and processes, which are categorized under specialized headings such as vegetation, geology, and air. GIS provides a computer platform for organizing, processing, storing, and analyzing these checklists (Ramesh P. Bhatt, 1999).

The **Matrix method** is a modification of the Checklist method, it categorized specific project activities to specific types of impacts. They are required because they emphasize only on direct impacts. They force consideration of the impact of each aspect of a proposal for a range of environmental distresses and they consider both the magnitude and importance of impacts. Again, GIS provides a powerful tool for organizing, analyzing, and storing matrices (Ramesh P. Bhatt, 1999).

The **Network methodology** defines a network of possible impacts that may be triggered by project activities and that require the analyst to trace out project actions and direct and indirect consequences. From the network methodology, direct, secondary, tertiary, and other higher-order impacts of action may be traced out. This method cuts across disciplinary lines and it forces the identification of site-specific factors and conditions necessary for the establishment of a proposed cause-effect relationship. This technique, however, requires that the analyst be knowledgeable in the various types of environmental components and dynamics (Erickson, 1994). On a GIS platform, the analyst is further aided as large volumes of data can be better analyzed in a short while (Ramesh P. Bhatt, 1999). GIS has also been used for the presentation of environmental baseline information and project description, through the preparation of thematic maps for the several environmental impact assessment.

Table 3-1: EIA Stages and Application of GIS/Remote Sensing in Each Stage

(adapted from Joao and Fonseca, 1996).

No.	Stage	Possible Usage of GIS
1	Screening and Scoping	GIS datasets overlay provides a suitable tool for data analysis, data gathering, spatial data modelling, calculation of impact magnitude
2	Description of the project	Mapping of the spatial extent of the project (geographical context)
3	Description of baseline conditions	biophysical inventories, hydrology, soils, archaeological and historical resources, land ownership, topography, roads, utilities
4	Impact Identification	Overlay analysis, modelling, habitat suitability analysis
5	Prediction of impact magnitude	GIS predictive and modelling function – percentage change, impact magnitude maps, risk maps, modelling results
6	Assessment of impact significance	Map impact significance by alternative
7	Impact mitigation and control	GIS/RS to identify best mitigation measures or effectiveness of mitigation strategies, spatially and/or temporally impacts.
8	Public consultation and participation	Preparation presentation material, to explain the project to the public, responses to comments
9	Monitoring and auditing	Remote Sensing provides datasets for monitoring of environmental impacts of projects/program overtime. While GIS design monitoring programs, processing, and storage of monitoring data, comparison of actual outcomes with predicted outcomes, impacts over time

Figure 3-1 gives the overall picture for GIS integration into the EIA process through the ten stages. Which illustrates the nine sequential stages of the EIA process beginning with screening to Scoping and ending with monitoring. Public participation, the tenth stage surrounds the sequential stages as it is conducted during most stages. GIS is at the centre which is utilized in each stage of the process to enhance and improve its performance.

Remote Sensing

Methods of Impact Assessment

EIA

Overlay–Checklist–Matrix–Network

Physical Environment (Land Cover/Land Use Soil Type, Hydrogeo-Mophology, Geology, Drainage & Water Bodies, Elevation etc.) Ground Water Level)

Physical Environment (Soil Quality, Ambient Air Quality, Noise Level, Surface and Ground Water Level)

Socio- Cultural Environment (Population, Facilities, Roads, Income level)

Integrated GIS

Stage 1: Screening

Stage 2: Scoping

Stage 3: Description of the project

Stage 4: Baseline Conditions

Stage 5: Identification of Impact

Stage 6: Predicting impact magnitude

Stage 7: Assessing impact significant

Stage 8: Impact mitigation & control

Stage 9: Monitoring

Stage 10: Public Participation

GIS: Mapping, spatial analysis, modelling, overlays, database integration

Social Environment	Physical Environment	Biological Environment
Recreation	Landform	Wetlands
Landscape/Visual	Nuisance (noise, dust, smell)	Marine
Historical/Cultural	Climate/Atmosphere	Intertidal
Personal/Social Values	Foundation Materials	Estuaries Rivers
Risks and Anxieties	Agricultural Soil	Lakes Urban
Existing Land Uses Land	Ground Water	Land Crop Land
Value Settlement	Surface Water	Sand/Shingle/Rock
Employment	Sedimentation	Herb field (alpine)
Public Participation	Erosion/Land Stability	Grassland Shrub land
	River Regime	

Figure 3-1: GIS integration into EIA

3.5. EIA – An instrument for Sustainable Development

According to Glasson and Therivel et al. 1994, Environmental impact assessment (EIA) has been used as an instrument for sustainable development. Its role in environmental sustainability and development planning is thus unique and essential. It is a useful tool for promoting sustainable development because it contains many components that can facilitate equality in every aspect and it can minimize environmental degradation by identifying problems before they occur. Conducting an environmental impact assessment study in the mining sector can contribute to poverty alleviation, employment generation, environmental protection, and improved economic development effectively towards achieving sustainable development. Environmental Impact Assessment was introduced in Sierra Leone in 2008, with the Environment Protection Agency Act of 2008. Several different EIAs have been developed since then. Amongst them are Environmental Social and Health Impact Assessment (ESHIA), Strategic Environmental Assessment (SEA), Cumulative Environmental Impact Assessment (CEIA). EIA provides a unique opportunity to demonstrate ways in which the environment can be improved as part of the development process and it enables monitoring programs to be established to assess future impacts and provide data on which managers can make informed decisions to avoid environmental damage and increase of poverty among the people.

The widely accepted definition of sustainable development describes it as "a development that meets the needs of the present without compromising the ability of future generations to meet their needs and aspirations" (WCED, 1987). The need to strike a balance between socio-economic and environmental considerations as well as comply with national and international regulatory requirements was a driver for comprehensive environmental impact assessment studies. The concept of sustainable development was first introduced into the global environmental debate in the 1980s. there is an interdependency between

environmental impact assessment and sustainable development (economic development, social environment, the natural environment) and people and it is given in figure 3-2. Sustainable development establishes a path along which development can progress and enhancing the quality of life of people and ensuring the sustainability of the natural systems on which that development depends. The potential role of EIA in attaining the objective of sustainable development was explicitly recognized during the Earth Summit 1992 held in Rio de Janeiro (United Nations 1992). EIA has been a great interest in virtually all of the industrialized nations of the world, where it has now become a major tool for environmentally sound management practices and the attainment of sustainable development goals.
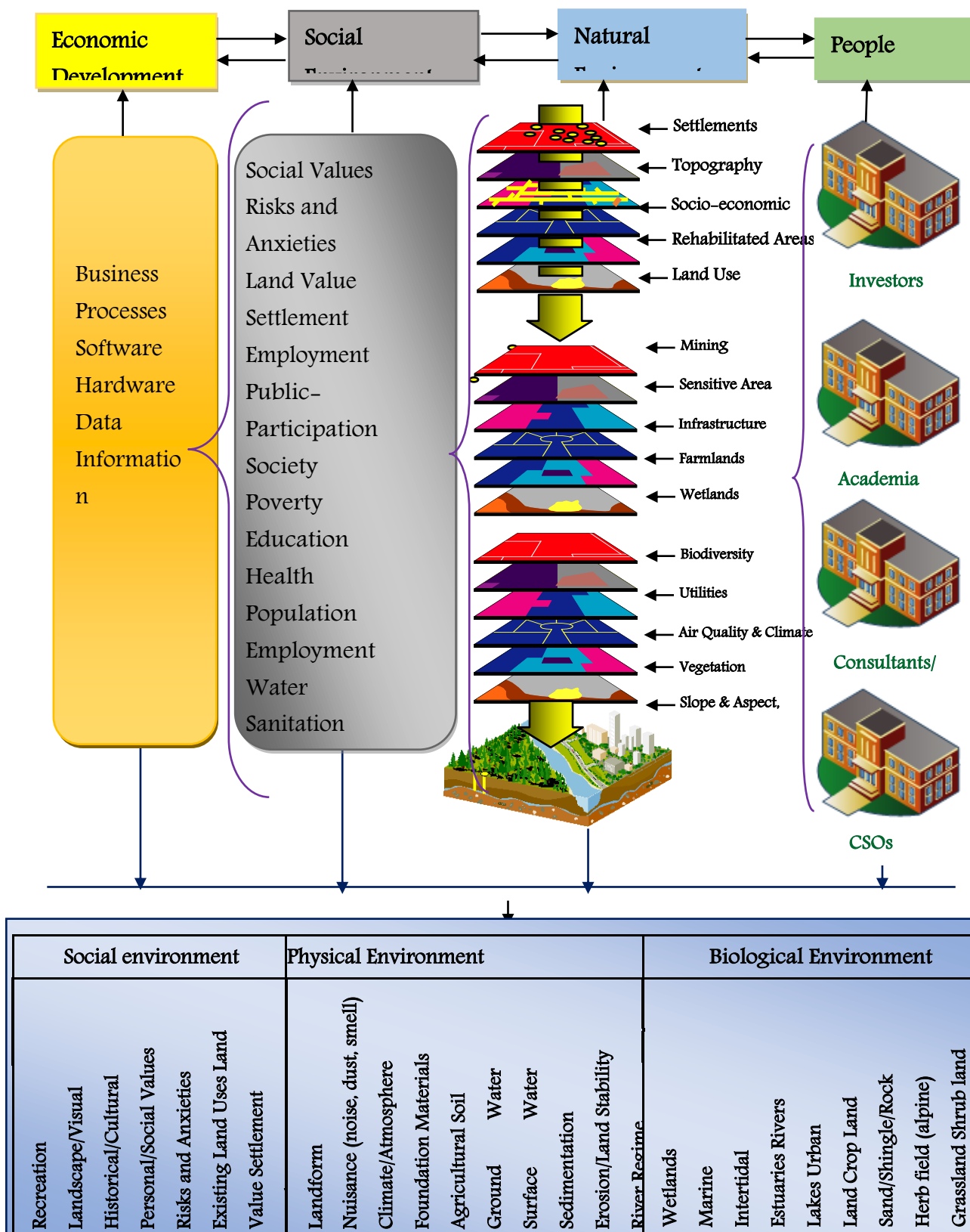
Figure 3-2. Interdependence between economic development, social environment, the natural environment, people and environmental impact assessment.

3.6. Baseline data collection methodology for environmental impact assessment of mining.

To perform an accurate environmental impact assessment study for any kind of project, the first step is to undertake a reconnaissance survey to the proposed project site, identify the most feasible method for impact analysis, and carry out spatial impact analysis.

Reconnaissance survey also known as environmental baseline analysis entails the establishment of the present state of the environment in the absence of the proposed project taken into account changes resulting from natural events and other human activities (Ilaboya, I. R. et al, 2014). In a reconnaissance survey, the interdisciplinary team undertaking the EIA project will have to make a first-hand visitation to the proposed project site to get relevant information regarding the present state of the environment. It is necessary to have an accurate and thorough picture of what the existing environmental conditions are at or near the proposed site. Some of the present environmental information that is of interest include among others: Soil types and characteristics, existing surface and groundwater qualities, existing air quality, socioeconomic status of the people, existing vegetation and wildlife, Existing historical or unique cultural features, existing aquatic population, existing land cover/land uses, existing biological flora and fauna, existing climate change conditions. Many methodologies have been developed over the years for analyzing the environmental impact of a proposed mining project. However, they all share the basic goal of providing a comprehensive and systematic environmental impact evaluation of the project. When choosing the most feasible method for impact analysis, the analyst needs to consider more specific aims, some of which are as follows: the method must comply with standard environmental regulations, the method must provide comprehensive coverage of a full range of impacts including social, economic and physical, the method should be flexible

and economical to use, the method should be able to distinguish between significant and insignificant impacts, the method should allow for comparison of alternatives development proposals, impact analysis is necessary to assess the significant effects of a project on the physical, biological and social environment to identify appropriate restorative measures and proffered options (Ilaboya, I. R. et al, 2014). The choice of impact analysis method should be related to the task in hand and the resources available in accordance with the prediction. The nature of method use may vary for example according to the number of alternatives under consideration, according to the level of aggregation of information and according to the number and type of parties involved. Results of project impact evaluation are normally checked against the existing baseline data to assess the overall impacts of the proposed project on the environment.

Chapter 4: Developing the Baseline GIS spatial geodatabase template for evaluating the environmental baseline impact assessment.

4.1. Introduction

Environmental impact assessment (EIA) of mining projects creates a challenging environment for data collection and impact prediction. Geographic information systems (GIS)-based EIA, using appropriate spatial analysis methods can sufficiently reduce the challenges created by mining environments. The traditional way of carrying out an EIA study is considered to be less accurate and more time-consuming process due to the over-dependence of EIA on spatial data and because of the dependent and independent variables that always have to be taken into consideration (e.g. Land use, land price, population density, socio-economic levels, road accessibility, railway accessibility, air quality, groundwater quality, noise level, biological content, historical value, archaeological and visual importance), which will all have different consequences (Muthusamy and Ramalingam, 2003). These create many challenges on management multi-parameter and multi temporal-spatial data of environmental management of mining. The chapter of the EIA report of mining that details existing conditions (often called the 'environmental baseline') demonstrates whether the EIA Consultant/ Proponent truly understands the environmental, social, and economic impact that the proposed mining project may create. For example, if the EIA does not include details about existing Land use, vegetation, surface water quality, air quality, and the abundance and distribution of threatened and endangered species, then it

simply is not possible for the EIA Consultant/ Proponent to formulate accurate predictions about how the project would impact Land use, vegetation, water quality, air quality, and threatened and endangered species.

The chapter of the EIA report of mining that describes the environmental baseline may often contain misleading information. For example, it is in the interest of the EIA Consultant/ Proponent to describe environmental conditions as already degraded or impaired or to minimize the extent to which local communities inhabit and make use of the project concession area. If the environmental baseline contains claims that the environment is degraded or uninhabited, then those claims should be questioned and evidence to the contrary provided.

This chapter forms the basis of this research which gives a more detailed discussion of the specific kinds of environmental baseline data that an EIA of mining for a proposed mining project needs to contain for a detailed analysis of baseline conditions for any mining project. The objective of this present research is to develop a baseline Geographic Information Systems geodatabase template and spatial analysis methods for evaluating potential and predicted environmental impact for sustainable impact assessment of mining in Sierra Leon that can support the data acquisition process of environmental impact assessment given the general list of data and the contents of relevant information systems and offers a concept for developing an environmental database management system for environmental management of mining to minimize the undesired environmental impacts of mining and give an optimal proposal for data collection and analysis of mining industry in attaining sustainable development. This chapter focuses on the development of the spatial geodatabase template and it also includes a description of the basic steps of the methodology that are used and an explanation of the data structure, characteristics, and the database design process. This

GIS spatial geodatabase template is designed using ArcCatalog ArcGIS 10.7.1 Software, through the following steps as explained in detail in the sections that follow.

4.2. Exploration of the general data requirement of environmental impact assessment studies of mining.

The first step of my research was to study the specifications relative to data contained in national laws and regulations about an environmental impact analysis of mining in Sierra Leone. I explored the relevant literature and ESHIA reports of mining companies in Sierra Leone; moreover, I followed the method used by Hemann et al. (2007) and analyzed the documentation of completed impact studies of mining companies in Sierra Leone. In the course of my investigations, I examined 54 environmental impact assessments, of which 30 were completed environmental impact studies for small scale mining companies reports documentations and 24 were completed environmental impact studies for large scale mining companies. Most of the environmental impact assessments for investigation were selected through the impact assessment database of the Environmental Cadastral and Administrative system (ECAS) electronic system which are studies conducted by different environmental consulting firms in Sierra Leone. In the course of my investigation, I determined the general primary environmental data that the laws of Sierra Leone prescribe or recommends, or that were used by the authors of the examined environmental impact assessments for the various mining companies. On this basis, a data list was compiled containing only those data fields that occurred with at least 85% frequency in the examined impact assessment studies as a result of statistical evaluation.

4.3. Definition of the general baseline datasets requirement of environmental impact assessment in mining

Environmental datasets for environmental impact assessment in mining operations were compiled with the related Sierra Leone environmental laws, quality standards, and regulations as discussed in chapter two. In examining the phases and work stages of environmental impact analysis, it was established that the data collection and surveying phase is primarily the basic state in which databases or information systems can serve as potential data sources. Consequently, in my research, the analysis of data needed for the examination of the basic state of the environment was emphasized; hence, they are taken into consideration for impact assessment and appraisal. The section of an EIA that details existing conditions (often called the 'environmental baseline') demonstrates whether the project proponent truly understands the environmental and social conditions that the proposed mining project may disturb. For example, if the EIA does not include details about existing surface water quality, air quality, and the abundance and distribution of threatened and endangered species, then it simply is not possible for the project proponent to formulate accurate predictions about how the project would impact water quality, air quality, and threatened and endangered species. The section of an EIA that describes the environmental baseline may often contain misleading information. For example, it is in the interest of the project proponents to describe environmental conditions as already degraded or impaired or to minimize the extent to which local communities inhabit and make use of the project area. If the environmental baseline contains claims that the environment is degraded or uninhabited, then those claims should be questioned and evidence to the contrary provided. The following is a more detailed discussion of the specific kinds of environmental baseline data that an EIA for a proposed mining project needs to contain.

Those environmental data were incorporated into my master data list, which occurred in at least (85%) of the studies that were investigated. Table 4-1 shows the primary data grouped as elements of the environment.

Table 4-1: General baseline datasets of Environmental Impact Assessments of mining

Soil	topography, geomorphology, geological structure and bedrock, parent material, the direction of slope, genetic and physical soil type, water balance, location and sensitivity of the soil layers, soil texture, pH, soil water management categories, depth of the column, soil compaction depth of the groundwater, protected geological values
Air	average hours of sunshine, prevailing wind direction, wind speed, precipitation conditions, the spatial and temporal distribution of rainfall, average temperature data, air quality, background contamination, protected and sensitivity categories
Water	size and location of surface and groundwater, water flow conditions, standard flow, protected hydrological values, water facilities, water quality (pH, Total suspended residue, Fe Total, and Mn Total)
Wildlife, Biological Flora & fauna	types of habitat, habitat patches, species composition, rare plant communities, protected plants, animal species and population of the examined area, protected animals
Socio-Economic	size and distance of built environment, built-up, cultural values, historical monuments, function of the examined area
Base Map	Administrative boundary, Concession area boundary, District boundary, Chiefdom boundary, Section boundary, Scanned parcel Maps, Digital Orth photos, imagery
Population	the size of the affected population, population by sex and age

Land cover /land use	landscape, land use, nature-function areas, protected areas, landscape values

4.4. Structure of the environmental impact assessment baseline spatial geodatabase.

The structure of the spatial geodatabase includes two types of data, i.e. Spatial and non-spatial (attributes data). The structure of the spatial geodatabase contains ten features datasets namely: The Basemap dataset, the Air quality dataset, Water quality dataset, the population dataset, the Flora and fauna datasets (Biological dataset), Land Cover/Land use datasets, Settlement, and artificial environment datasets, waste management dataset, climate change dataset and Soil quality dataset as shown in Figure 4-1.

Environmental impact assessment of Mining baseline spatial geodatabase

Contai

Base Map

Waste managem.

Air quality dataset

Water quality

Population

Flora & fauna

Land Cover/Land

Socio economic

Soil quality dataset

Climate change
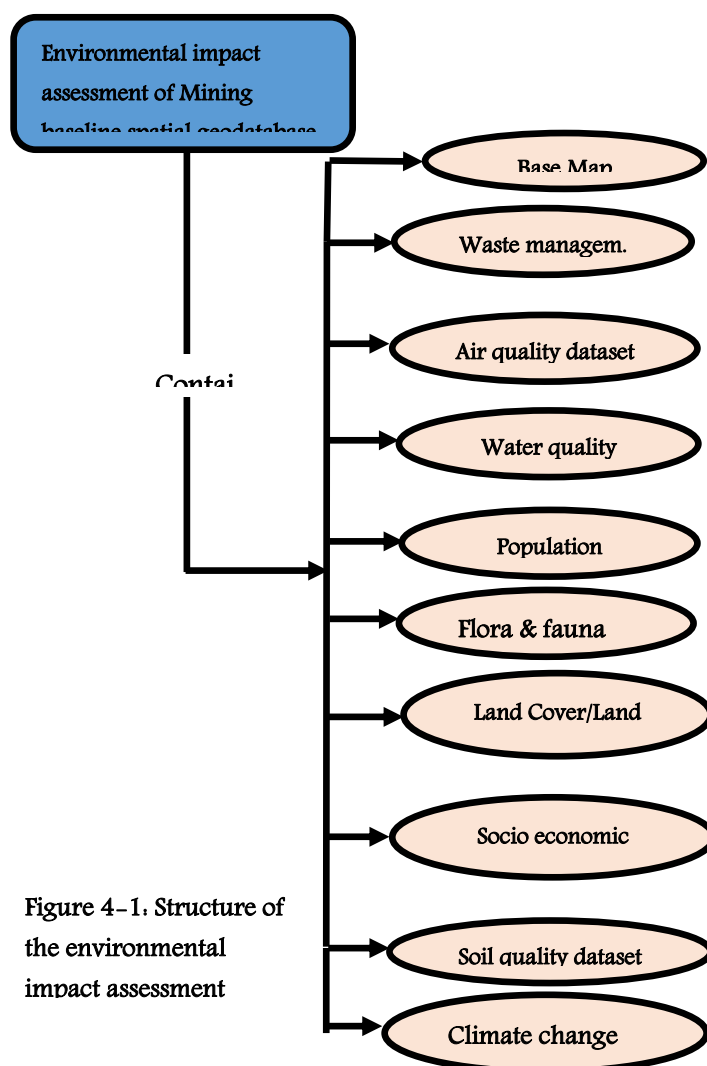
Figure 4-1: Structure of the environmental impact assessment

4.4.1. Creating the geographic geodatabase dictionary

The data dictionary is the result of the analysis phase of existing needs in terms of geospatial data. This data is available either in analog form (maps) or digital (computer support). A data dictionary is a collection of metadata and necessary reference data for designing a geographic database and is a catalog or table containing information about the datasets stored in a database It describes data definition, data type, coordinate system, feature class field properties, relationship diagram, and reference table. It's contained the full names of attributes, meanings of codes, the scale of the source data, accuracy of locations, and map projections used. Creating a data dictionary allows other users to view information about the data. The data dictionary is useful for environmental practitioners, engineers, surveyors, GIS experts, and analysts for data processing and analysis, GIS users and decision-makers, environmental technicians involving in environmental impact assessment studies of the mining operation.

This is the main referential of the database template. It is often represented by a table containing the name, code, data type, and comments, etc. as shown in (Figure 4-2).

Figure 4-2: Geographic data dictionary of the geodatabase template

4.4.2. Selecting, matching geographic data with Geodatabase Structure and designing the Feature class and Attributes

GIS database design is about identifying the thematic layers to be used and specifying the contents and representations of each thematic layer. This involves defining how the geographic features are to be represented (for example, as points, lines, polygons, raster's, or tabular attributes); how the data is organized into feature classes, attributes, and relationships; and the spatial and database integrity rules for implementing rich GIS behavior using topologies, networks, raster catalogs, and so forth. Designing of feature classes and attributes is the most important step in the building of the template databases because this step determines what the database looks like. This step includes determination of feature class name, determination of coordinate system, determination of data type, determination of field name and field properties, determination of code for each environment parameters, and creating reference tables. The environmental impact assessment baseline spatial geodatabase contains a series of GIS data layers. The list above, sorted by layer category, shows the vector data layers in the database that model real-world features as points, lines, or polygons in a UTM (WGS 1984) projected geographic coordinate system. All feature classes in the geodatabase have the following common attributes as shown in Table 4-2.

Table 4-2: Common Attributes of the geodatabase

Attribute	Data Type	Length	Description
NAME	String	200	An attribute that is typically used for labeling the feature.
SOURCEFEATUREID	String	20	Unique ID of the feature. This attribute should be mapped to the source dataset's unique feature ID.
DATASOURCENAME	String	100	Data source name (geodatabase name, shapefile name, and so on).
LASTUPDATE	Date	8	Date when the feature was last loaded or updated.
ISVISIBLE	Small Integer	2	A flag used for turning features on and off in ArcMap through definition queries.
LASTEDITOR	String	100	Name of the person who migrated or edited the data.
EDITCOMMENTS	String	250	Description of the edit performed on the feature.

Source:http://help.arcgis.com/en/communitymaps/10.0/help/index.html#/Geodatabase_model

The NAME attribute is used in ArcMap for labelling purposes, and most of the feature classes have a typical characteristic that is used for symbolizing features. The remaining attributes are primarily used for quality control and metadata purposes.

The environmental impact assessment baseline spatial geodatabase model template consists of a set of core templates (sub-models) and extensions. These core templates and extensions can be linked using a common theme in the model, i.e. the concession area.

A concession area can be represented as a polygon, using a unique identifier for each concession area. Templates may interact with each other with a combination of spatial and non-spatial data with reference information to form the environmental impact assessment baseline spatial geodatabase layers, the geodatabase data model is dynamic; it will provide flexibility for end-users to manipulate the selection criteria and organizing them on a priority basis depending on the development strategies considered.

4.5.Creating the baseline GIS geodatabase template

The GIS baseline geodatabase was created in the ArcCatalog of the ArcGIS Desktop 10.7.1. Software. This is a collection of feature datasets and a feature dataset is a group of feature classes. This step includes creating personal geodatabase, creating feature datasets, creating feature class, and determine the feature class properties.

Figure 4-3, shows the personal Environmental GIS baseline Spatial Geodatabase. This geodatabase contains ten (10) feature datasets

Figure 4-3: Environmental GIS baseline Spatial Geodatabase
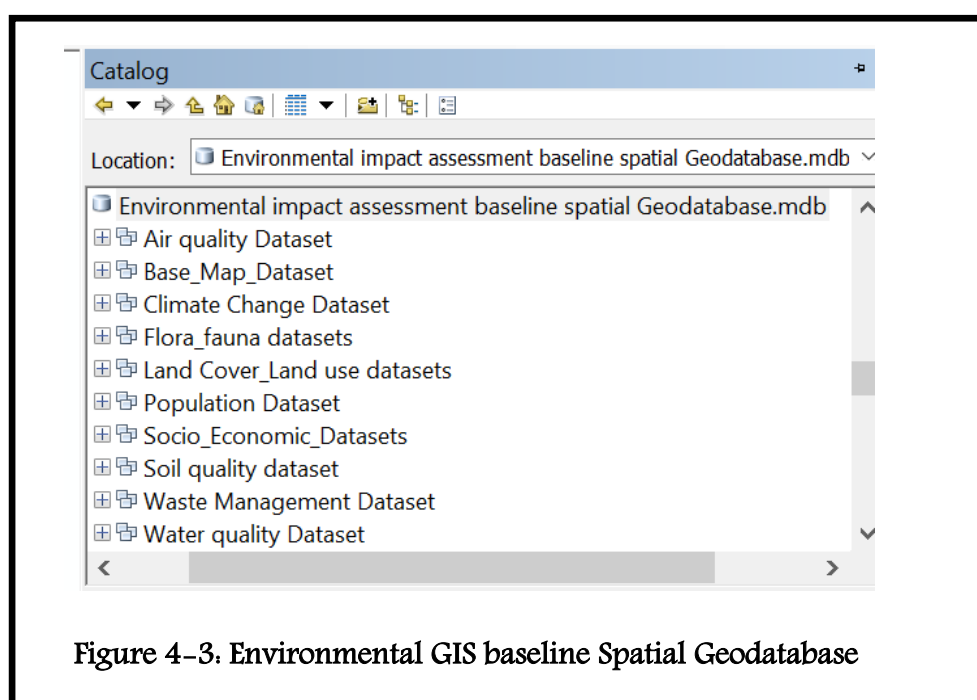
A feature is a collection of features representing the same geographic elements such as boreholes, parcels, or soil types. All the features in features in a future class have the same spatial representation (for example point, line, or polygon) and share a common set of descriptive attributes. Feature datasets are organized collections of related feature classes. The feature class properties (Figure 4-4) provide information regarding field properties, coordinate system, tolerance, resolution, domain indexes, subtypes, relationship, and representation. All information about the spatial data is stored in the field's attribute. the field properties include the field name, data type, alias, allow null values, default value, and length.
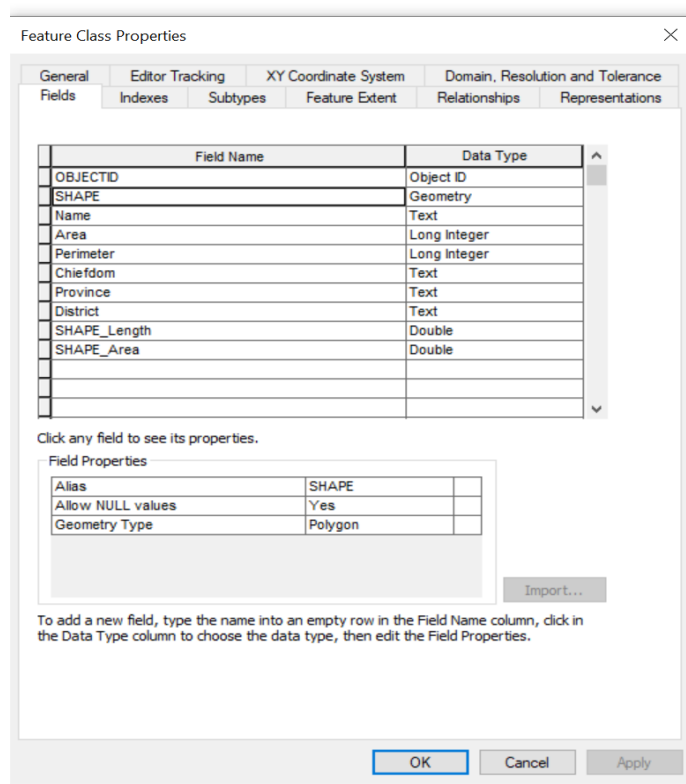
Figure 4-4: Feature class properties

4.5.1. Creating the baseline base map dataset

The base map datasets are the datasets that contain the feature classes to be used as a base map for the creation of the thematic maps for the baseline environmental impact assessment of mining projects. This dataset includes Administrative boundary, Provincial boundary, Concession area boundary, District boundary, Chiefdom boundary, Section boundary, Village boundary Infrastructure, Public road, mined road, Railway, and River as shown in (Figure 4-5).
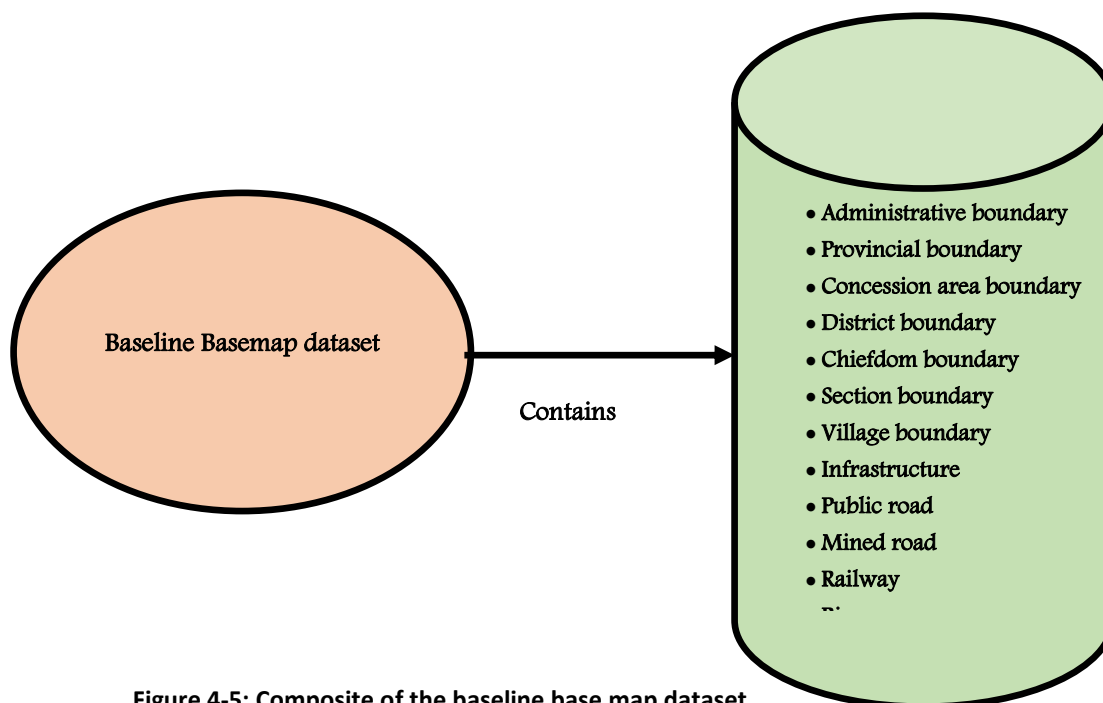
Figure 4-5: Composite of the baseline base map dataset

Baseline Basemap dataset

Contains

- Administrative boundary
- Provincial boundary
- Concession area boundary
- District boundary
- Chiefdom boundary
- Section boundary
- Village boundary
- Infrastructure
- Public road
- Mined road
- Railway
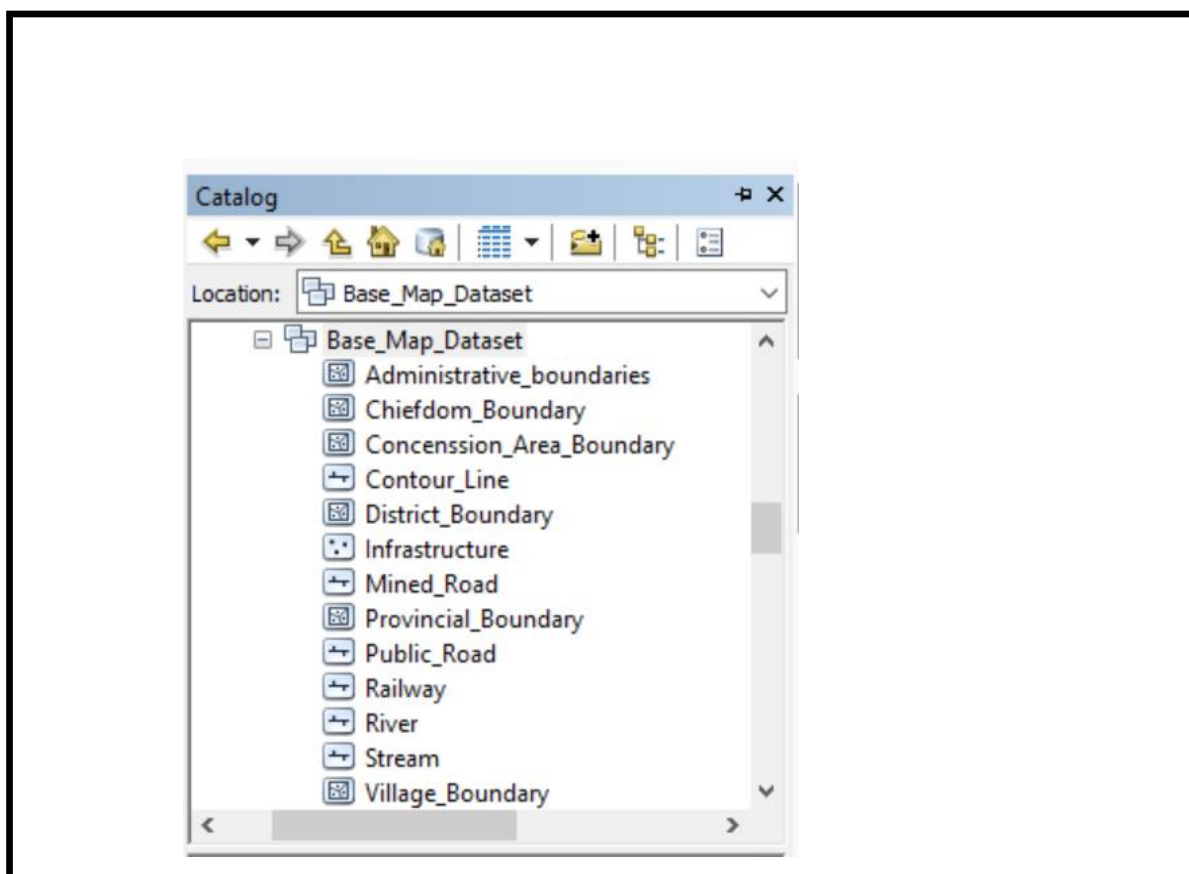
Figure 4-6: Feature classes of baseline base map

From Figure 4-6 above, The GIS Base map personal geodatabase was created in the ArcCatalog of the ArcGIS Desktop 10.7.1. Software.

Table 4-3: Description of baseline Base map layers' attributes

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Contour	Required	Polyline	Elevation, Slope, Contour ID, Shape, Contour Type, Height, Collection Date, Remarks, SHAPE_Length
2	Administrative Boundary	Required	Polygon	Name, Adm ID, Shape, SHAPE_Length, SHAPE_area Collection Date, Remarks
3	Stream	Required	Polyline	Stream Name, Stream ID, Shape, SHAPE_Length, Stream Type, Collection Date, Remarks
4	Provincial boundary	Required	Polygon	Name, Type, Province Code, SHAPE_Length, SHAPE_area
5	Concession area boundary	Required	Polygon	Name, Shape SHAPE_Length, SHAPE_area, Con ID, Application Month, Application Year, Mapping date, Mapper name, Remarks
6	District boundary	Required	Polygon	Name, Type, District Code, SHAPE_Length, SHAPE_area
7	Chiefdom boundary	Required	Polygon	Name, Chiefdom Code, SHAPE_Length, SHAPE_area
8	Railway	Required	Polyline	Rail ID, Shape, SHAPE_Length, Surface Type, Rail Condition, Rail Name, Rail Type, Remarks,
9	Village boundary	Required	Polygon	Name, Village ID, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
10	Infrastructure	Required	Polygon	Name, Inf ID, Shape, SHAPE_Length, SHAPE_area Collection Date, Remarks
	Public Road	Required	Polyline	Road ID, Shape, SHAPE_Length,

				Surface Type, Road Condition ,Road Name, Road Type, Remarks,
11				Surface Type, Road Condition ,Road Name, Road Type, Remarks,
12	Mined road	Required	Polyline	Road ID, Shape, SHAPE_Length, Surface Type, Road Condition ,Road Name, Road Type, Remarks,
13	River	Required	Polyline	River ID, Shape, SHAPE_Length, River Type, River Name, Collection Date, Remarks
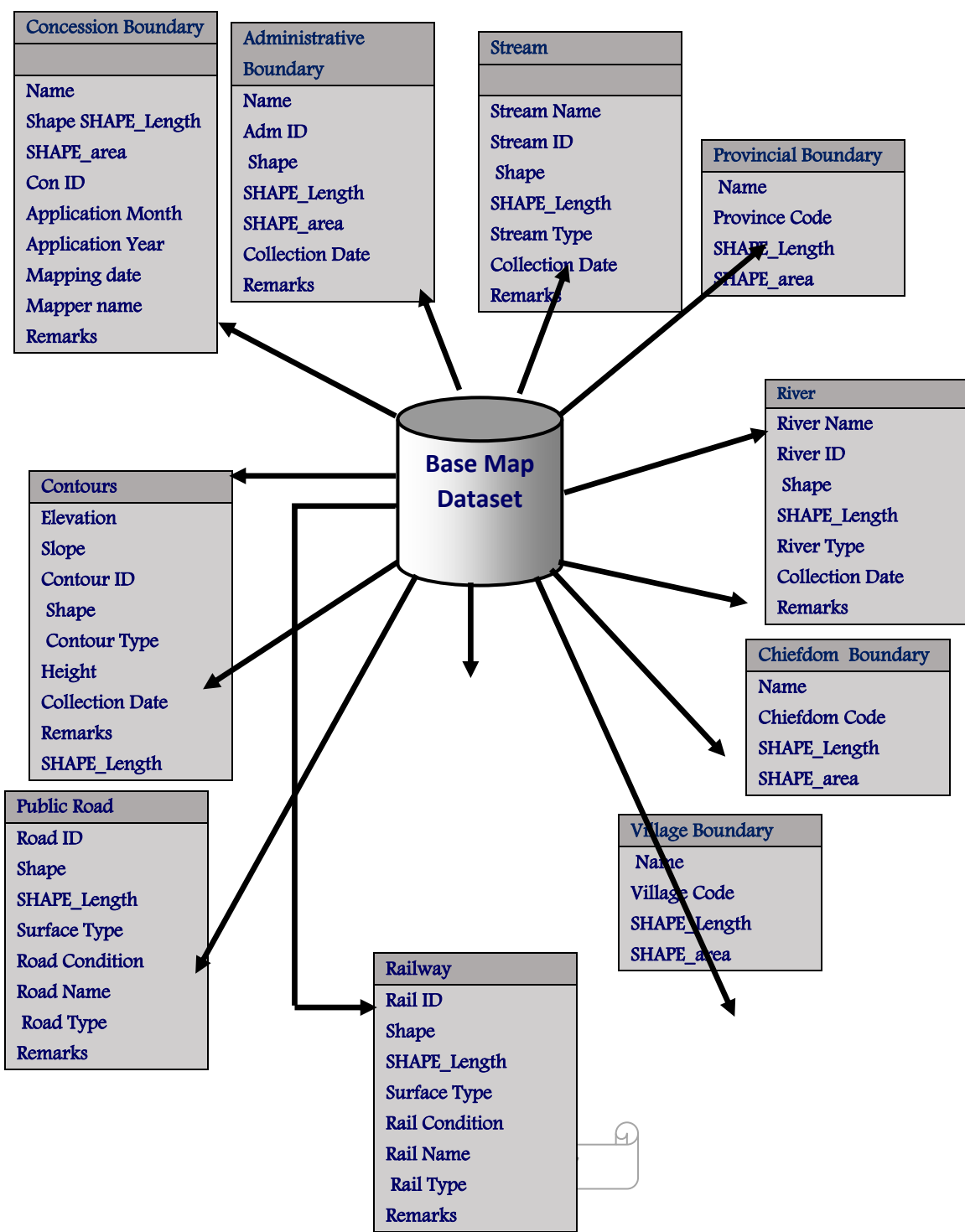
District Boundary

Name
District Code
SHAPE_Length
SHAPE_area

Mined Road

Road ID
Shape
SHAPE_Length
Surface Type
Road Condition
Road Name
 Road Type
Remarks

Infrastructure

Name
Inf ID
Shape
SHAPE_Length
SHAPE_area
Collection date
Remarks

Figure 4-7 illustrates the conceptual design of the base map datasets As can be seen in Figure 4-7, the base map dataset contains thirteen feature classes. Attributes of these future classes are further illustrated in Table 4.

4.5.2. Creating the baseline Land Cover/ Land Use dataset

The land cover/land use datasets are the datasets that contain the feature classes to be used as a base map for the creation of the thematic maps for the baseline environmental impact assessment of mining projects. It contains mainly the feature classes related to the mining operations in the project concession area which includes; land cover feature class, land use feature class, mined-out land feature class, land topography feature class, soil type feature class, geology type feature class as shown in (Figure 4-8).
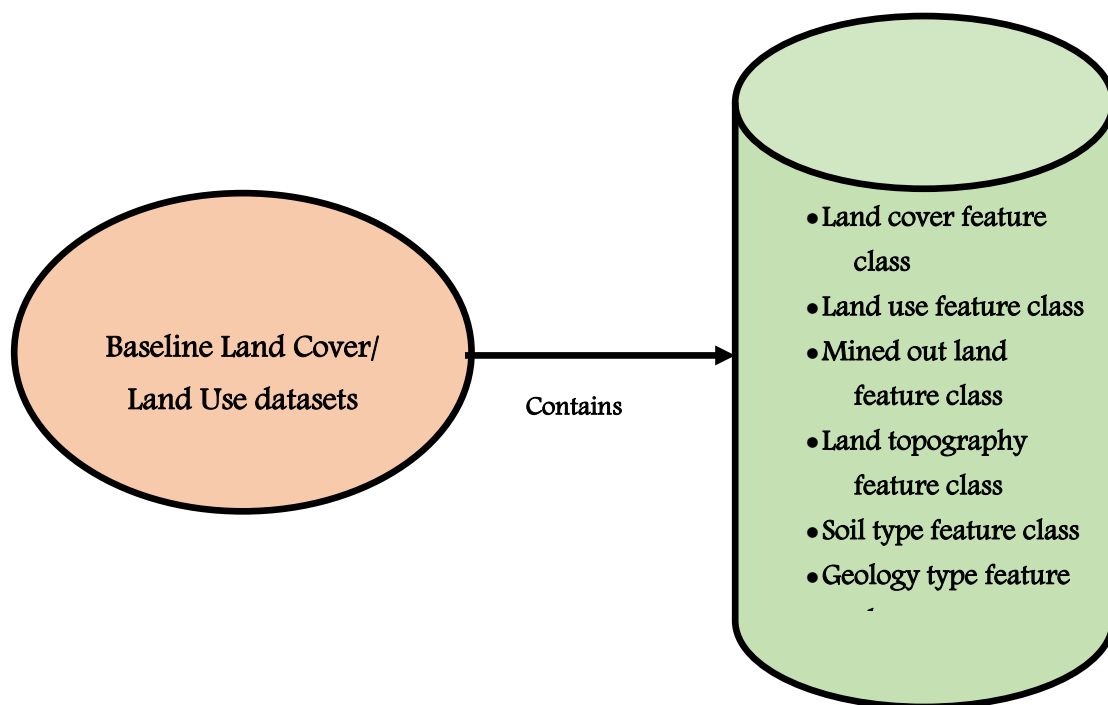
Figure4-9 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software and Figure 4-10 illustrates the conceptual design of the Land Cover/ Land Use datasets. As can be seen in Figure 4-10, the Land Cover/ Land Use datasets dataset contains six feature classes. Attributes of these future classes are further illustrated in Table 4-4.

Table 4-4: Description of the baseline Land Cover/ Land Use dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Land cover	Required	Polygon	Land cover ID, Land Cover type, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
2	Land Use	Required	Polygon	Land Use ID, Land Use type, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
	Mined outland	Required	Polygon	Land Use ID, Land Use type,

				Shape, SHAPE_Length, SHAPE_area
3				Mapping Date, Remarks
4	Land Topography	Required	Polygon	Land Use ID, Topography type, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
5	Soil	Required	Polygon	Land Use ID, Soil type, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
6	Geology	Required	Polygon	Land Use ID, Geology type, Shape, SHAPE_Length, SHAPE_area Mapping Date, Remarks
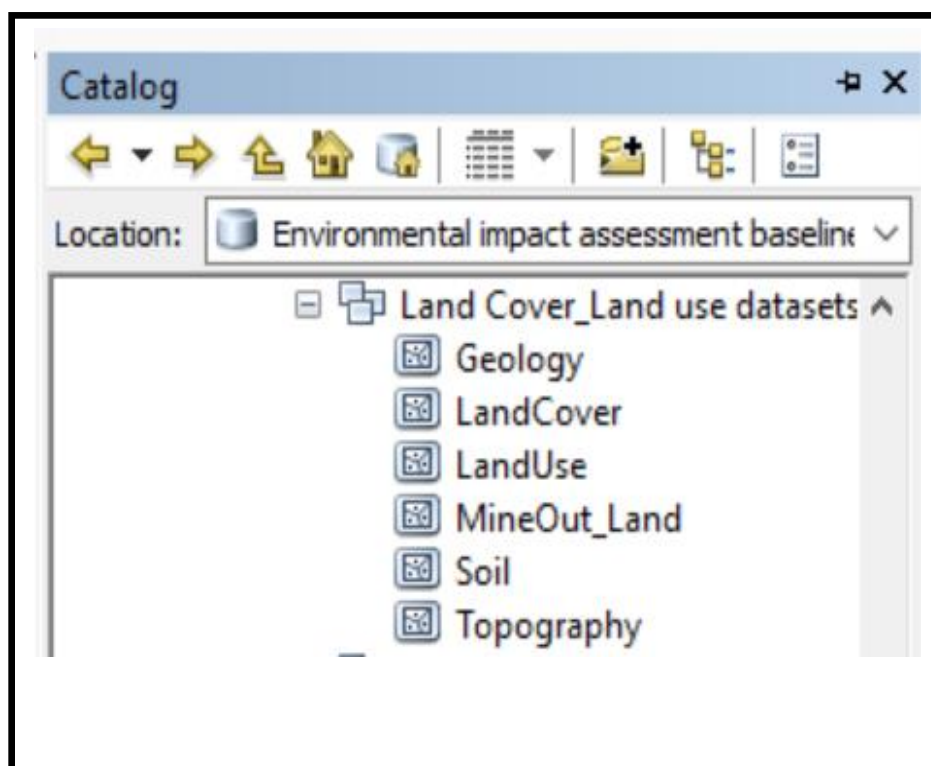
Figure 4-9: Feature classes of baseline Land Cover/Land Use dataset.

Land Cover
Land Cover ID
Shape
Land Cover type
Mapping Date
Remarks
SHAPE_Length

Land Use
Land Use ID
Shape
Land User type
Mapping Date
Remarks
SHAPE_Length
SHAPE_area

Land Cover/ Land Use datasets

Topography
Land Use ID
Shape
Landscape type
Mapping Date
Remarks
SHAPE_Length
SHAPE_area

Mined Out Land
Land Use ID
Shape
Mined Out type
Collection Date
Remarks
SHAPE_Length
SHAPE_area

Land Use ID
Shape
Soil Type
Collection Date
Remarks
SHAPE_Length
SHAPE_area

SHAPE_area

Figure 4-10: Conceptual design of the baseline Land Cover/ Land Use dataset

4.5.3. Creating the baseline Air Quality dataset

Baseline Air quality datasets for a mining project concession area are critical to evaluating the potential distribution of air pollutants and their effects in the area of influence. Air pollutants can travel long distances, so baseline air quality information should be considered about meteorological conditions, wind patterns, geological formations, and anything else that might

influence the distribution of air pollutants. Baseline air quality datasets should include the following: location of air monitoring and/or sampling stations and measurements of these common parameters; Particulate matter (PM10 and PM2.5), Carbon monoxide (CO), Nitrogen oxides (NOx), Lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), Total Suspended Solids (TSS), and Sulfur dioxide (SO$_2$). This dataset includes noise, air temperature, air humidity, wind speed rainfall, air quality point, ambient air quality, and air vibration, Figure 4-11 illustrates the conceptual design of the air quality dataset.

Table 4-5: Description of the baseline Air quality dataset.

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Air quality point	Required	Point	Air Quality ID Shape, Point Name, Mapping Date, Remarks
2	Air Humidity	Required	Point	Air Quality ID, Shape, Point Name, Humidity, mapping Date Remarks
3	Ambient Air Quality	Required	Point	Shape, Point Name, Sulphur Dioxide, Carbon Monoxide, Nitrogen Dioxide, Oxidant, Hydro Carbon, PM<10, PM<2.5, TSP, Plumbum, Dustfall, Total Florides, Fluor Index, Lead(Pb), Sulphate dioxide, Mapping Date, Remarks
4	Air Vibration	Required	Point	Air Quality ID, Shape, Point Name, vibration, Mapping Date Remarks
5	Noise Point	Required	Point	Air Quality ID, Shape, Point Name, Noise, Mapping Date, Remarks
6	Air Temperature	Required	Point	Air Quality ID, Shape, Point Name, Temperature, Mapping Date, Remarks
7	Wind Speed		Point	Air Quality ID, Shape, Point Name, Wind Speed, Mapping Date, Remarks
8	Rain Fall		Point	Air Quality ID, Shape, Point Name, Rain Fall, Mapping Date, Remarks
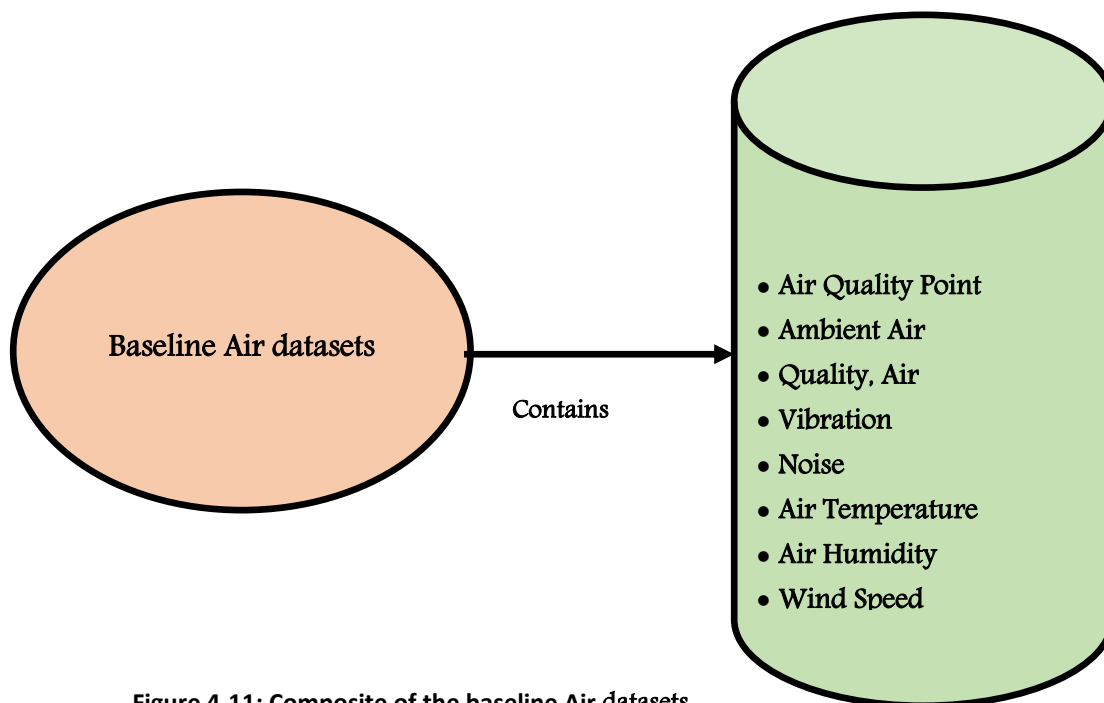
Figure 4-11: Composite of the baseline Air datasets
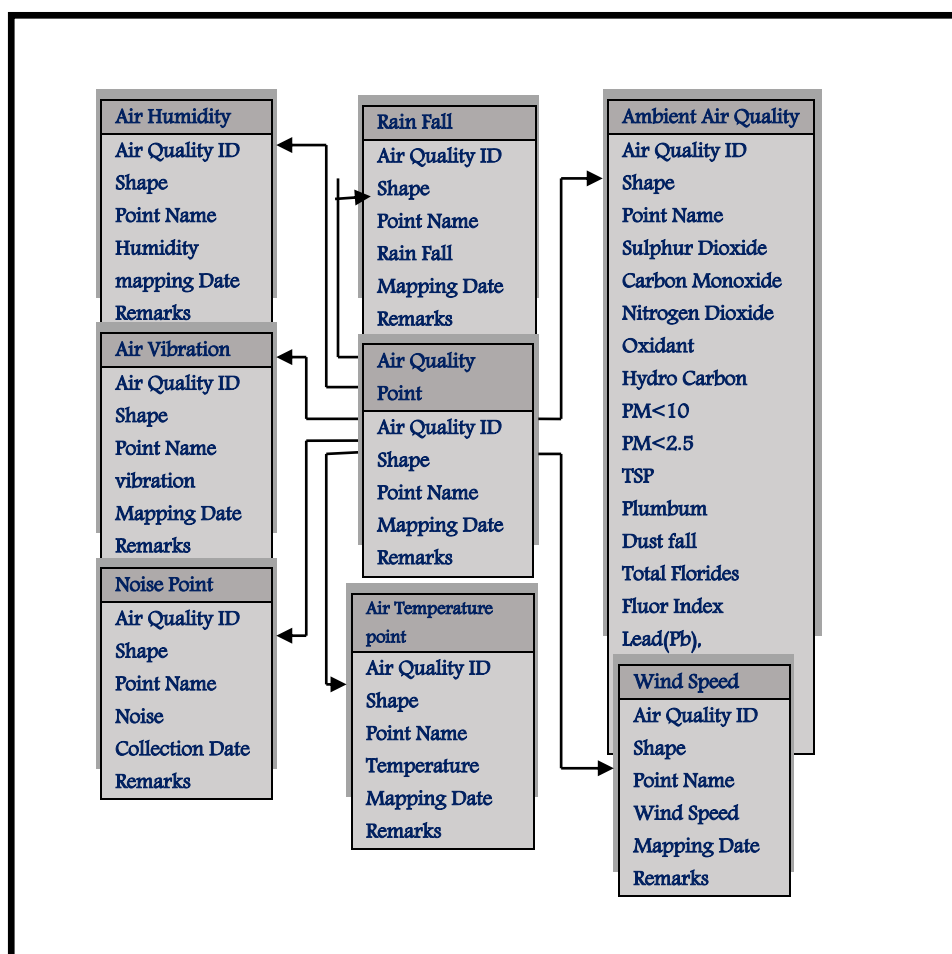
Figure 4-12: Conceptual design of the baseline Air dataset.

Figure4-13 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. As can be seen in Figure 4-12, the Air quality datasets contain eight feature classes. Attributes of these future classes are further illustrated in Table 4-5.
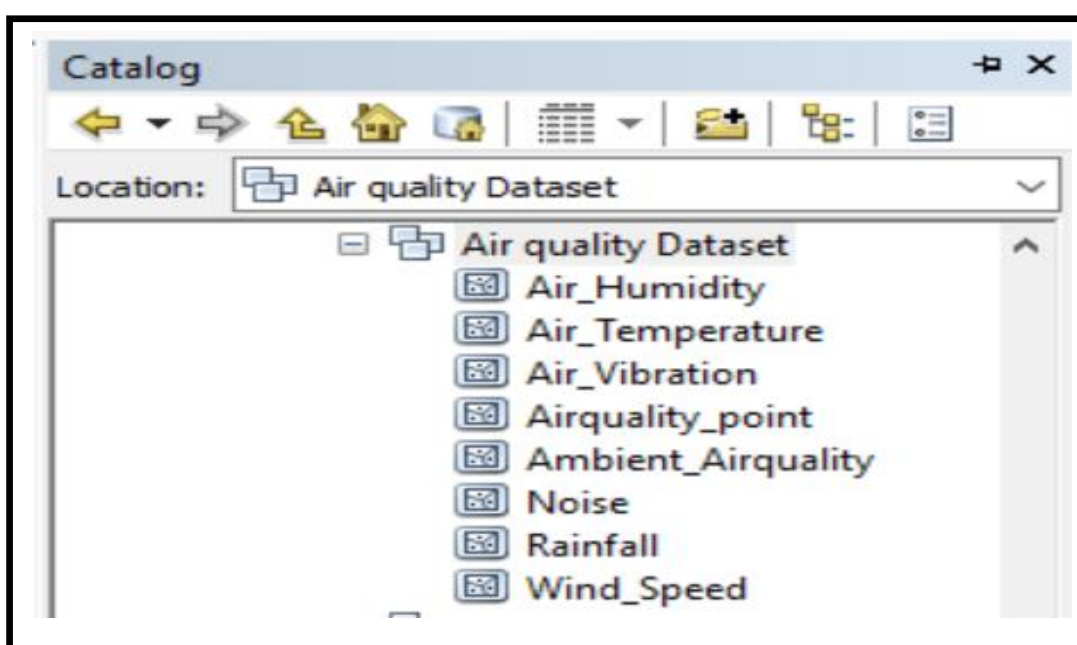
Figure 4-13: Feature classes of baseline Air quality dataset.
4.5.4.

4.5.5. Creating the baseline wildlife, flora and fauna datasets

The Wildlife datasets comprise all living things that are undomesticated. This includes plants, animals (vertebrates, birds, fish), and other organisms (invertebrates). The baseline wildlife, flora, and fauna datasets must include a list of wildlife species within the project area and interactions between species. This should include all endemic flora and fauna in the project concession area that have a special conservation status – for example, listed by the

International Union for Conservation of Nature (IUCN) or by national legislation as a threatened or endangered species, a description of the region and species distribution. The dataset contains mainly feature classes related to wildlife, flora, fauna, and biodiversity. This dataset contains six feature classes includes terrestrial species, aquatic species, habitats critical to ecological processes, biology point. Figure 4-14 illustrates the Composite of the wildlife, flora, and fauna datasets, Figure 4-15 illustrates the conceptual design of the wildlife, flora, and fauna datasets and Figure 4-16 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Each feature class contains information regarding mapping point names and UTM XY position coordinates. Attributes of these future classes are further illustrated in Table 4-6.

Figure 4-14: Composite of the baseline wildlife, flora and fauna dataset
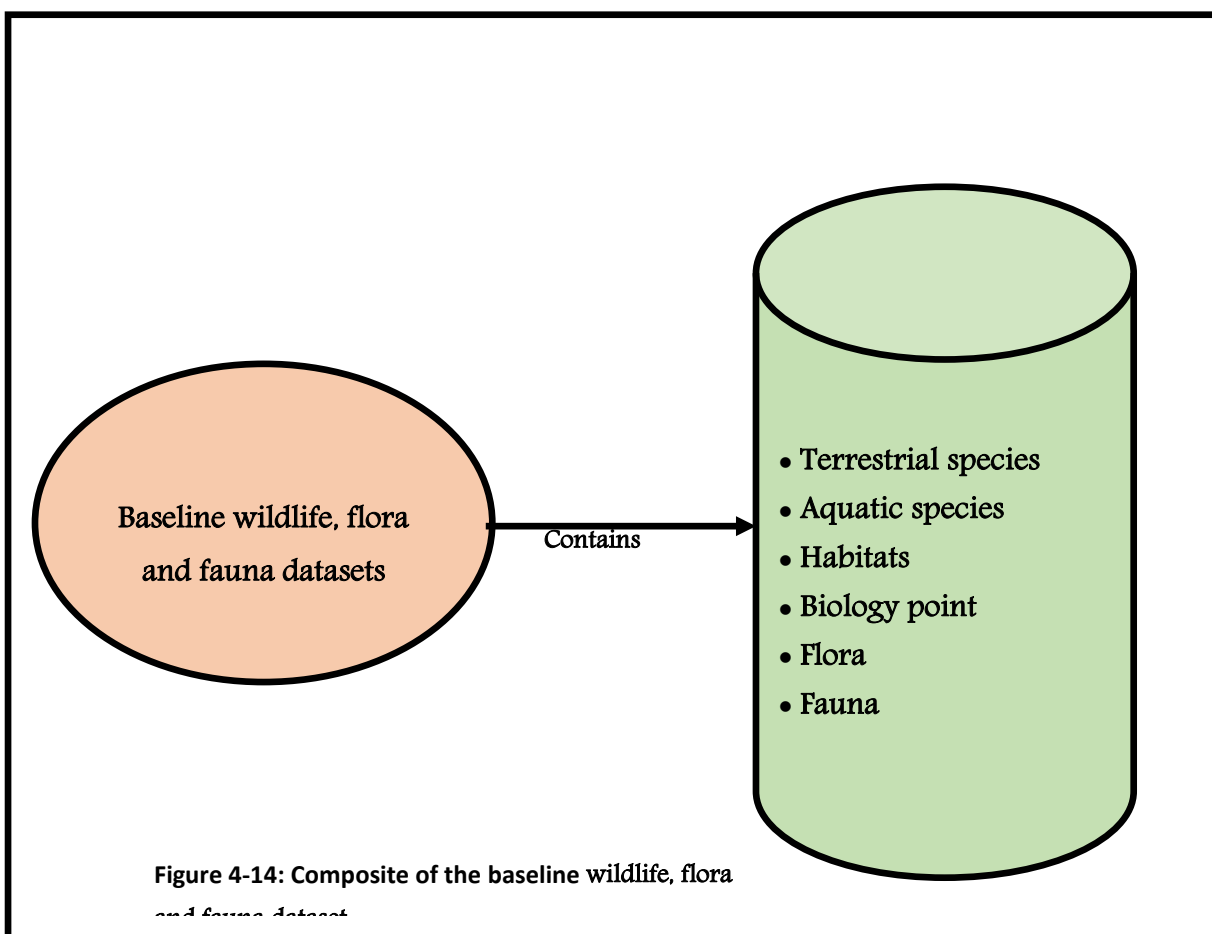
Table 4-6: Description of the baseline wildlife, flora and fauna dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Terrestrial species	Required	Point/polygon	Composition, Shape, Point Name, density, distribution Status, X_Coordinate, Y_Coordinate, vegetative cover, Mapping Date, Remarks
2	Aquatic species	Required	Point/Polygon	Composition, Shape, Point Name, density, distribution Status, X_Coordinate, Y_Coordinate, Mapping Date, Remarks
3	Habitats	Required	Point/Polygon	Biology ID, Shape, Point Name X_Coordinate, Y_Coordinate, Results, Mapping Date, remarks
4	Biology point	Required	Point/Polygon	Biology ID, Shape, Point Name X_Coordinate, Y_Coordinate, Results Mapping Date, remarks
5	Flora	Required	Point/Polygon	Biology ID, Shape, Point Name X_Coordinate, Y_Coordinate, Results Mapping Date, remarks
6	Fauna	Required	Point/Polygon	Biology ID, Shape, Point Name X_Coordinate, Y_Coordinate, Results Mapping Date, remarks
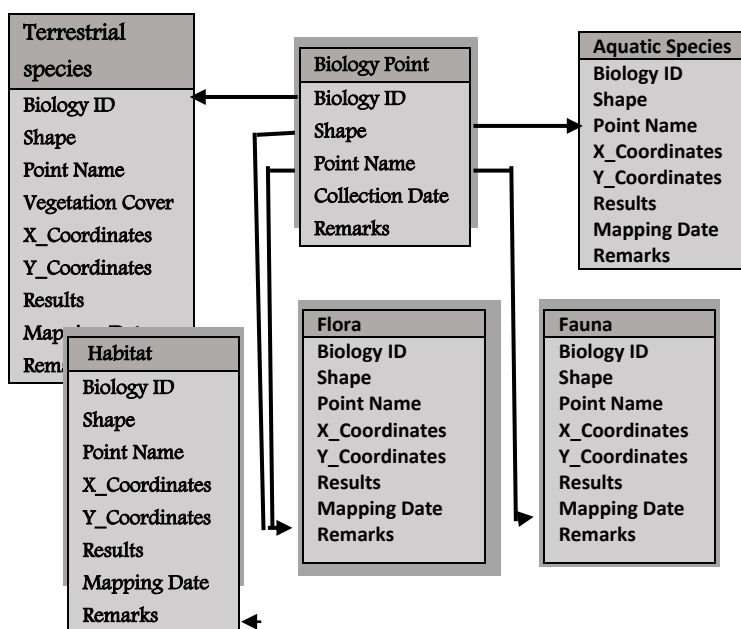
Figure 4-15: Conceptual design of the baseline wildlife, flora and fauna
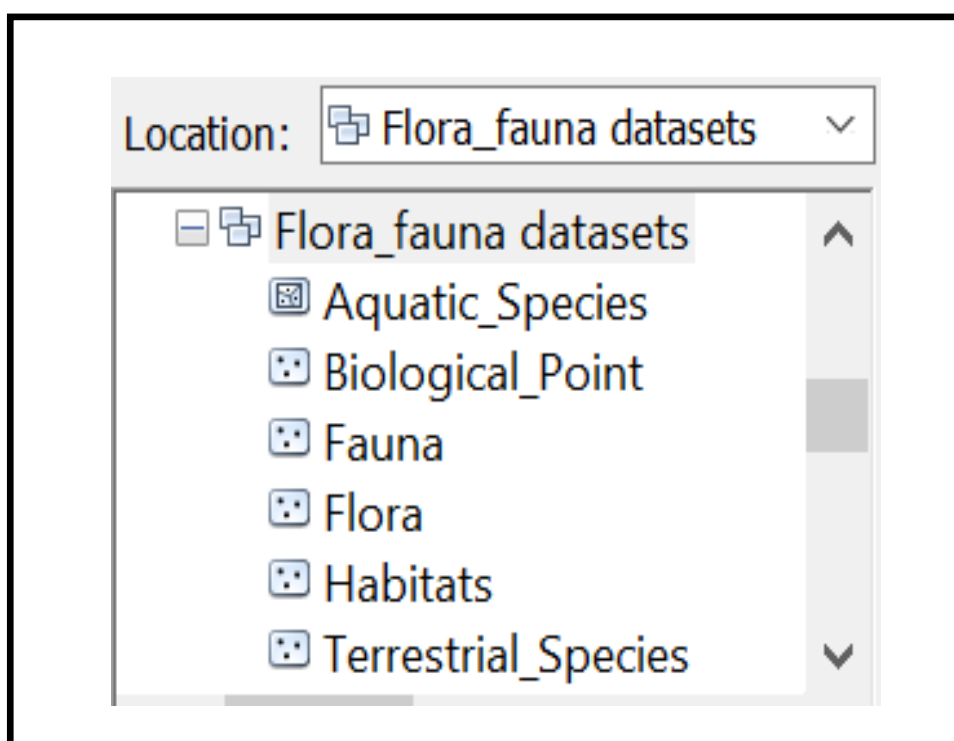
Figure 4-16: Feature classes of the wildlife, flora and fauna dataset

4.5.6. Creating the baseline surface and groundwater quality datasets

The baseline surface and groundwater quality datasets must include a list of Common water quality attributes such as Physical, chemical: pH, turbidity, suspended solids, temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Solids, salinity, conductivity and for groundwater should include; Groundwater flow directions, Locations/flows of springs and seeps, Groundwater discharge locations in streams, Groundwater uses, depth to groundwater under different seasonal conditions, Geology and locations of aquifers, thicknesses, and their hydraulic conductivity ranges. Describing baseline surface water quality should provide detailed information on the location, distribution, quantity, and quality of all water resources that could be affected by a project and its alternatives. The data and analysis should have a reasonable level of detail, to help understand the conditions of the environmentally important geographic locations. When baseline water quality (surface water or groundwater) samples are collected, they should be analyzed for the full suite of parameters and contaminants of concern.

This baseline surface and groundwater quality datasets contain seven feature classes including Water pH, Turbidity, TSS (Total Suspended Sediment), salinity, water quality point, Fe Total, and Mn Total. Figure 4-17 illustrates Composite baseline surface and groundwater quality datasets, Figure 4-18 illustrates the conceptual design of the baseline surface and groundwater quality datasets and Figure 4-19 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-17.

Table 4-7: Description of the baseline surface and ground water dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
	Water quality point	Required	Point	Water Quality ID, Shape, Point Name, X_Coordinates,

1				Y_Coordinates, Mapping Date, Remarks
2	TSS (Total Suspended Sediment),	Required		Water Quality ID, Shape, Point Name, TSS, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
3	Iron (Fe) Total	Required	Point	Water Quality ID, Shape, Point Name, Fe Total, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
4	Mn Total	Required	Point	Water Quality ID, Shape, Point Name, Fe Total, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
5	Water pH	Required	Point	Water Quality ID, Shape, Point Name, pH, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
6	Turbidity	Required	Point	Water Quality ID, Shape, Point Name, Turbidity, X_Coordinates, Y_Coordinates Mapping Date, Remarks
7	Salinity	Required	Point	Water Quality ID, Shape, Point Name, Salinity, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
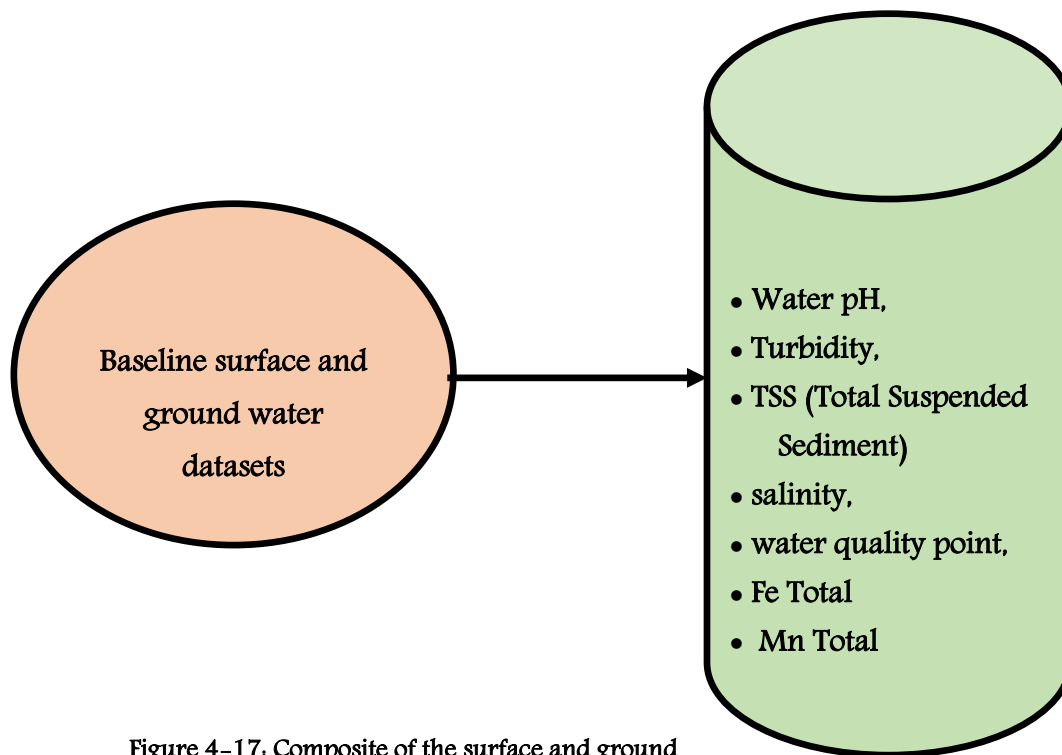
Figure 4-17: Composite of the surface and ground water dataset

- Water pH,
- Turbidity,
- TSS (Total Suspended Sediment)
- salinity,
- water quality point,
- Fe Total
- Mn Total

Baseline surface and ground water datasets
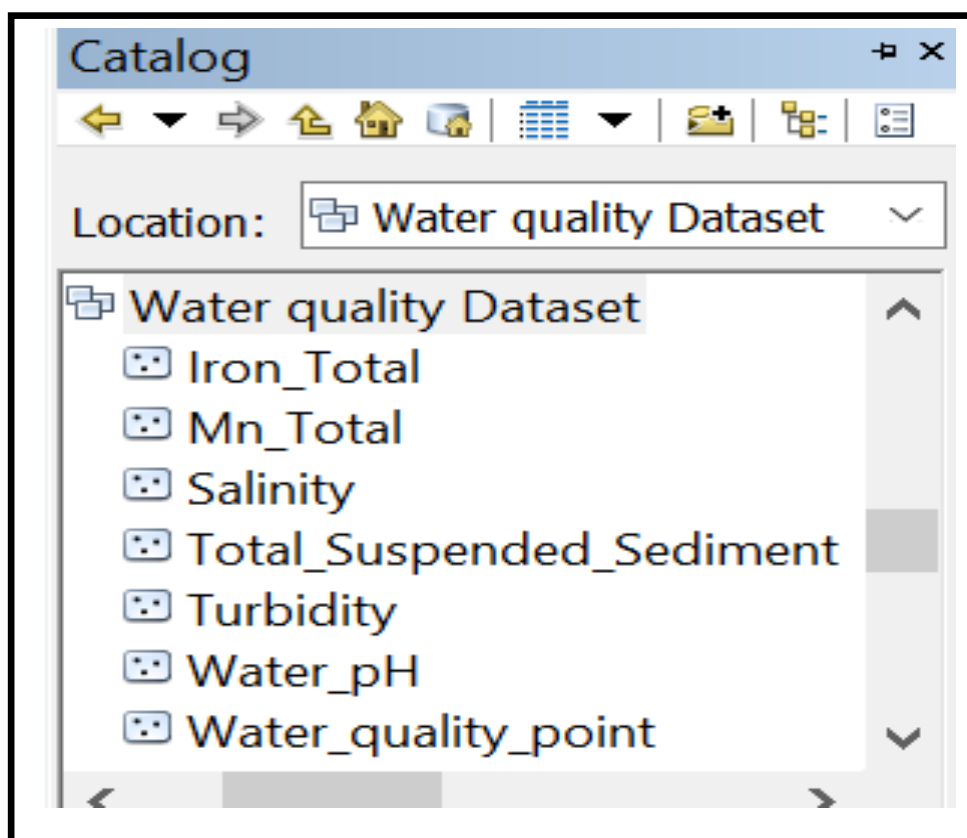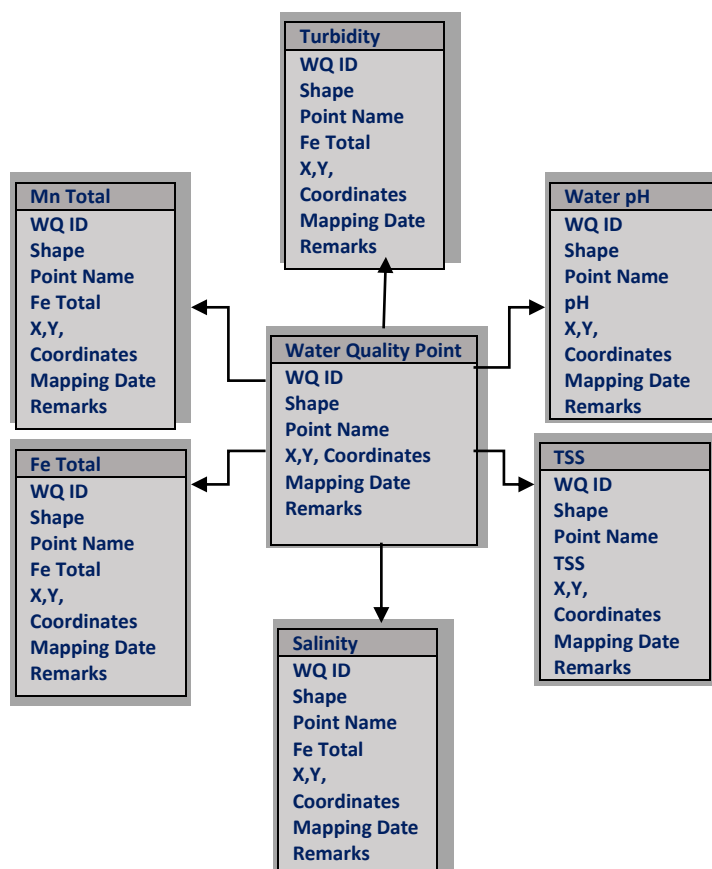
Figure 4-19: Feature classes of the baseline surface and ground water quality dataset

4.5.7. Creating the baseline soil quality dataset

The baseline soil quality datasets mainly contain feature classes related to soil based on conditions typically found in the mining concession area. Soil baseline studies are based on three major sources of information: desk study, fieldwork, and laboratory analysis. Baseline soil quality datasets should include measurements of these common parameters: soil composition, soil strength (resistance to crushing), mineral content, and pH. Some measure of water content, organic content, soil texture, particle size, and bulk density. This dataset contains six feature classes includes soil sample points, dumping soil area, soil   pH,   Cation exchange capacity, Soil nutrient (potassium, calcium, magnesium, nitrogen, phosphorus), and Heavy metals (lead, copper, zinc, cadmium, mercury, and chromium).

Figure 4-20 illustrates Composite baseline soil quality datasets, Figure 4-21 illustrates the conceptual design of the baseline soil quality datasets and Figure 4-22 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-8.

Table 4-8: Description of the baseline soil quality datasets

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Soil quality point	Required	Point	Soil Quality ID, Shape, Soil type, X_Coordinates, Y_Coordinates sample depth, Mapping Date, Remarks
2	Dumping soil area	Required	Polygon	Soil Quality ID, Shape, Soil type, Shape area, shape length, sample depth, Mapping Date, Remarks

3	Soil pH	Required	Point	Soil Quality ID, Shape, Point Name, Soil type, pH, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
4	Heavy metals	Required	Point	Soil Quality ID, Shape, Point Name, Soil type, heavy metals, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
5	Cation exchange capacity	Required	Point	Soil Quality ID, Shape, Point Name, Soil type, exchange capacity, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
6	Soil nutrient	Required	Point	Soil Quality ID, Shape, Point Name, Soil type, nutrients, X_Coordinates, Y_Coordinates Mapping Date, Remarks
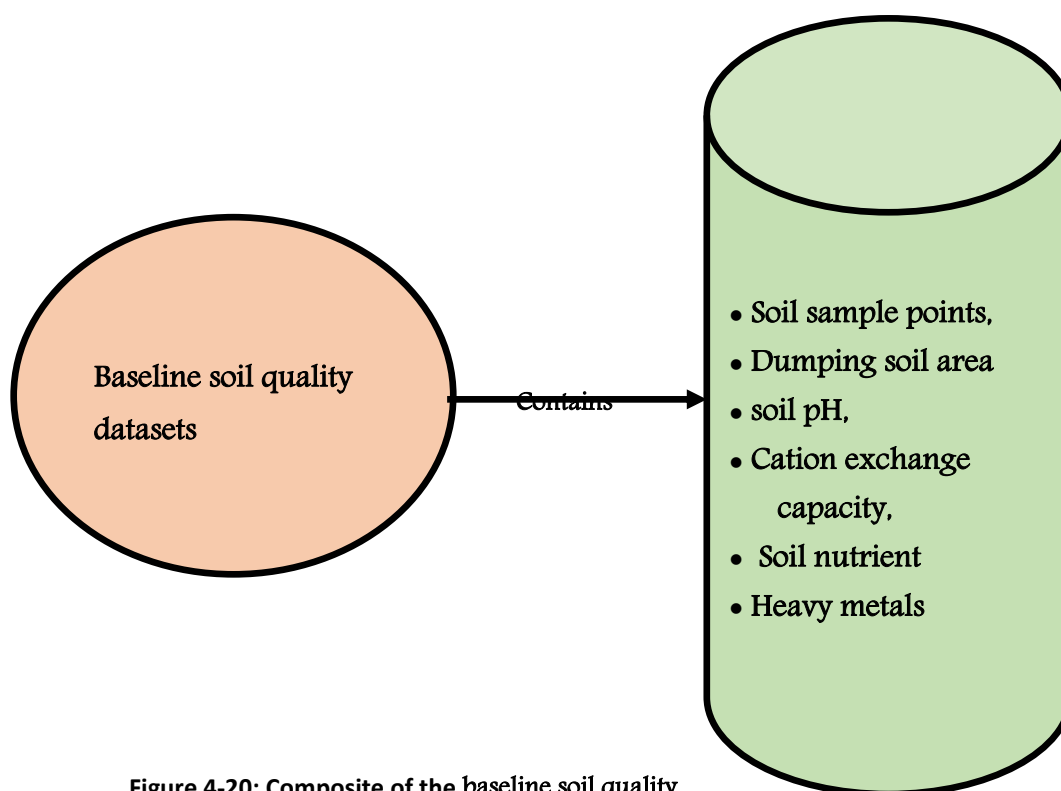
Figure 4-20: Composite of the baseline soil quality
dataset
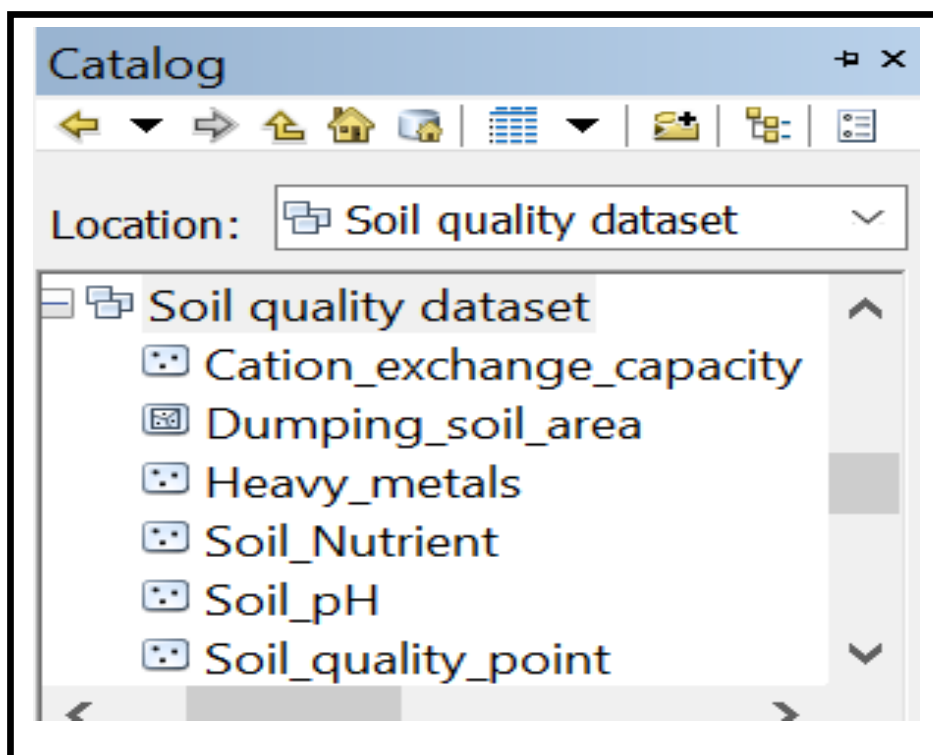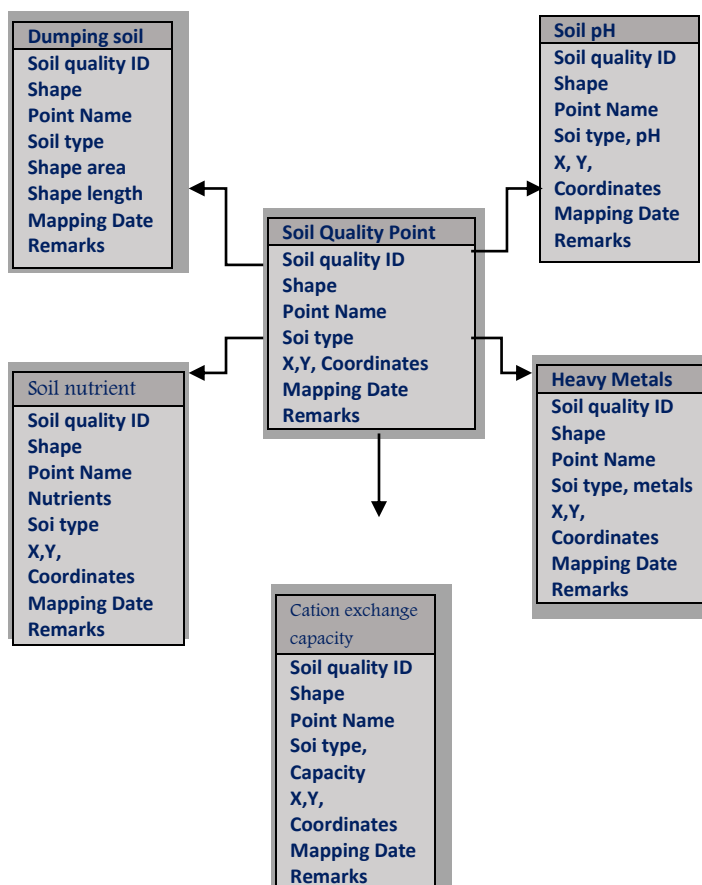
Figure 4-22: Feature classes of the baseline soil quality dataset

4.5.8. Creating the baseline Socio-Economic dataset

The socio-economic environment is defined as all activities, and social and economic processes, that could be influenced directly or indirectly by the mining project which includes the size and distance of built environment, built-up, cultural values, historical monuments, the function of the examined area. This dataset contains nine feature class includes, socio-economic quality point, Quality of life, Housing quality and quantity (this is particularly important if people are to be relocated), Public safety (police, fire), Education (average level, access, public and/or private), Health services, Recreation (public, private), public services sanitation, livelihood. In this dataset, the field attributes related to field measurement results are not filled in using specific code but filled with real results of field measurements.

Figure 4-23 illustrates the Composite baseline Socio-Economic datasets, Figure 4-24 illustrates the conceptual design of the baseline Socio-Economic datasets and Figure 4-25 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-9.

Table 4-9: Description of the baseline socio economic dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Socio-economic	Required	Point	Socio-Economic ID, SE type, Village, town X_Coordinates, Y_Coordinates, Mapping Date, Remarks
2	Quality of life	Required	point	Socio-Economic ID, Shape, SE type, Village, Town, Quality of life, Mapping Date, Remarks
	Housing quality and quantity	Required	Point	Socio-Economic ID, SE type, Village, town, housing

3				quality, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
4	Public safety facility	Required	Point	Socio-Economic ID, SE type, Village, town, facility type, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
5	Education facility	Required	Point	Socio-Economic ID, SE type, Village, town, facility type, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
6	Health facility	Required	Point	Socio-Economic ID, SE type, Village, town, facility. type, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
7	Recreation facility			Socio-Economic ID, SE type, Village, town, facility. type, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
8	public services sanitation		Point	Socio-Economic ID, SE type, Village, town, facility. type, X_Coordinates, Y_Coordinates, Mapping Date, Remarks
9	Livelihood		Polygon	Socio-Economic ID, shape, shape area, shape length SE type, Village, town, livelihood type, Mapping Date, Remarks

Figure 4-23: Composite of the baseline socio economic dataset

The cylinder contains:

- socio economic quality point,
- Quality of life,
- Housing quality and quantity
- Public safety
- Education
- Health facility
- Recreation

The ellipse contains: Baseline socio economic datasets
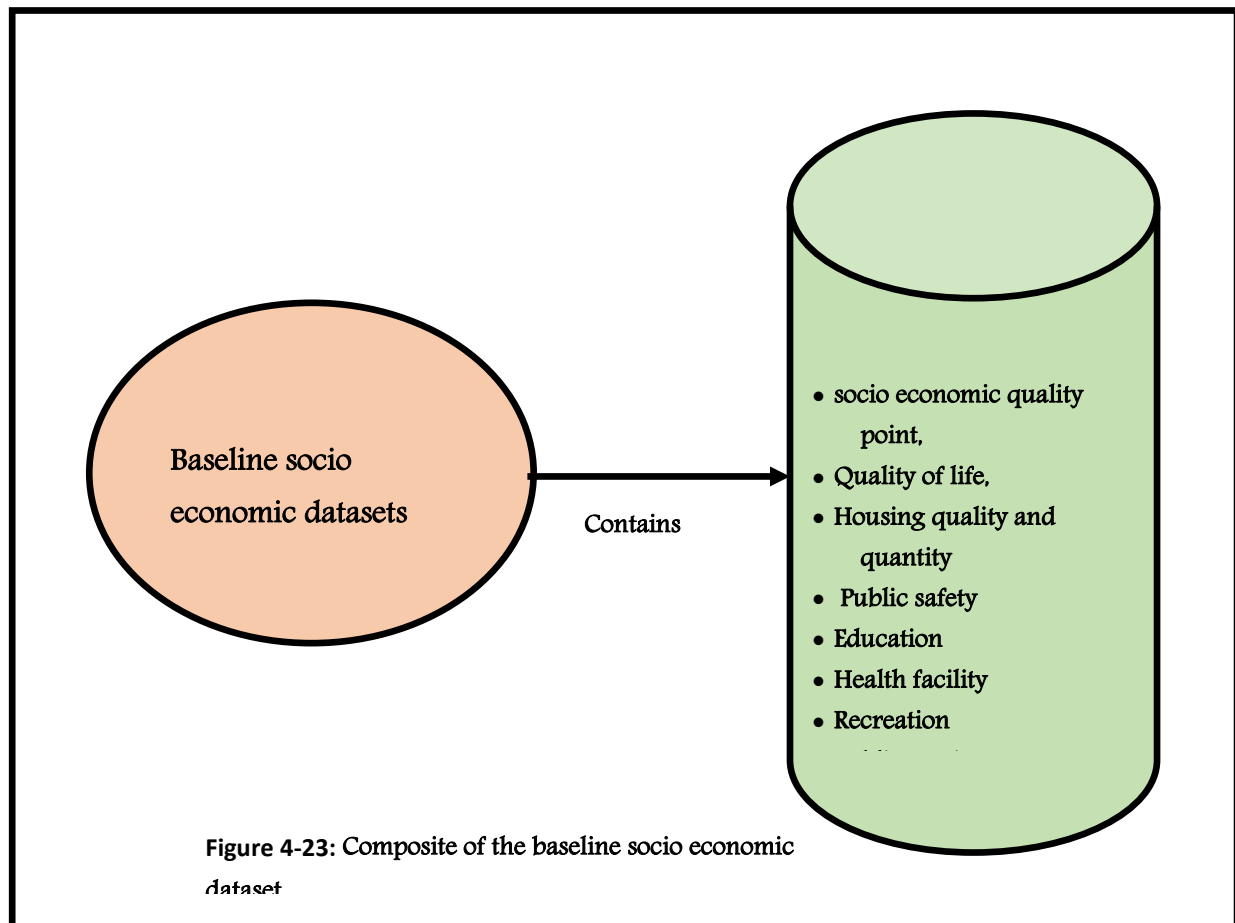
Contains

Figure 4-24: Conceptual design of the baseline socio economic dataset
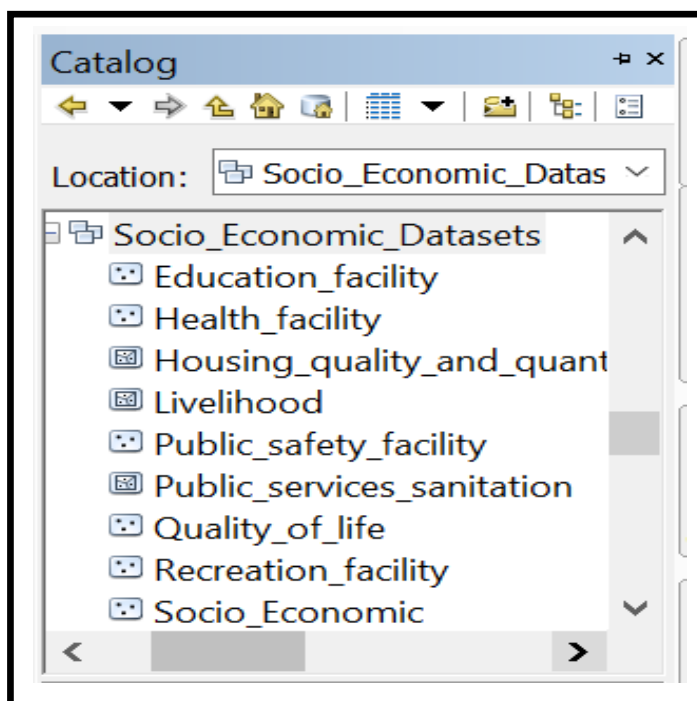
Figure 4-25: Feature classes of the baseline socio economic dataset

4.5.9. Creating the baseline Population dataset

The baseline population datasets mainly contain Location of the local population about the proposed project area, this dataset contains four feature classes which includes population size, (age composition, growth) Economic activities, employment facility and income (inventory of present economic environment without the project) usually measured with surveys and interviews. Figure 4-26 illustrates the Composite baseline population datasets, Figure 4-27 illustrates the conceptual design of the baseline population and Figure 4-28 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-10.

Table 4-10: Description of the baseline population dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Population size	Required	Point	Population ID, age composition, size, growth, X_Coordinates, Y_Coordinates Mapping Date, Remarks
2	Economic activities	Required	Polygon	Population ID, age composition, size, growth, activity, X_Coordinates, Y_Coordinates Mapping Date, Remarks
3	Employment facility	Required	Point	Population ID, age composition, size, growth, facility, X_Coordinates, Y_Coordinates Mapping Date, Remarks
4	Income	Required	Point	Population ID, age composition, size, growth, income type, X_Coordinates, Y_Coordinates Mapping Date, Remarks

Baseline population datasets

Contains

- population size
- Economic activities
- employment facility
- income

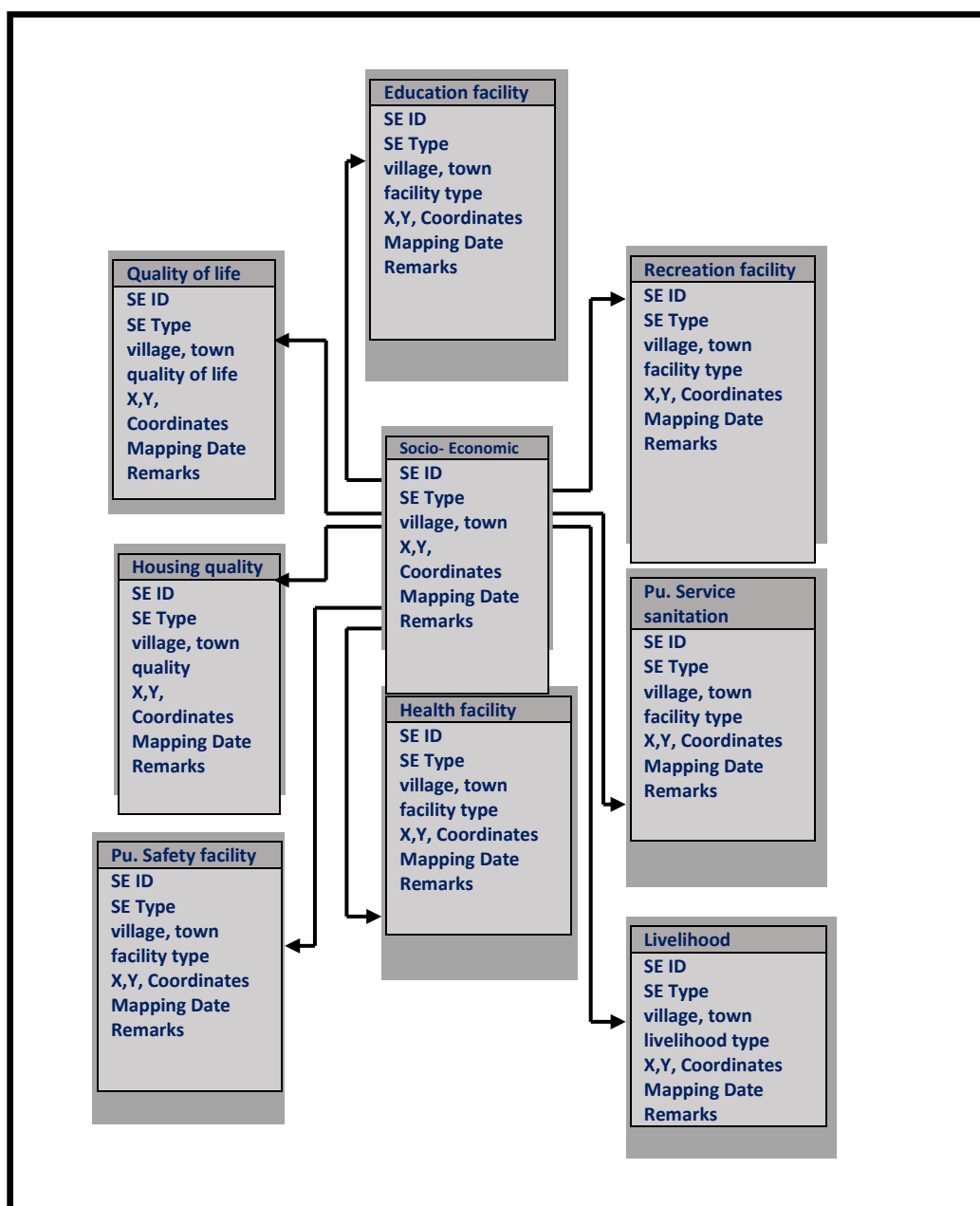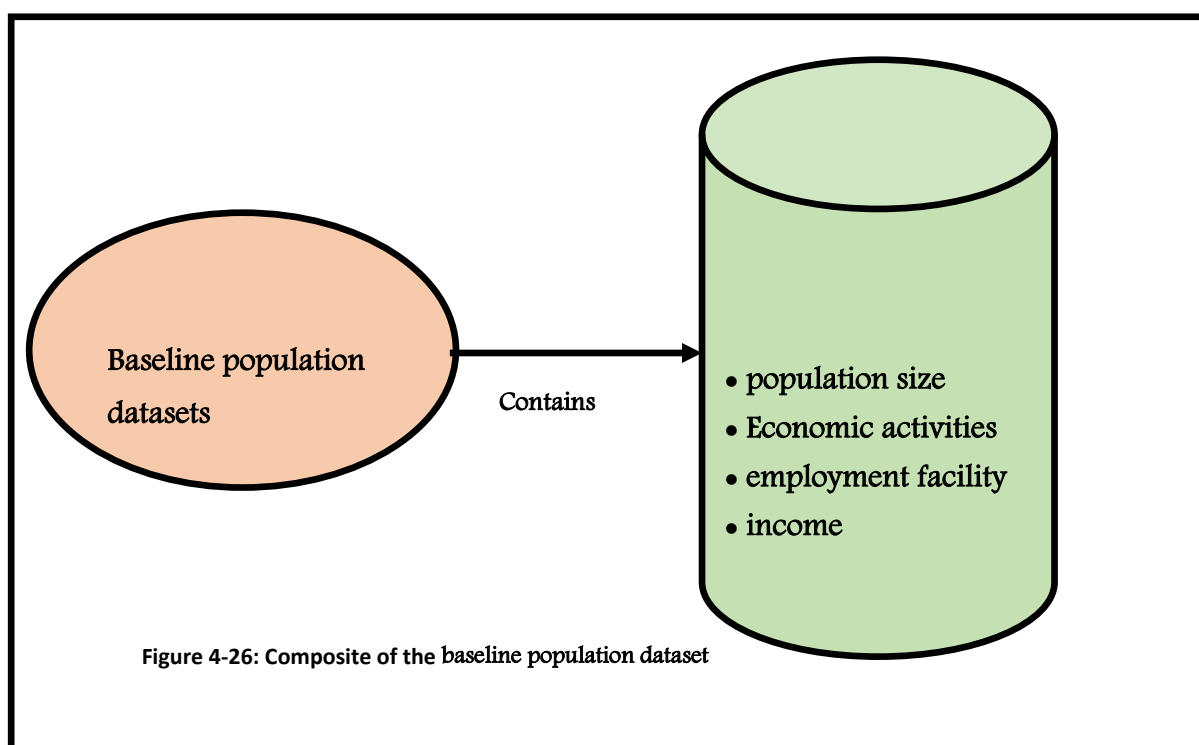**Figure 4-26: Composite of the baseline population dataset**

Figure 4-27: Conceptual design of the baseline population dataset
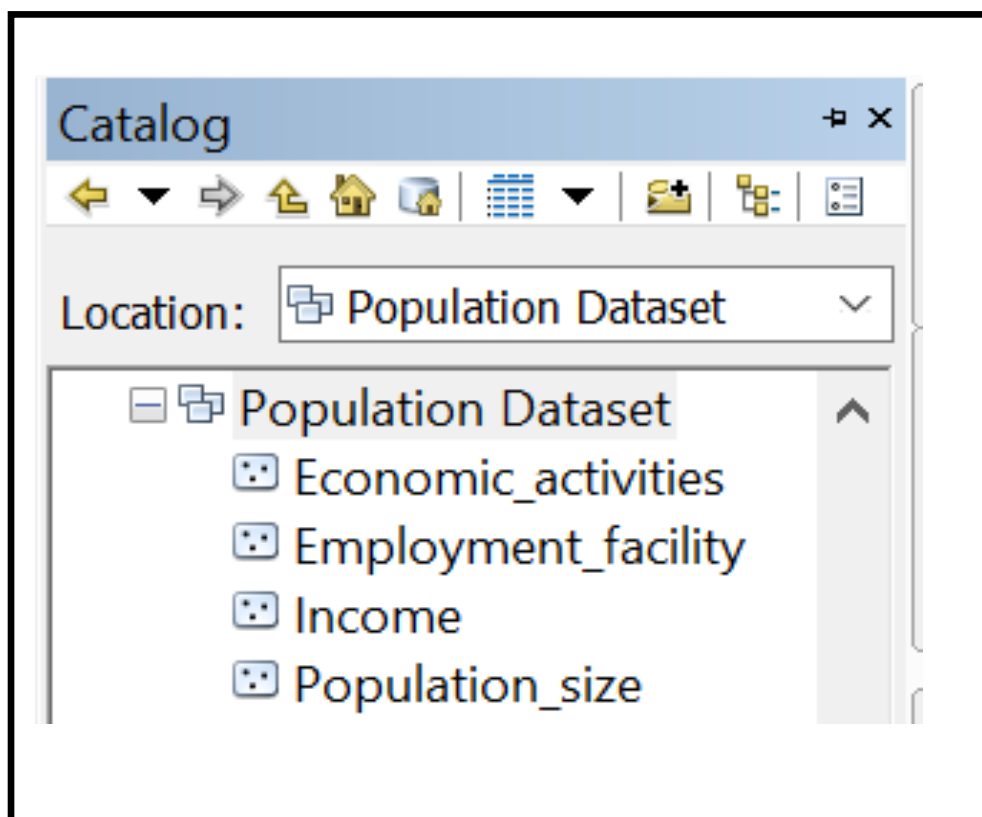
Figure 4-28: Feature classes of the baseline socio economic dataset

4.5.10. Creating baseline waste management dataset

The baseline waste management dataset contains six feature classes related to waste generated during the mining operation. This dataset includes waste point, solid waste, chemical waste, waste treatment plant (WTP), tailings impoundment facility, and tailings disposal.

Figure 4-29 illustrates the Composite baseline waste management dataset, Figure 4-30 illustrates the conceptual design of the baseline waste management dataset and Figure 4-31 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-11. Each feature class contains information include point name, spatial position, and field check result.

Table 4-11: Description of the baseline waste management dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Waste point	Required	Point	Waste ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
2	Solid waste	Required	Point	Waste ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
3	Chemical waste	Required	Point	Waste ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
4	Waste treatment plant (WTP)	Required	Point	Waste ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
5	Tailings impoundment facility (TIF)	Required	Polygon	Waste ID, Shape, Shape Name, Shape length, Shape Area, Results, Mapping Date Remarks
6	Tailings disposal site (TDS)	Required	Polygon	Waste ID, Shape, Shape Name, Shape length, Shape Area, Results, Mapping Date Remarks

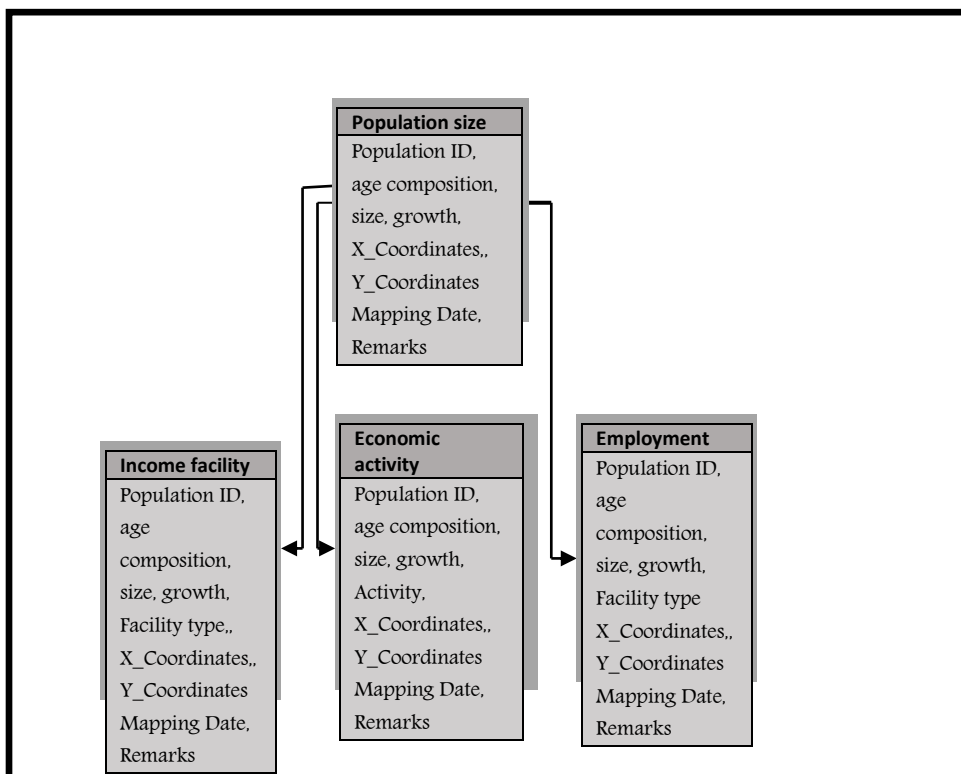**Figure 4-29: Composite of the baseline waste management dataset**

Figure 4-30: Conceptual design of the baseline waste management dataset
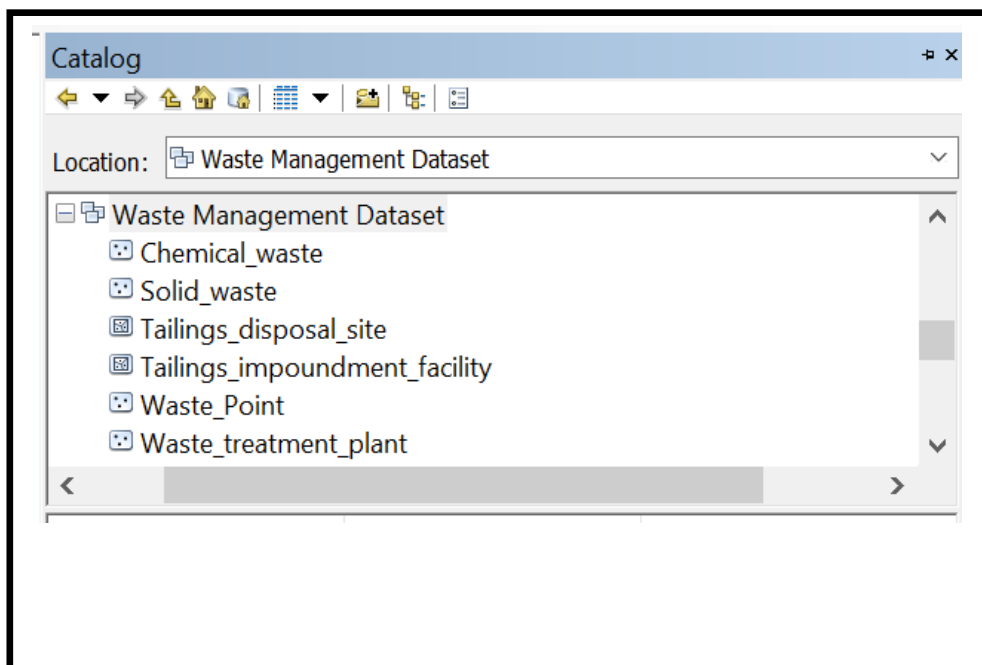
Figure 4-31: Feature classes of the baseline socio economic dataset

4.5.11. Creating the baseline Climate Change dataset

The baseline climate change dataset contains six feature classes related to climate conditions around the surroundings of the mine site operation and concession area. This dataset includes a Concession area, Rainfall, temperature, air, protected, and sensitive areas. Figure 4-32 illustrates the Composite baseline climate change dataset, Figure 4-33 illustrates the conceptual design of the baseline climate dataset and Figure 4-34 illustrates the design of the geodatabase in the ArcGIS/ArcCatalog software. Attributes of these future classes are further illustrated in Table 4-12. Each feature class contains information include point name, spatial position, and field check result.

Table 4-12: Description of the baseline climate change dataset

No	LAYER	Requirement Level	Geometry Type	Required Attributes
1	Concession area (CA)	Required	Point	CA ID, Shape, Shape Name, Shape length, Shape Area, Results, Mapping Date Remarks
2	Rainfall	Required	Point	CA ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
3	Temperature	Required	Point	CA ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
4	Air	Required	Point	Waste ID, Shape, Point Name X_Coordinates, Y_Coordinates Results, Mapping Date, Remarks
5	Protected areas	Required	Polygon	CA ID, Shape, Shape Name, Shape length, Shape Area, Results, Mapping Date Remarks
6	Sensitive areas	Required	Polygon	CA ID, Shape, Shape Name, Shape length, Shape Area, Results, Mapping Date Remarks

Figure 4-32: Composite of the baseline waste climate change datasets

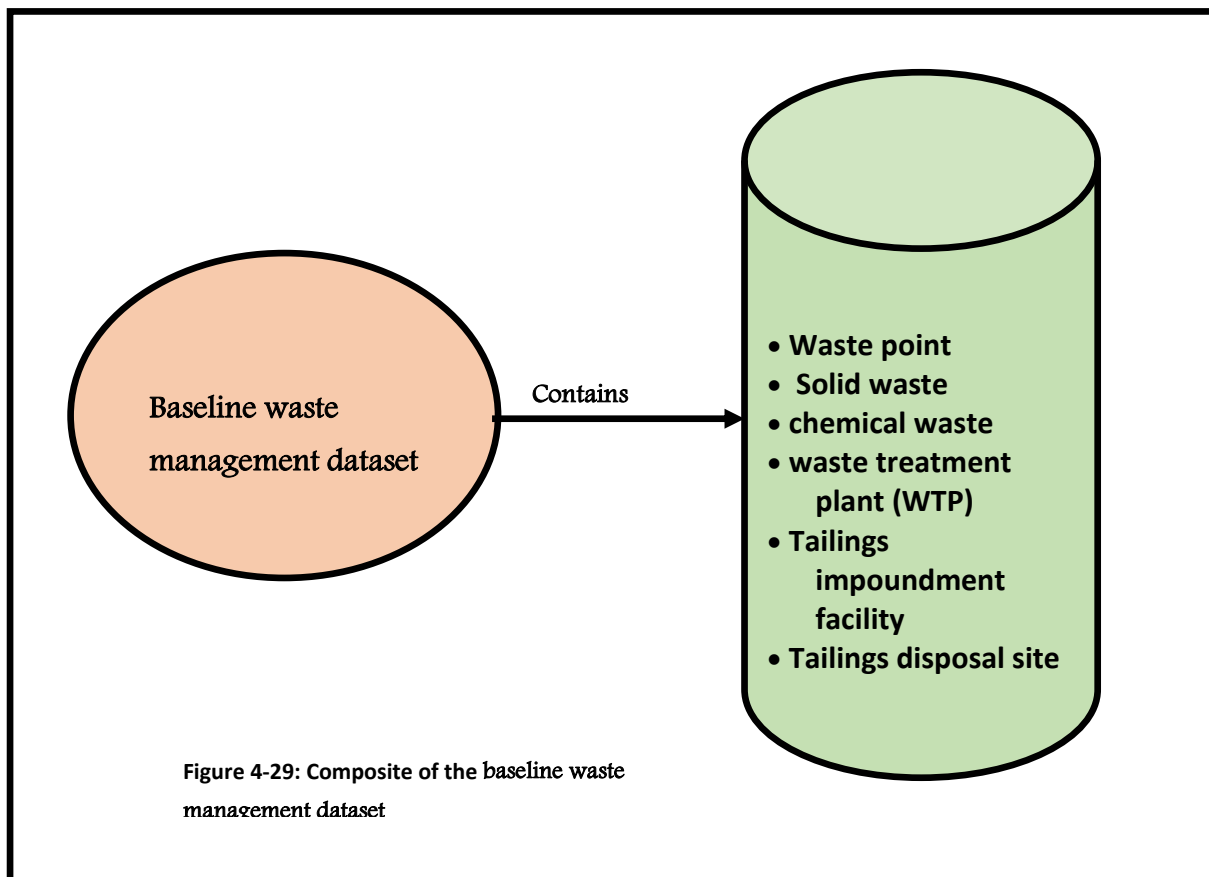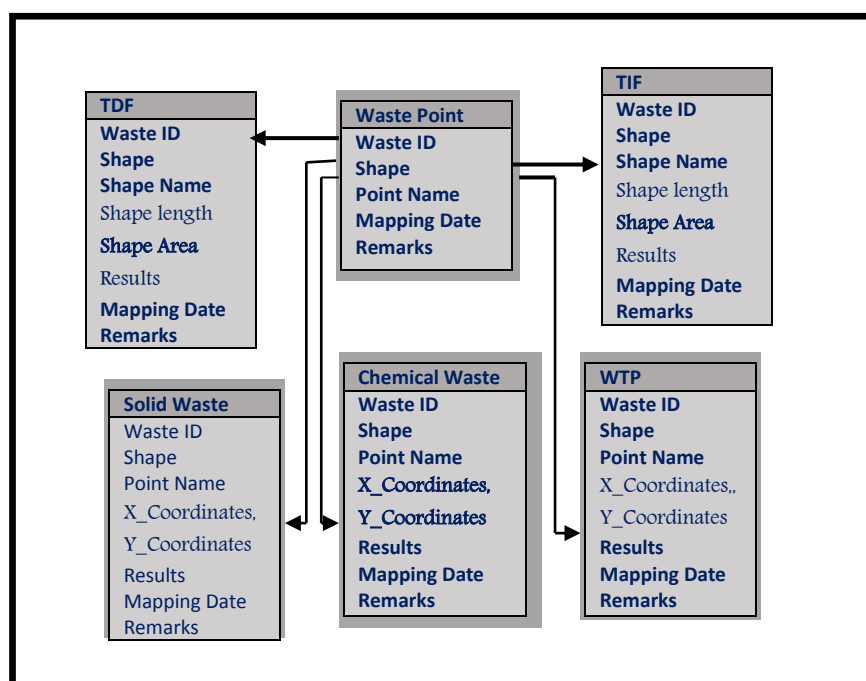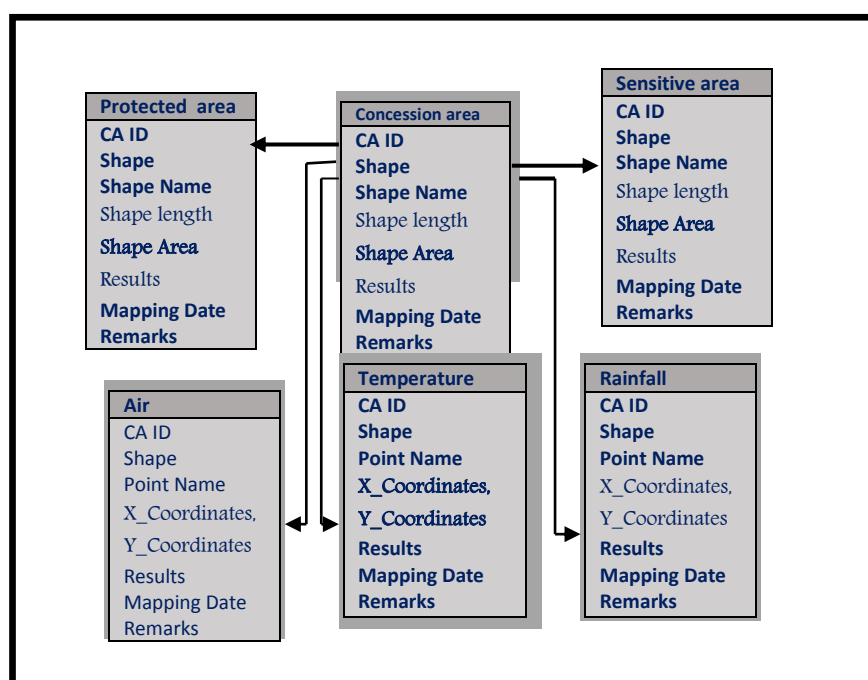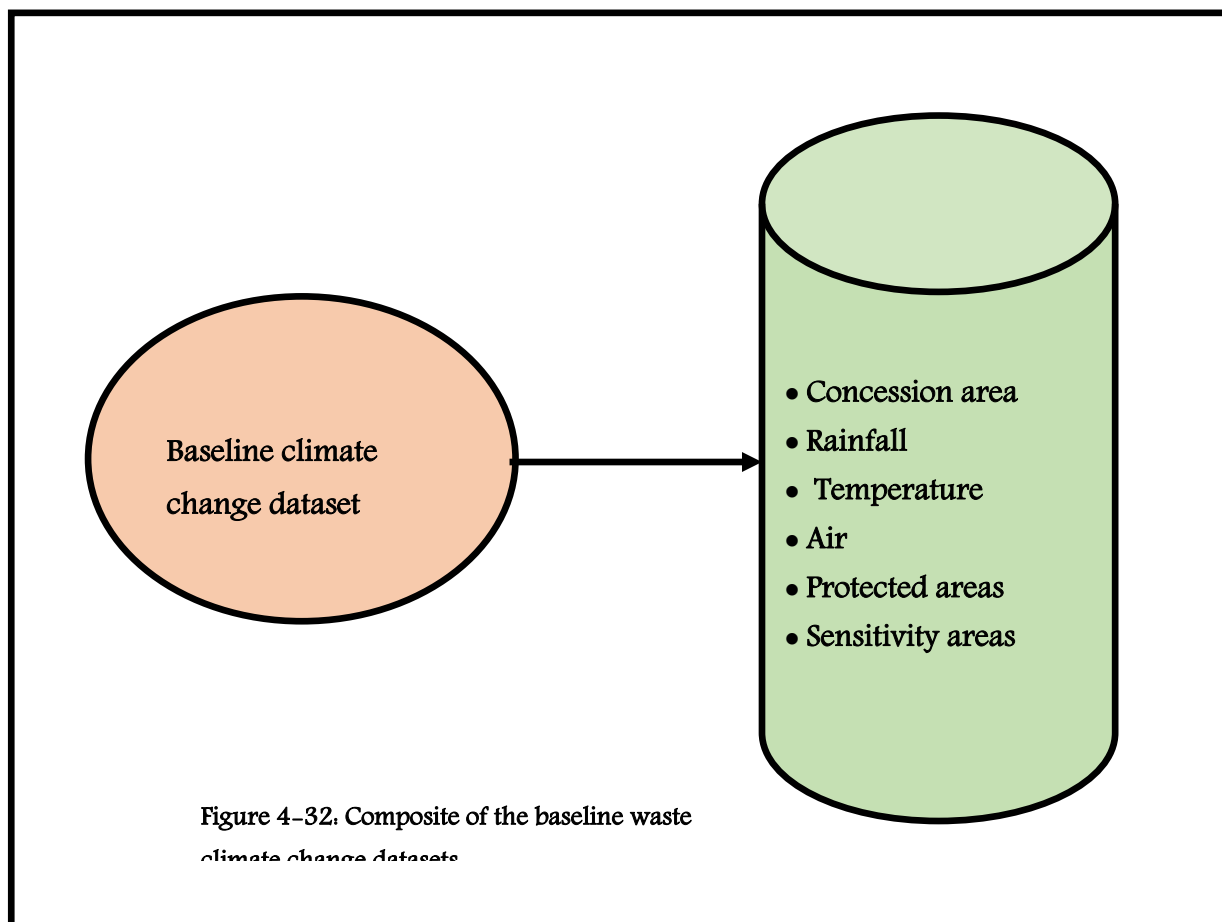Figure 4-33: Conceptual design of the baseline climate change dataset
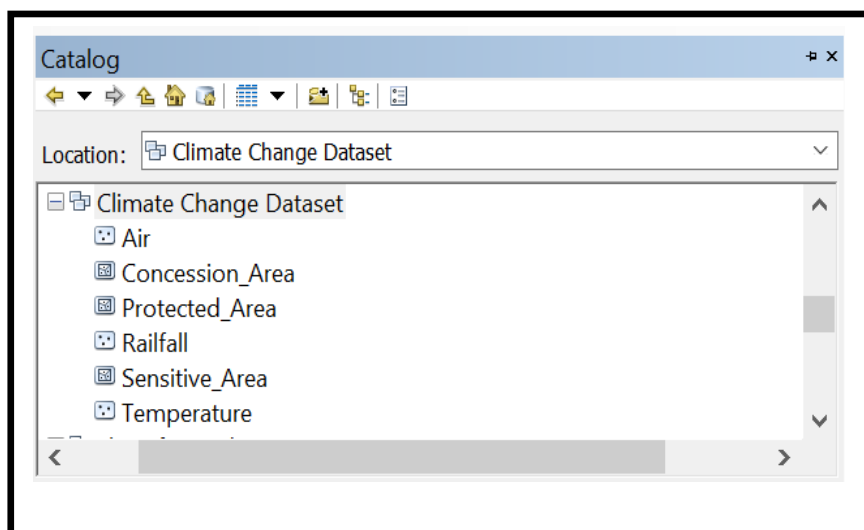
Figure 4–34: Feature classes of the baseline climate change datasets

4.6. Composition of the Baseline GIS spatial geodatabase template

As already stated in the previous sections, the Environmental impact assessment studies in mining operations should be conducted by the related government laws and regulations. As a result of inventory and assessment of those government laws and regulations, the baseline environmental GIS spatial database template for a proposed mining project contained ten (10) datasets with seventy-one (71) feature classes as shown in Figure 35. Geographic information systems (GIS) are founded upon the capability to organize information into a series of layers that can be integrated using geographic location. As a fundamental level, each GIS dataset is organized as a series of thematic layers to represent and answer questions about a particular problem set such as environmental impact assessment of mining. The basis of this step enables us to arrange the datasets required to support the baseline database of the EIA of mining and organized these data into logical feature sets. As it was discussed these blocks represent data groups or feature datasets. This provides us with a framework for understanding the design process that was presented throughout the geodatabase design. The geographic representations are organized in a series of thematic layers. A thematic layer is a collection of

common geographic elements, such as road network, a collection of parcel boundaries, land use types, soil types, and elevation surface, and satellite imagery for a certain date or well locations. This concept of a thematic layer is to describe the distribution of the baseline data phenomenon and how it should be portrayed across a geographic extent. Most of the themes should be represented by a single collection of homogeneous features while other themes are represented by multiple datasets. Gridded datasets should be used to represent continuous surfaces, such as elevation, georeferenced imagery, slope, and aspect

Air quality datasets
- Air Humidity
- Air Temperature
- Air Vibration
- Air quality point
- Ambient Air Quality
- Noise
- Rainfall
- Wind Speed

Flora & Fauna datasets
- Aquatic Species
- Biological Points
- Fauna
- Flora
- Habitats
- Terrestrial Species

Basemap dataset
- Administrative Boundary
- Chiefdom Boundary
- Concession Area
- Contour line
- District Boundary
- Infrastructure
- Mined Road
- Provincial Boundary
- Public Road
- Railway
- Stream
- River
- Village Boundary

Soil dataset
- Cation exchange capacity
- Dumping soil area
- Heavy metals
- Soil nutrient
- Soil pH
- Soil quality point

Environmental impact assessment of Mining baseline spatial geodatabase

Population dataset
- Economic activities
- Employment facilities
- Income
- Population size

Water quality dataset
- Iron (Fe) Total
- Mn Total
- Salinity
- TSS (Total Suspended Sediment)
- Turbidity
- Water pH
- Water quality point

Land Cover/Land Use dataset
- Geology
- Land Cover
- Land Use
- Mined Out Land
- Soil
- Topography

Figure 35: Composition of the Baseline GIS spatial geodatabase template

	Climate change dataset
	Air
	Concession Area
	Protected Area
	Sensitive Area
	Rainfall
	Temperature

	Waste management dataset
	Chemical waste
	Solid waste
	Waste point
	Waste treatment plant (WTP)
	Tailings impoundment facility (TIF)
	Tailing disposal

	Socio Economic dataset
	Education facility
	Health facility
	Housing quality & quantity
	Livelihood
	Public safety facility
	Public service sanitation
	Quality of life
	Recreation facility
	Socio-economic

–

. These data collections should be organized as feature classes and raster-based data layers. Figure 4-35 shows the overall view of the structure of the baseline spatial geodatabase datasets of Environmental Impact Assessments of mining. There are 10 environmental datasets and 71 feature classes. Those featured classes were grouped into feature datasets. Parameters which have the same characteristic and belong to a specific theme were grouped and organized into one feature dataset. The grouping is not based on feature data type and attributes fields and it combines features that logically belong together.

The datasets and data layers are grouped and subcategorized into blocks. As shown in Figure 35. The above blocks develop the conceptual data model, model features based on the data needed for the environmental impact assessment spatial analysis functions, and determine the spatial representation (i.e. point, polygon, line, image, surface) and non- spatial representation (i.e. attributes) of each feature. These blocks also create the logical data model, which will link the conceptual model with a GIS geodatabase. The list above is sorted by layer category, shows the vector data layers in the geodatabase that model real-world features as points, lines, or polygons in a UTM (WGS 1984) projected geographic coordinate system.

Chapter 5: Developing the Baseline Spatial Analysis Methods for Evaluating Potential and Predicted Environmental Impacts.

5.1. Introduction

Baseline Environmental Impact Assessment (EIA) of mining projects in Sierra Leone creates a challenging environment for data collection and impact prediction. Geographic information systems (GIS)-based EIA, using appropriate spatial analysis methods can sufficiently reduce the challenges created by mining environments. This research identifies the spatial analysis methods for evaluating potential and predicted environmental impacts of conducting GIS-based EIA of mining projects in Sierra Leone. It is observed that spatial analysis of impacts of mining projects on the environmental attributes, especially air, noise, water, land, and socio-economy in mining areas are largely unexplored in Sierra Leone. Spatial modelling of spatial distributions makes it possible to estimate the widest range of impacts of existing trends of population and economic and environmental change in the mining environment. For example, a range of environmental impacts can be investigated through the projection of future demand for land resources from population and mining economic activities, modelling of the spatial distribution of such demand, and then using GIS map overlay analysis to identify areas of impacts. Using environmental attributes, especially air, noise, water, land and socio-economy and environmental data stored in the GIS database template developed in this research, environmental spatial analysis were developed to aid environmental practitioners, engineers and planners to analyze different environment

scenarios in the environmental impact assessment studies of mining in Sierra Leone. Developing the GIS geodatabase template discuss in chapter 4 which acts as a spatial database management tool, where data can be imported, exported, and stored for a query for EIA of mining projects. Application on the environmental impact assessment of mining depends on the availability of spatial data and its attributes. Base on the above data coverage and the baseline geodatabase template developed for baseline data collection for environmental impact assessment of mining, the following environmental spatial analysis methods for evaluating potential and predicted environmental impacts were recommended to be applied to analyzed date during the baseline studies for a typical EIA of mining in Sierra Leone. They are; spatial analysis of air quality impact assessment, spatial analysis of noise quality impact assessment, spatial analysis of socio-economic impact assessment, spatial analysis of landslide susceptibility impact assessment, spatial analysis of soil quality impact assessment, spatial analysis of water quality impact assessment, spatial analysis of areas susceptible to environmental pollution impact assessment, spatial analysis of land-use contributing to pollutions impact assessment, spatial analysis of areas subjected to pollution treat impact assessment, spatial analysis for environmentally sensitive areas impact assessment. Detail of these analyses was explained in the subsequent sections.

5.2. GIS spatial analysis development

Integrating GIS application can help determine the baseline conditions of mining concession sites by applying various criteria in which taking into account major factors such as baseline spatial data parameters combined with the statistical techniques through the adoption of the spatial modelling techniques using various GIS spatial analysis functions and ArcGIS model builder. To assist the decision-maker in determining the baseline conditions and provide

mitigation measures from the number of feasible choice alternatives we set up the analysis for the EIA of the mining as shown in Figure 5-1.

Spatial Analysis is defined as:

i. A general ability to manipulate spatial data into different forms and extract additional meaning as a result (application dependent).

ii. A collection of techniques for analyzing geographical events where the results of analysis depend on the spatial arrangement of the events.

iii. Designed to answer questions about the spatial order and/or spatial association of a phenomenon.

The Spatial modelling environment is often viewed as an integrated set of software tools needed to develop and execute spatially explicit simulations and display model results. It worked with a Spatial Decision Support System (SDSS).

The GIS spatial analysis model consists of ten sub-models of spatial data analysis for the baseline environmental impact assessment of mining namely; spatial analysis of air quality impact assessment, spatial analysis of noise quality impact assessment, spatial analysis of socio-economic impact assessment, spatial analysis of landslide susceptibility impact assessment, spatial analysis of soil quality impact assessment, spatial analysis of water quality impact assessment, spatial analysis of areas susceptible to environmental pollution impact assessment, spatial analysis of land-use contributing to pollutions impact assessment, spatial analysis of areas subjected to pollution treat impact assessment, spatial analysis for environmentally sensitive areas impact assessment. For each of these spatial analyses, spatial operations may be done but not limited to the following shown in Table 5-1.
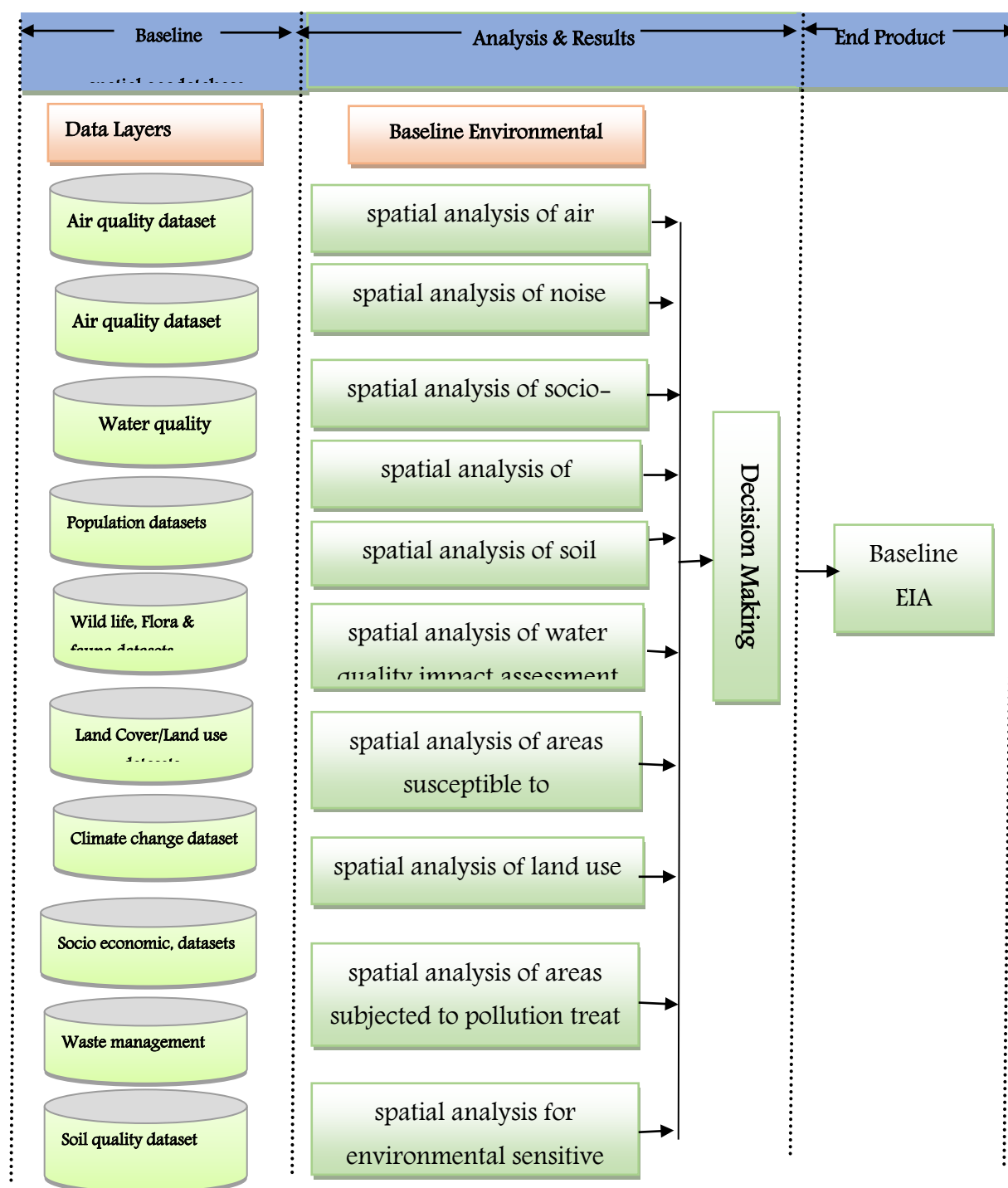
Figure 5-1: baseline spatial analysis methods with spatial data integration

Table 5-1: description of spatial analysis methods

Spatial analysis Method	Description
Buffering	a process of creating an area around a map feature delineated by a specific distance from the selected feature
corridor analysis	method of finding the optimal path between source and surrounding cells in a raster map subject to certain criteria
Cost distance analysis	a process of putting a cost to each cell in a raster map (based on factors like elevation, time or fuel spent, etc.) followed by calculating the total cost incurred in moving from one location to another
cumulative effects analysis	a process of assessing cumulative change in a set of the variable of an area during a period using overlay analysis
data reclassification	a process of reclassifying cell values in a raster map based on certain criteria to generate a new raster map digital
Digital Elevation Model (DEM)	the data model of uniformly distributed elevation data of a terrain
Inverse distance Weighing (IDW)	a deterministic spatial interpolation method based on the principle that estimate of value at a location is more influenced by its immediate surrounding points than the ones away from it
Kriging	a spatial interpolation method based on the probabilistic assumption that a spatial change of an attribute has a spatially correlated component. It has several variates like ordinary kriging and universal kriging
map algebra	a process of using algebraic operators on raster maps to generate a new raster map
nearest neighbour method	a statistical method that compares the distance between each point with its nearest neighbour point to an average distance
overlay analysis	a process of combining spatial and attribute data of two maps to generate a new map
proximity analysis	a distance-based selection process of features or cells in a map
sensitivity analysis	a process to analyze the effect of change in the parameters on the system
spatial interpolation	a collection of methods for predicting the value of unsampled points of an area using the values of sampled points
spline (also known as thin-plate spline)	a deterministic spatial interpolation method that generates a surface which passes over the known points with a least possible change in the slope of the surface
triangulated irregular network (TIN) analysis	a data model which approximates a terrain using non-overlapping triangles Uncertainty

ce: Wikipedia (2016b), chang (2008), Longley et al. (2005), Demers (2009), and Lloyd (2010).

GIS-based spatial analysis, like spatial interpolation, helps in generating interpolated surfaces of the environmental attribute using the sample points. Moreover, overlay analysis, GIS-based statistical modelling, process modelling, and index modelling bring out the spatial dimension of environmental impacts, which conventional EIA fails to highlight. GIS uses maps, charts, 3D-simulation, and spatiotemporal simulation for data interpretation. Thereby, the use of GIS in the interpretation of EIA makes it much more understandable for decision-makers and stakeholders, which eventually leads to well-informed decision making (Polash Banerjee, Mrinal K. Ghose, 2016).

5.2.1. Spatial analysis of baseline Air quality impact assessment

Air quality affects wildlife (plants and animals). human health, and the water quality in large mining areas. Spatial analysis of baseline air quality conditions in a project concession area is very important in assessing the potential effect of air pollutants and their impacts within the project concession area. The use of a Geographic Information System approach permits a geo-referenced environmental air quality assessment and an accurate mapping of air pollution problems to be made.

Sources of baseline Potential Environmental Impacts on air quality

Air pollution, mainly from particulate, in the surrounding villages within the project concession area as a result of several activities such as topsoil and subsoil removal and storage, civil construction work for surface or, underground structures, overburden and ore removal, loading and transportation, overburden dumping, and the operation of ore handling plant; gas exhaust from equipment used in perforation, loading, and transportation of materials, gases from explosives used in blasting operations, dust from excavation, and other operations, dust from grinding and segregation of materials, Sulphides, hydrocarbons, and other gas emissions

from vents in underground mining operations, gas emissions from drying operations in ore or other minerals processing, etc.

The database required for the spatial analysis: In preparing the air quality analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. These are land cover/Land use, satellite imageries, ambient air quality, base map, air quality monitoring, and meteorological data observation points from monitoring stations, demographic data, topography and contours, roadway datasets and maps, and road traffic emission data.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed to identify air pollution levels of the mining concession area about land use using GIS software. The EIA must integrate the baseline data (environmental conditions before the project) with the spatial assessment of potential impacts on air quality in all project stages. The spatial analysis assessment must consider the influence of industries already existing in the project area (and area of influence), relevant meteorological data (trends of wind direction), and the impacts of particulates and gas emissions on water, wildlife, soil, and human health. Baseline Air quality parameters to be analyzed and mapped are Particulate matter (PM10 and PM2.5), Nitrogen oxides (NOx), Lead (Pb), cadmium (Cd), arsenic (As), Carbon monoxide (CO), mercury (Hg), The average Total Suspended Solids (TSS) concentration per land-use unit, the distribution of exceeding TSS concentration, Average Sulfur dioxide (SO2) concentration per land-use unit and the distribution of exceeding SO2 concentration per land use. The geostatistical kriging method is normally used for the spatial estimation and modelling of the baseline air quality. Spatial interpolation methods like ordinary kriging, universal kriging, inverse distance weighting, and spline have been widely used to predict the concentration of air pollutants of the study area (Janssen et al. 2008; Kumar & Foster 2009; Wang & Kockelman 2009; Tang et al. 2010; Syafei et al. 2013; Halek & Kavousi-rahim 2014; Li et al. 2014). Thematic maps and DEM have been used to visualize these studies (Chattopadhyay et al. 2010).

Expected Results: Results of Spatial analysis of baseline air quality impact assessment should provide baseline air quality maps for the following assessment parameters; the average Particulate matter (PM10 and PM2.5) concentration per land-use unit, the average Nitrogen oxides (NOx) concentration per land-use unit, the average Lead (Pb) concentration per land-use unit, the average cadmium (Cd) concentration per land-use unit, the average arsenic (As) concentration per land-use unit, the average Carbon monoxide (CO) concentration per land-use unit, the average mercury (Hg) concentration per land-use unit, the average Total Suspended Solids (TSS) concentration per land-use unit, the distribution of exceeding TSS concentration, Average Sulfur dioxide (SO2) concentration per land-use unit and the distribution of exceeding SO2 concentration per land use with clear description of the following; local climate and topography, historical air quality trends, the proposed mining area and/or air basin, the exact location of air monitoring and/or sampling stations. These should be representative of the project's area of impact. Normally, this information is included in tables and figures and the laboratory reports are included as annexes. The EIA must include a clear description of the air sampling methods, and the number and exact location of sampling points, and the results of air quality data must be compared to existing national air quality standards or international guidelines. It should include estimated amounts of air pollutants, identify the most significant pollutants (particulates, gas emissions from stationary and mobile sources), and include modelling studies and dispersion analysis of these pollutants.

5.2.2. Spatial analysis of Noise quality impact assessment

Noise pollution is a major negative impact on the mined site. Noise receptors such as communities or community use areas associated with mining may include noise from vehicle engines, loading and unloading of rock into steel dumpers, chutes, power generation, and other sources related to construction and mining activities.

Sources of baseline Potential Environmental Impacts on noise quality

Sources of baseline noise emissions about land use and the proximity of noise receptors such as communities or community use areas associated with mining may include noise from vehicle engines, loading and unloading of rock into steel dumpers, chutes, power generation, and other sources related to construction and mining activities. Additional examples of noise sources include shoveling, ripping, drilling, blasting, transport (including corridors for rail, road, and conveyor belts), crushing, grinding, and stockpiling.

The database required for the spatial analysis: In preparing the GIS-based noise quality analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. These are: roadway geometry, satellite and areal imageries for geolocation of vegetation areas, buildings, houses and other noise barriers, and receivers, global positioning system (GPS) coordinates of noise monitoring stations, digital elevation model (DEM), traffic data like traffic volume, composition, speed and standard emissions at various locations along the roadway (Matejicek & janour 2011)

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed to identify noise pollution levels of the mining concession area about land use using GIS software). GIS-based Spatial Noise Impact Analysis (GSNIA) can describe the spatial and temporal distribution of noise quality in a mining site. It can be done by using the traffic noise simulation model and spatial tools of GIS.

Spatial analysis of noise assessment includes spatial interpolation for predicting the noise level in the unsampled space of the study area. According to (Murphy et al. 2006; Kurakula 2007; Eason 2013; Taghizadeh et al. 2013), the spatial interpolation methods include kriging, inverse distance weighting, triangulated irregular network (Tin) and nearest neighbour method are used. Conventional statistical methods like regression analysis can be applied for further interpretation of the results.

Expected Results: Results of Spatial analysis of baseline noise quality impact assessment should provide a baseline noise quality map. The map should be reclassified using the state noise impact category to evaluate the spatial impact of the noise and its impact on land use.

5.2.3. Spatial analysis of Socio-economic impact assessment

Socio-economic characteristics are intimately linked to their natural system and environment. Mining projects in Sierra Leone causes a lot of socio-economic impacts. Large-scale mining projects will cause severe and even permanent social impacts through the displacement of residents, displacement of business and community services, impacts on the residents like, changes to land use, access to water, and environmental contamination will for good affect the lives of native people. Spatial analysis of baseline Socio-economic conditions in a project concession area is very important in assessing the potential effect of social and economic impact and their impacts within the project concession area. The use of a Geographic Information System approach permits a geo-referenced socio-economic assessment and an accurate mapping of socio-economic problems.

Sources of baseline Potential Environmental Impacts on Socio-economic impact assessment

Factors that ought to be enclosed within the social impact analysis are Characteristics of native populations within the project space and areas of influence: population location, age distribution, increase rate, and group composition, Relevant info concerning access to education and health services, Sanitation, Development trends (some communities have community life plans and/or native development plans), Employment and financial gain, Social-economical stratification, Housing (infrastructure, range of houses), Land use and land property, Presence of autochthonous communities, customary land uses rights, Relevant health knowledge (most prevailing diseases, causes of death), Access to info and information concerning the project, attitudes towards the project, Infrastructure (roads, transportation), Migration, Rural/urban population distribution, etc.

The database required for the spatial analysis: In preparing the GIS-based socio-economic quality analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. These are GPS tagged socio-economic data, imagery, population (size, composition, traditions, productive activities), quality of life, housing quality, and quantity, public safety, education, recreation, public services, sanitation, farmlands. basic services (health, education, sanitation), and water resources, road network.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed to identify the socio-economic impacts in the mining concession area in relation to land use using GIS software. The questionnaire method and direct interview should be used to collect data on employment opportunities, educational facilities, health facilities, demographic profile, per capita income, industrial activities. Multiple linear regression should be used in predicting the farm income potential from cost distance from the market and land quality parameters (Krishna Bahadur 2011). Spatial interpolation and cost distance analysis should be used to observe the impact of the road network and accessibility to the road on the socio-economic condition in the mining concession area.

Expected Results: Results of Spatial analysis of baseline socio-economic impact assessment should produce baseline spatial analysis maps related to the following: Employment and income distribution, Social-economical stratification, Housing (infrastructure, number of houses), land use and land property, presence of indigenous communities, customary land uses, territorial rights, relevant health data (most prevalent diseases, causes of death), migration, and rural/urban population distribution (size, composition, traditions, productive activities).

5.2.4. Spatial analysis of landslide susceptibility impact assessment

Landslide leads to loss of life and property, blocking of roads and rivers, disruption of communication, and triggering of the flood. Landslide susceptibility assessment which is an essential part of quantitative risk mapping forms the basis of any hazard mapping. The choice of susceptibility mapping methodology depends on a variety of factors that may be listed as mapping unit, the scale of investigation, type of methodology used, type of landslide, variety of data needed, triggers, and purpose of mapping. To assess the standard of susceptibility maps, these factors have to be compelled to be investigated thoroughly. Production of a landslide susceptibility map for a mining concession project site starts with the selection of a suitable mapping unit (Guzzetti et al. 2005). choice of the mapping unit largely influences all the following analyses and modelling. A mapping unit is that the division of the land surface in such a way that it contains a collection of ground conditions that differ from the adjacent units across definable boundaries (Hansen 1984). Once the determination of the mapping unit, a value is assigned to every unit for every factor taken into consideration, and every unit is treated as a case or sampling unit in the susceptibility mapping.

Sources of baseline Potential Environmental Impacts on landslide susceptibility impact assessment

Heavy rainfall, geology, and human activities are Some of the triggering factors of landslides (Lee 2008; Sharma et al. 2009; Sengupta et al. 2010). heavy precipitation, stream erosion of slope toes, weathering of the bedrock are the natural triggers, steeply and improperly cut slopes, poorly controlled surface drainage and uncontrolled settlement and agricultural activities are the artificial triggers (Akgün and Bulut 2007). Road construction, potential slope instability, surface drainage, ditches and culverts, subsurface water movement, changes the distribution of mass on a sloped surface and facilitates erosion by slides due to road construction related deforestation facilitate landslide during and after road construction (Swanson & Dyrness 1975) are also potential environmental impacts on landslide

susceptibility. The factors affecting land sliding in most mining sites can be categorized into three types namely: The morphological factors (slope, aspect, curvature, plan curvature, profile curvature), geological factors (lithological formations of alluvium, andesite, claystone, limestone, clay-limestone, conglomerate, distance to fault, soil types and environmental factors [topographic wetness index, normalized difference vegetation index (NDVI), hydrologic network, road density, hydrologic density, land use classes of bare rock and debris, flood inundation area, dry farming, settlement, and forest].

The database required for the spatial analysis: In preparing the GIS-based landslide susceptibility impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. The primary input data consisted of orthophotos, topographic maps, geological maps, soil maps, land-use/land cover maps, and digital elevation maps (DEM). Based on this input, a landslide causative factors database should be built in a GIS environment, including the following information layers: geology, soil, land use (as qualitative variables), Digital Elevation Model (DEM) derived from topographic maps, geomorphometric parameters (slope angle, slope height, slope aspect, mean curvature, plan curvature, profile curvature, wetness index, modified catchment area), distance to drainage network, distance to roads.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed to identify the landslide susceptibility impact in the mining concession area in relation to land use using GIS software.

Information theory and regression analysis have been used in the GIS framework to prepare landslide hazard zones. GIS-based logistic regression and bivariate statistical analysis have been used to predict the presence or absence of landslide occurrence as a dependent variable against a set of independent variables. Artificial neural networking, the weight of evidence model, decision tree, support vector machine, adaptive neuro-fuzzy inference system,

bivariate statistical analysis, multivariate adaptive regression spline model has been used in association with GIS to prepare landslide susceptibility maps.

Expected Results: Results of Spatial analysis of baseline landslide susceptibility impact assessment should produce baseline spatial analysis landslide susceptibility maps of the following, landslide location points map, landslide location points overlaid with the DEM of the study concession area map, landslide locations overlaid with the villages and road network map, etc.

5.2.5. Spatial analysis of soil quality impact assessment

Accurate assessment of the spatial quality of soil properties is a key component of the mining ecosystem and environment modelling. Spatial analysis of Soil erosion risk mapping provides a visual aid to identify problematic areas for soil erosion since mining projects can contaminate soils over a large area, potentially affecting nearby agricultural activities. Spills and leaks of hazardous materials and the deposition of contaminated windblown dust can lead to soil contamination. Sustainable land management requires reliable information on the spatial distribution of soil properties affecting both landscape processes and services (Lin et al. 2005; Shibu et al. 2006).

Sources of baseline Potential Environmental Impacts on soil quality impact assessment

High levels of arsenic, lead, and radionuclides in windblown dust usually pose the greatest risk of soil quality assessment in mining sites. Spatial impacts analysis should include quantitative estimates of how the deposition of contaminated windblown dust could elevate levels of soil contaminants and impact nearby agricultural activities.

The database required for the spatial analysis: In preparing the GIS-based landslide susceptibility impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. This dataset

includes soil sample points, dumping soil area, soil pH, Cation exchange capacity, Soil nutrients (potassium, calcium, magnesium, nitrogen, phosphorus), and Heavy metals (lead, copper, zinc, cadmium, mercury, and chromium). The spatial distribution of electrical conductivity (EC), pH, and OC in the soil are influenced by structural factors, such as climate, parent material, topography, soil properties, and other natural factors.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed for soil quality impact in the mining concession area in relation to land use using GIS software. A combination of conventional analytical methods and geostatistical methods should be used to analyze the data for spatial variability (The geostatistical method is a spatial distribution and variability analysis method that was developed from classical statistics). Soil properties of pH, electric conductivity (EC), phosphorus (P), potassium (K), and organic carbon (OC) should be estimated using the standard analytical methods. Classical ordinary kriging (OK) interpolation should be used for direct visualization of soil properties and prediction of the values of the unmeasured sites (un-samples locations). The Morgan model has also been used for the preparation of soil erosion risk mapping (Ustun 2008).

Expected Results: Results of Spatial analysis of baseline landslide susceptibility impact assessment should produce baseline spatial analysis soil quality maps of the following, the spatial distribution of soil properties of EC, pH, K, P, and OC. spatial correlation maps of soil properties (EC, pH, K, and P), Spatial variability maps among the soil pH, EC, K, and P, etc.

5.2.6. Spatial analysis of water quality impact assessment

Water is integral to virtually all mining activities and typically the prime medium, besides air, that can carry pollutants into the wider environment. Among various pollutions, water environmental pollution, as a vital threat to human being health, also became the most remarkable issue for sustainable development. According to the IFC/World Bank Group, mines can use large quantities of water, mostly in processing plants and related activities, but

also in dust suppression among other uses. Water is lost through evaporation in the final product but the highest losses are usually into the tailings stream. the EIA for a proposed mining project must use design criteria that can accommodate the amount of water that might enter and leave specific locations at the mine site during a certain mining operation. Sustainable water management requires reliable information on the spatial distribution of water in the mining concession area and surroundings. Water quality assessment at the mined concession area requires not only an investigation of water pollution and the recognition of main pollution factors but also the identification of polluted risky areas that resulted in polluted surrounding rivers and streams in the mined site.

Sources of baseline Potential Environmental Impacts on water quality impact assessment

Change in quantity of surface water; alter flow due to construction; destruction of streams; effects on water quality parameters, alter the rate or direction of groundwater flow; alter the quality or quantity of groundwater; impact on recharge area or recharge rate, etc.

The database required for the spatial analysis: In preparing the GIS-based water quality impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis. This including Water pH, Turbidity, TSS (Total Suspended Sediment), salinity, water quality point, Fe Total, and Mn Total, geological data, soil data, land cover/ land use map, topography, biological flora and fauna

The baseline spatial analysis of surface and groundwater quality must include a list of Common water quality attributes such as Physical, chemical: pH, turbidity, suspended solids, temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Solids, salinity, conductivity and for groundwater should include; Groundwater flow directions, Locations/flows of springs and seeps, Groundwater discharge locations in streams, Groundwater uses, depth to groundwater under different

seasonal conditions, Geology and locations of aquifers, thicknesses, and their hydraulic conductivity ranges.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed for water quality impact in the mining concession area in relation to land use using GIS software. Single-factor pollution index method and comprehensive water quality index method and inverse distance weight interpolation may be used for the prediction of water pollution (Gajendra 2011).

Expected Results: Results of Spatial analysis of baseline water quality impact assessment should provide detailed maps and information on the location, distribution, quantity, and quality of all water resources that could be affected by a project and its alternatives. The data and analysis should have a reasonable level of detail, to help understand the conditions of the environmentally important geographic locations.

5.2.7. Spatial analysis of areas susceptible to environmental pollution

the contamination of the physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected during mining activities. Spatial analysis to determine the baseline scenario should be made to determine the pollution coverage as well as to identify the present land use which is susceptible to environmental pollution in the mining concession area.

The database required for the spatial analysis: In preparing the GIS-based areas susceptible to environmental pollution impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis; Land cover/land use, water quality stations, neighbourhood mining sites, settlements, soil map, erosion map, river/ stream data, noise quality stations, air quality stations.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed for areas susceptible to environmental pollution in the mining concession area in relation to land use using GIS software. Overlay techniques, Thiessen polygon, triangulated irregular network and the environmental isoline model may be used to perform the spatial analysis.

Expected Results: Results of Spatial analysis of baseline areas susceptible to environmental pollution should provide detailed maps and information on environmental pollution maps, water, air, and noise pollution maps in relation to areas susceptible to environmental pollution.

5.2.8. Spatial analysis of land-use contributing to pollution

Baseline spatial analysis of land-use contributing to pollution should be conducted to defined the mining development areas and highly populated areas that have the potential of contributing to pollution.

The database required for the spatial analysis: In preparing the GIS-based Spatial analysis of land-use contributing to pollutions analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis; Land use/land cover, population density, administrative boundary, district boundary, mining concession area, administrative boundary, district boundary, mining concession area, settlements, built-up area, roads, soil map, erosion map, river and stream system, noise quality stations, air quality stations, water quality stations.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed for analysis of land-use contributing to pollutions in relation to land use using GIS software. The union process and overlay method may be used to perform the analysis and modelling.

Expected Results: Results of Spatial analysis of baseline land-use contributing to pollutions should provide detailed maps and information on environmental pollution maps, water, air, and noise pollution maps in relation to land-use contributing to pollutions.

5.2.9. Spatial analysis of areas subjected to pollution threat.

Assessment of areas subjected to pollution threat to determine the most threatened areas that needed quick action in terms of controlling and enforcement of laws and regulations. Pollution from mining can occur in land use, surface water, groundwater, soil, and air.

The database required for the spatial analysis: In preparing the GIS-based Spatial analysis of areas subjected to pollution threat impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis; noise quality stations, air quality stations, water quality stations, population density, administrative boundary, district boundary, mining concession area.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed using GIS software for Spatial analysis of areas subjected to pollution threat. The Inductive and deductive modelling proposed by Skidmore 2002, both can be used to give an understanding of Spatial analysis of areas subjected to pollution effect.

Expected Results: Results of Spatial analysis of baseline analysis of areas subjected to pollution threat should provide detailed maps and information of environmental pollution maps, water, air, and noise pollution maps in relation to land-use subjected to pollution threat.

5.2.10. Spatial analysis for environmentally sensitive areas

Spatial Analysis for environmentally sensitive areas such as catchment areas, reservoirs, wildlife, biological flora and fauna, rivers, streams, forest reserves, lakes should be done because disturbance of these areas would destabilize the environment and potentially cause environmental pollution.

The database required for the spatial analysis: In preparing the GIS-based for environmentally sensitive areas impact analysis maps, the following data should be extracted from the baseline spatial database template prepared in chapter 4 and used for the analysis; Forest reserves, contour, lake, soil, soil erosion, water quality stations, river/stream system, land cover/land use, administrative boundary, district boundary, catchment areas, reservoirs, mine concession area, wildlife, biological flora and fauna, rivers, streams.

The methodology of spatial analysis: a georeferenced GIS spatial data analysis should be performed for environmentally sensitive areas in the mining concession area in relation to land use using GIS software. Union, reselect and buffer analyses may be applying for the spatial analysis and modelling in the GIS software.

Expected Results: Results of Spatial analysis of baseline of environmentally sensitive areas should provide detailed sensitivity maps and information of Forest reserves, catchment areas, reservoirs, wildlife, biological flora and fauna, rivers, streams.

In conclusion, the table below(table 5-2) shows a summary of the types of baseline spatial analysis methods together with the GIS spatial data required to performed those analyses and the associated recommended GIS spatial methodologies.

Table 5-2: Baseline spatial analysis methods with associated GIS spatial methodologies.

No	Type of baseline spatial analysis	GIS spatial data required	Recommended GIS spatial methodology

1	Spatial analysis of baseline Air quality impact assessment	land cover/Land use datasets, satellite imageries, ambient air quality, base map, air quality monitoring points, meteorological data, observation points from monitoring stations, demographic data, topography and contours, roadway datasets and maps, and road traffic emission data.	Geostatistical kriging method, Spatial interpolation methods like ordinary kriging, universal kriging, inverse distance weighing, spline, air dispersal models have been widely used in conjuncture with GIS for spatial analysis and visualization of spatial and temporal impacts of air pollution in the project affected areas
2	Spatial analysis of Noise quality impact assessment	roadway geometry, satellite and areal imageries for geolocation of vegetation areas, buildings, houses, and other noise barriers, and receivers, global positioning system (GPS) coordinates of noise monitoring stations, digital elevation model (DEM), traffic data like traffic volume, composition, speed and standard emissions at various locations along the project concession area	Spatial interpolation methods like kriging, inverse distance weighting, triangulated irregular network (Tin) and nearest neighbour method
3	Spatial analysis of Socio-economic impact assessment	GPS tagged socio-economic data, imagery, population (size, composition, traditions, productive activities), quality of life, housing quality, housing quantity, public safety, education, recreation, public services, sanitation, farmlands. basic services (health, education, sanitation), water resources, and road network.	questionnaire method, direct interview should be used to collect data on employment opportunities, educational facilities, health facilities, demographic profile, per capita income, industrial activities. Multiple linear regression should be used in predicting the farm income potential from cost distance

			from the market and land quality parameters Spatial interpolation and cost distance analysis should be used to observe the impact of the road network and accessibility to the road on the socio-economic condition in the mining concession area
4	Spatial analysis of landslide susceptibility impact assessment	Soil map, land-use map, geology map, imagery, topography map, digital elevation model map (DEM). geology, soil, land use (as qualitative variables), Digital Elevation Model (DEM) derived from topographic maps, geomorphometric parameters (slope angle, slope height, slope aspect, mean curvature, plan curvature, profile curvature, wetness index, modified catchment area), distance to drainage network, distance to roads.	Information theory, regression analysis has been used in the GIS framework to prepare landslide hazard zones. GIS-based logistic regression and bivariate statistical analysis have been used to predict the presence or absence of landslide occurrence as a dependent variable against a set of independent variables. Artificial neural networking, the weight of evidence model, decision tree, support vector machine, adaptive neuro-fuzzy inference system, bivariate statistical analysis, multivariate adaptive regression spline model has been used in association with GIS to prepare landslide susceptibility maps.
5	Spatial analysis of soil quality impact assessment	soil sample points, dumping soil area, soil pH, Cation exchange capacity, Soil nutrients (potassium, calcium, magnesium, nitrogen, phosphorus), and Heavy metals (lead, copper, zinc, cadmium, mercury, and chromium). The	A combination of conventional analytical methods and geostatistical methods should be used to analyze the data for spatial Soil properties of pH, electric conductivity (EC), phosphorus (P), potassium (K), and organic carbon (OC)

		spatial distribution of electrical conductivity (EC), pH, and OC in the soil are influenced by structural factors, such as climate, parent material, topography, soil properties, and other natural factors	should be estimated using the standard analytical methods. Classical ordinary kriging (OK) interpolation should be used for direct visualization of soil properties and prediction of the values of the unmeasured sites (un-samples locations). The Morgan model has also been used for the preparation of soil erosion risk mapping (Ustun 2008).
6	Spatial analysis of water quality impact assessment	Water pH, Turbidity, TSS (Total Suspended Sediment), salinity, water quality point, Fe Total, and Mn Total, geological data, soil data, land cover/ land use map, topography, biological flora and fauna	Single-factor pollution index method and comprehensive water quality index method and inverse distance weight interpolation may be used for the prediction of water pollution (Gajendra 2011).
7	Spatial analysis of areas susceptible to environmental pollution	Land cover/land use, water quality stations, neighbourhood mining sites, settlements, soil map, erosion map, river/ stream data, noise quality stations, air quality stations	Overlay techniques, Thiessen polygon, triangulated irregular network and the environmental isoline model may be used to perform the spatial analysis.
8	Spatial analysis of land-use contributing to pollutions	Land use/land cover, population density, administrative boundary, district boundary, mining concession area, administrative boundary, district boundary, mining concession area, settlements, built-up area, roads, soil map, erosion map, river and stream system, noise quality stations, air quality	The union process and overlay method may be used to perform the analysis and modelling.

		stations, water quality stations.	
9	Spatial analysis of areas subjected to pollution treat	noise quality stations, air quality stations, water quality stations, population density, administrative boundary, district boundary, mining concession area	Inductive and deductive modelling proposed by Skidmore 2002, both can be used to give an understanding of Spatial analysis of areas subjected to pollution effect
10	Spatial analysis for environmentally sensitive areas	Forest reserves, contour, lake, soil, soil erosion, water quality stations, river/stream system, land cover/land use, administrative boundary, district boundary, catchment areas, reservoirs, mine concession area, wildlife, biological flora and fauna, rivers, streams.	Union, reselect and buffer analyses may be applying for the spatial analysis and modelling in the GIS software

Chapter 6: Conclusion and future research

Baseline Environmental Impact Assessment (EIA) of mining projects in Sierra Leone creates a challenging environment for data collection and impact prediction. Geographic information systems (GIS)-based EIA, using appropriate spatial analysis methods can sufficiently reduce the challenges created by mining environments.

This research identifies the spatial analysis methods for evaluating potential and predicted environmental impacts of conducting GIS-based EIA of mining projects in Sierra Leone. It is observed that spatial analysis of impacts of mining projects on the environmental attributes, especially air, noise, water, land, and socio-economy in mining areas are largely unexplored in Sierra Leone. Spatial modelling of spatial distributions makes it possible to estimate the widest range of impacts of existing trends of population and economic and environmental change in the mining environment.

The purpose of this study is in two-fold: (1) to elaborate the role of GIS in the development of a Geographic Information Systems Baseline Geodatabase Template and spatial analysis in the impact assessment of mining projects, and (b) to discuss the state of art spatial analysis methods for impact assessment for the evaluation of potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra Leone. The rest of the research unfolds as follows. In chapter two give an overview of Policy, Legal Instruments, and Processes of the Environmental Impact Assessment System of mining in Sierra Leone, chapter three method and methodology used for the literature review is briefly discussed which focus on the literature reviews obtained by previous researchers in the field of GIS and the integration of GIS as a tool into environmental impact assessment studies in general and the solution to the environmental impact assessment of mining in

Sierra Leone. It followed by an overview of methods and principles of EIA for sustainable development and provide a summary of the environmental impacts of mining. It further explains how the use of GIS software together with the other software's can be used to solve environmental problems in the mining environment and its potentials as a core part of an Environment Database management system. Chapter four, focus on the development of the baseline spatial database template. This chapter also includes a description of the basic steps of the methodology that are used and an explanation of the data structure, characteristics, and the database template design process. Chapter five deals with the development of the baseline Spatial Analysis Methods for Evaluating Potential and Predicted Environmental Impacts of mining. A more detailed explanation of these methods was given and a clear description of the datasets required and GIS spatial analysis techniques were recommended to carry out the analysis in a GIS platform, the subsections under it discuss the data required, determinants, techniques and models for the impact assessment. Finally; Chapter six, the Conclusion and Future Research chapter, gives a complete summary of my research and state which added further research to be done. The study shows that GIS-based Baseline Geodatabase Template and spatial analysis methods can be an effective tool in various stages of mining EIA, by overcoming this great complexity with the innovation and application of a system of computer tools such as the Geographic Information System (GIS) and related technology.

Spatial analysis of mining involves the use of GIS integrated spatial analysis methodologies. Such spatial analysis methodologies use mathematical, statistical and algorithmic methods to predict the spatial and temporal distribution of impacts on environmental attributes. GIS-based techniques viz., overlay analysis, buffering, proximity analysis, spatial interpolation, least cost path, geostatistical methods, uncertainty analysis, and sensitivity analysis, are used in the spatial and temporal simulation of impacts. Data visualization, in the form of 3D visualization, TIn, thematic maps, symbolic maps, tables, and charts are

used in the communication and decision-making of mining EIA reports. However, application of GIS in mining EIA is always constrained by availability of an appropriate baseline digital geodatabase on environmental attributes, due to (i) the absence of comprehensive understanding of interrelated environment impacts caused by the mining of different minerals, (ii) the environmental uniqueness of each mine, which make it difficult to develop general tools of EIA analysis and models (iii) the availability of adequate spatial data, information and appropriate GIS technics (iv) because of the dynamic characteristics and multivariate nature of the environment, it has often been difficult to collate, analyze and interpret its datasets (v) lack of appropriate temporal and spatial resolution of remotely sensed imageries and accurate geospatial data can be a major limitation on spatial modelling (vi) Finally, the availability of GIS professionals and affordability of GIS software and related hardware is a major constraint on EIA budgeting, especially for developing countries like Sierra Leone, on the other hand, with the rapid fall in price of PCs, internet service, open source GIS, online GIS, GPS integrated mobiles, and freely downloadable mobile apps there is an immense scope in geovisualization of spatio-temporal impacts of such EIA studies in mining areas..

Limited studies have been done in the field of spatial analysis of mining. Moreover, most studies have focused only on one or a limited set of impacts of the project on the physical, ecological, or social environment. Thereby, such studies have not provided a holistic picture of the impact scenario. Development of a Geographic Information Systems Baseline Geodatabase Template and Spatial Analysis Methods for evaluation potential and predicted Environmental Impact for Sustainable impact assessment of Mining in Sierra Leone offers a tempting avenue for further studies on designing environmental spatial analysis models for environmental impact assessment and ways of integrating into GIS.

References

Abbas II, Ukoje jA. 2009. Application of remote sensing and geographic information systems to environmental impact assessment for sustainable development. res j Environ Earth Sci. 1:11–15.

Abbas, II., & Ukoje, J. A. (2009). Application of Remote Sensing (RS) and Geographic Information Systems (GIS) to Environmental Impact Assessment (EIA) for sustainable development. Research Journal of Environmental and Earth Sciences, 1(1), 11-15.

Agrawal, M. L. and Dikshit, A. K. (2002), Significance of Spatial Data and GIS for Environmental Impact Assessment of Highway Projects, Indian Cartographer MUIP-04, pp: 262–266.

A. J. Sinclair, A. Diduck and P. Fitzpatrick, "Conceptualizing Learning for Sustainability Environmental Assessment: Critical Reflections on 15 Years of Research," Environmental Impact Assessment Review, Vol. 28, No. 7, 2008, pp. 415-428. DOI: 10.1016/j.eiar.2007.11.001.

Alan r. 2007. A participatory GIS approach to environmental impact assessment: a case study of the Appalachian Corridor H transportation project [Ph.D. thesis]. Morgantown (WV): Dept of Geology and Geography, West Virginia University.

Antunes, P., Santos, R. & Jardao, L. (2001). The Application of Geographical Information System to determine environmental impact significance", Environmental Impact Assessment Review, Vol. 21, pp 511-535.

Argent, R.M. – Perraud, J.M. – Rahman, J.M. – Grayson, R.B. – Podger, G.M. (2009): A new approach to water quality modelling and environmental decision support systems. Environmental Modelling & Software 24 (7): 809–818.

Armstrong M P, Densham P J 1990 Database organization strategies for spatial decision support systems. International Journal of Geographical Information Systems 4: 3–20.

Arcadio, P. S., and Gregoria, A. S., 2006, Environmental engineering; a design Approach, prentice – hall of India private limited, New Delhi, Pgs: 67 – 120.

Barker, A. – Wood, C. (1999): An evaluation of EIA system performance in eight EU countries. Environmental Impact Assessment Review 19: 387–404.

Bond and J. Pope, "The State of the Art of Impact Assessment in 2012," Impact Assessment and Project Appraisal, Vol. 30, No. 1, 2012, pp. 1-4.

Bhatta Ramesh Prasad January 2009, the Need and Use of Geographic Information System for Environmental Impact Assessment in Nepal; Journal of Water Energy and Environment, Issue No (4) PP (29-31).

Biswas, A.K. and Geping Q. (eds) 1987.Ahmad y. and G.K.Sammy 1985, Environmental Impact Assessment for developing countries. London. Typcooly international.

C. Wood, "Environmental Impact Assessment. A Comparative Review," 2nd edition, London, Prentice-Hall, 2003.

Duong, N. D., Nierynck, E., Van, Y T. and Hens L. (1999), Land Use Changes and GIS-Database Development for Strategic Environmental Assessment in Ha Long Bay, Quang Ninh Province, Vietnam," Proceedings of Application of Resource

Information Technologies (GIS/GPS/RS) in Forest Land and Resources Management Conference, Hanoi, Vietnam, pp: 92–110.

Eta J. B., Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A, Geographic Information Systems (GIS) As an Indispensable Tool for Environmental Impact Assessment (EIA), IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR–JESTFT) e–ISSN: 2319–2402,p– ISSN: 2319–2399.Volume 8, Issue 12 Ver. II (Dec. 2014), PP 32–39 www.iosrjournals.org.

Eedy, W., (1995). The use of GIS in environmental assessment, in Impact Assessment (International Association for Impact Assessment, IAIA), 13(20): 199–206.

Erickson, P.A., (1994). A Practical Guide to Environmental Impact Assessment (New York: Academic Press).

Eta J. B., Adepoju M. O., Halilu, S. A., Mohammed, S. O., Adeluyi, S. A,2014, Geographic Information Systems (GIS) As an Indispensable Tool for Environmental Impact Assessment (EIA), IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR–JESTFT) e–ISSN: 2319–2402,p– ISSN: 2319–2399.Volume 8, Issue 12 Ver. II (Dec. 2014), PP 32–39, www.iosrjournals.org.

Fedra K. (1993). GIS and environmental modelling. In: Goodchild, M.F., Parks, B.O., Steyaert, L.T., editors. Environmental modelling with GIS. (Oxford: Oxford Univ. Press. pp. 35– 50).Eedy, W., (1995). The use of GIS in environmental assessment, in Impact Assessment (International Association for Impact Assessment, IAIA), 13(20): 199–206.

Hassan, H. & O. Kjorven, 1993, Geographic Information Systems for Environmental Assessment and Review, in World Bank Environmental Assessment Sourcebook (Update No.3), Washington DC: World Bank.

Hassan, H., 1995, Implementing Geographic Information Systems in Environmental Assessment, in World Bank Environmental Assessment Sourcebook (Update No.9), Washington DC: World Bank.

Howard, .S. P; Donald, R. R.; and Tchobanoglous, G., 2008, Environmental Engineering, prentice – hall of India private limited, New Delhi. Pgs: 56 – 78.

IAIA, "EIA Follow-Up. International Best Practice Principles," Special Publication Series No. 6, 2007. www.iaia.org.

IAIA, "What Is Impact Assessment?" 2009. www.iaia.org

Ilaboya et al, 2011, Environmental Impact Assessment Methodology; A model designed to assess the feasibility of an integrated solid waste management scheme, Journal of Applied Technology in Environmental Sanitation, Indonesia.n the environment.

Ilaboya, I. R., Oti, E. O., Ekoh, G. O., Enamuotor, B. O. Road Map to an Effective Environmental Impact Assessment Module.American Journal of Renewable and Sustainable Energy. Vol. 1, No. 2, 2014, pp. 7-16.

Jacobs, P. & B. Sadler, 1989, Sustainable Development and Environmental Assessment: Perspectives on Planning for a Common Future, Ottawa: Canadian Environmental Assessment Research Council.

João, E. M., and Fonseca, A. (1996), Current Use of Geographical Information Systems for Environmental Assessment: a discussion document. Research Papers in Environmental and Spatial Analysis No. 36, Department of Geography, London School of Economics, London.

João, E. M., and Fonseca, A. (1996). The role of GIS in improving environmental assessment effectiveness: theory vs practice. Impact Assess 1996; 14:371– 87.

J. Weston, "EIA, Decision-Making Theory and Screening and Scoping in UK Practice," Journal of Environmental Planning and Management, Vol. 43, No. 2, 2000, pp. 185-203. DOI:10.1080/09640560010667.

Kamara, S.M.(2019) Integration of GIS in the Development of an Environmental Cadastre Administrative System for the Environment. Protection Agency Sierra Leone. Journal of Geographic Information System, 11, 411-428. https://doi.org/10.4236/jgis.2019.114026.

Koorosh Gharehbaghi and Christina Scott-Young 2018, GIS as a vital tool for Environmental Impact Assessment and Mitigation, IOP Conf. Ser.: Earth Environ. Sci. 127 012009.

Longley, Paul A.; Goodchild, Michael F.; Maguire, David W. & Rhind (2005). Geographic Information Systems and Science (2nd ed.) (England, John Wiley and Sons Ltd).

Lai, Y., L.W. Mills & C. Cheng, 2000, 'Implementation of a geographic information system (GIS) to determine wildlife habitat quality using habitat suitability index', GIS Development Net, The Asian GIS Portal.

Mohammad Ebrahim Qadeemi, Liyag Fan, A GIS-Based Environmental Management System for Mining in Afghanistan.

Munn, R. E. (Ed.) (1975), Environmental Impact Assessment: Principles and Procedures. SCOPE report 5: Toronto.

Nathanson, J.A., 2006, Basic Environmental, Technology, Water Supply, Waste Management, and Pollution Control, Fourth Edition, Prentice-Hall of India.

Polash Banerjee and Mrinal K. Ghose,2016, Spatial analysis of environmental impacts of highway projects with special emphasis on mountainous area: an overview, Vol. 34, no. 4, 279–293 http://dx.doi.org/10.1080/14615517.2016.1176403.

Pratik Dutta, Sandip Mahatha & Parijat De (2004) A methodology for cumulative impact assessment of opencast mining projects with special reference to air quality assessment, Impact Assessment and Project Appraisal, 22:3, 235-250, DOI: 10.3152/147154604781765905.

P. André, C. E. Delisle and J. P. Revéret, "Environmental Assessment for Sustainable Development: Processes, Actors and Practice," Presses Internationales Polytechnique, Montreal, 2004.

Perez, Sergio (2012) Environmental Impact Assessment (EIA), GIS for Water Environmental Management at URL: http://watergis.wordpress.com/2012/03/20/environmental-impact-assessment-eia/ [Date Accessed: 09 October 2013].

Piotr Jankowski (1995) Integrating geographical information systems and multiple criteria decision-making methods, International Journal of Geographical Information Systems, 9:3, 251-273, DOI: 10.1080/02693799508902036.

R. Gibson, "Sustainability Assessment: Basic Components of a Practical Approach," Impact Assessment and Project Appraisal, Vol. 24, No. 3, 2006, pp. 170-182. DOI:10.3152/147154606781765147

R. K. Morgan, "Environmental Impact Assessment: The State of the Art," Impact Assessment and Project Appraisal, Vol. 30, No. 1, 2012, pp. 5-14.

Sierra Leone (2008) Environment Protect Agency Act.

Sierra Leone (2010) Environment Protect Agency amended Act.

Sierra Leone (2010) Environment Impact Assessment License Regulations.

Sierra Leone (2010) Environment Protect Agency EIA Checklist.

Sierra Leone (2009) Mines and Minerals Act.

S. Nooteboom, "Impact Assessment Procedures for Sustainable Development: A Complexity Theory Perspective," Environmental Impact Assessment Review, Vol. 27, No. 7, 2007, pp. 645–665. DOI: 10.1016/j.eiar.2007.05.006.

Sri Maryati1, Hideki Shimada1, Takashi Sasaoka1, Akihiro Hamanaka1, Kikuo Matsui1, Hideaki Nagawa,2012, GIS Database Template for Environmental Management of Mining in Indonesia, Journal of Geographic Information System, 2012, 4, 62–70 http://dx.doi.org/10.4236/jgis.2012.41009 Published Online January 2012 (http://www.SciRP.org/journal/jgis).

Venugopala, P. R., 2004, Textbook of Environmental engineering, prentice – hall of India private limited, New Delhi, Pgs: 86 – 88.

Weaver, A. (2003), EIA and Sustainable Development: Key Concepts and Tools, In Tarr (Ed) Environmental Impact Assessment in Southern Africa, Southern African Institute for Environmental Assessment (SAIEA).

World Bank (1995), Implementing Geographic Information Systems in Environmental Assessment, in Kjørven, Davy (Ed) Environmental Assessment Sourcebook Update No.9, World Bank, Environment Department, Washington D.C., USA.

World Bank, 1993, Geographic Information Systems for Environmental Assessment and Review, in World Bank Environmental Assessment Sourcebook (Update No.3), Washington DC: World Bank.

World Bank, 1993, The World Bank and Environmental Assessment: An Overview, in World Bank Environmental Assessment Sourcebook (Update NO.1), Washington DC: World Bank.

Yousefi, H., Noorollahi, Y., and Sohrab, T., (2003). Environmental Impact Assessment of Meshkinshahr geothermal power plant. Proceedings of the 4th National Energy Congress, 2003, Tehran, Iran, 210–219.