# GIS-Applications for Environmental Reporting in the Mining Sector

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**Abstract**

The use of Geographical Information Systems (GIS) is state of the art in environmental planning and environmental protection. However, in Vietnam's mining sector GIS is still rarely applied.

This paper describes the strength of GIS applications and its significance for environmental protection within the mining industry. Main applications of GIS are mapping, storing, modification of environmental data and afterwards analysis and visualisation. This is especially interesting for mining companies as they work in large areas with ever changing conditions and a large number of environmental relevant data that can be handled well in GIS.

Examples from the Research Association Mining and Environment in Vietnam (RAME) funded by BMBF (German Federal Ministry of Education and Research) are given for GIS-applications like GIS database, spatial analyses of environmental data and environmental reporting. The presented applications were developed in one of the Quang Ninh coal mining areas. They are aiming to provide reliable information in a sound and clear way in order to allow decision makers to identify priority measures to be taken.

**Keywords:** mining, GIS, environmental management, environmental information, environmental analysis

## *1 Introduction*

*Geographic Information Systems (GIS)*

Geographic Information Systems (GIS) are all systems that store, edit, analyze, share and display geographic information. GIS applications can be described as tools allowing users to make interactive queries, analyze spatial information, edit data and maps, and present the outcome of these procedures [3].

Environmental management is inherently a spatial undertaking. Therefore using GIS in the field of environmental science has a long history [1]. With the advent of powerful, affordable computers since the 1980s, GIS applications in environmental science grew rapidly.

The mining sector is characterized by complex environmental phenomena and processes which are highly variable in space and time and cover large areas [2]. Environmental management is required for all phases of the mine site including exploration, exploitation and reclamation phases. For the management of environmental information related to a mine site as a part of environmental management GIS is an indispensable tool [7].

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*Environmental Reporting*

Environmental reporting is an instrument for organizations to mandatory or voluntary take on responsibility regarding their environmental impacts and environmental aspects of their activities. It aims in providing useful information for decision makers and promote environmental communication [6]. It is often part of sustainable reporting that in addition considers economical and social issues.

Environmental reports can be distinguished by the target group they are addressed to. There are internal and external reports.

Internal environmental reports are addressing decision makers within a company. Their goal is to inform decision makers in order to increase the environmental performance of a company by channelling environmental management and investments. Compared to other types of environmental reports internal ones are more detailed and can contain data. Their intentions are not only to inform about the status quo but also to identify need for action and chances for environmental or financial improvements. Herein maps contribute to visualize contents and to analyze environmental problems. Spatial data processing can be used for prioritizing environmental measures and investments.

External reporting can be divided into mandatory and voluntary reporting [4]. Mandatory reporting is usually the reporting of the environmental performance of the company towards government authorities. It mostly contains monitoring data that are compared to legal limits. Maps can be included in those reports, but are normally not demanded.

Reports to the general public are voluntary in most countries. They normally intend to inform, communicate with and influence stakeholders and the general public in a way that dispels concerns and creates a positive perception of the company. As maps are in general understood more easily than tables and are regarded more objective than written text, they are a good choice for this kind of report.

## *2 Internal GIS-based environmental report*

The environmental report has been identified as a potential tool for environmental management in the Vietnamese mining sector. So far the annual environmental reports list the monitoring data without any further evaluation. The authors have developed a concept for extending the report into an internal GIS-based environmental report including more information, evaluation, prioritization and recommendations for environmental measures to be used by decision makers.

The report has a general introductory part followed by the main chapters analyzing the environmental status for the fields of activity in mining. Fields of activity are water; dumps; waste and hazardous waste; dust and air; noise and vibration. The report is concluded with a chapter on organization, organization development and communication and the final conclusion.

*Introductory part*

The first part of the report describes the intention and scope of the report, the environmental policy of the company and environmental targets. The environmental policy is the foundation of a good environmental management as it shows the concrete ideas of the company management on environmental issues related to the activities of the company. This is very important as environmental management can only work if the management truly supports it. The environmental policy and environmental targets have to be updated regularly.

The proposed environmental management system is based on the quality management approach PLAN-DO-CHECK-ACT (PDCA) principle [5]. The principle is explained shortly in

order to understand the structure of the report. Composition and structure of the report are also explained in details in order to guide the reader to the chapters which are interesting for him.

The first part of the report is completed with a description of the reporting area. This is the area possibly influenced by mining activities including the mine site itself and the surrounding areas. The description includes information on topography, morphology, hydrology, climate and the mining activities, visualized in the so-called base maps which include a topographic map, a landuse map, an administrative map, a map of licensed mining areas and mining companies. All the data forming the maps are stored in one GIS database. Special characteristics of open pit mining are the regular changes in topography and landuse due to the progress of the mine. The corresponding information have to be updated on a regular basis which can be easily done when using a GIS database.

*Fields of activity*

The fields of activity are the relevant environmental media influenced by mining. In the example of the Quang Ninh area in Vietnam the following fields of activity were chosen: water; dumps; waste and hazardous waste; dust and air; noise and vibration. The report contains a separate chapter for each single field of activity. The content of the chapters follows basically a similar structure as described below.

The objectives and targets for the respective field of activity are defined and described. They include a vision which defines the overall goal to be reached in the long run. Based on this, short term targets are defined. The short term targets have to be measurable. They are defined for one reporting period which in our case is one year.

Also Management Units (MUs) are defined. These smaller spatial units are necessary for the evaluation process for finding priority areas for environmental measures. An alternative method would be a raster analysis of the whole reporting area. The MUs are defined based on management requirements i.e. who is responsible for a certain area. That’s why in most cases the licensed mining areas are used as MUs. In ideal cases each MU shows homogeneous characteristics e. g. for landuse. In case of water the MUs are defined based on the hydrological system. By using ArcGis ArcHydroTool water catchments are delineated and defined as MUs. In case of dumps each dump forms one separate MU regardless of one or more responsible mining companies. The resulting MUs are visualized in a map. The following analysis steps are performed based on MUs.

One parameter for prioritizing measures is the environmental sensitivity which describes to which degree the current landuse is sensitive to environmental impacts or environmental pollution. As the sensitivity of an area to water pollution can be different from the sensitivity to air pollution it has to be defined separately for each field of sensitivity. Currently, the sensitivity is divided into three classes: high, medium and low environmental sensitivity. The classification is based on sensitivity definition tables as shown in Table 1. The classification for each MU considers the percentage of areas of the different landuse types and thus different environmental sensitivities as well as sensitive points like schools, hospitals or waterworks. The final classification result is visualized in the environmental sensitivity map (Figure 1).

**Table 1: Example for a sensitivity definition table for surface water**

| *Name* | *Description* | *Sensitivity* |
|---|---|---|
| Urban areas sensitive | Urban areas using surface water | High |
| Water works | Water works for drinking water supply | High |
| Tourism areas | Areas with many hotels, tourism sites | High |
| Protected wetlands | Officially protected wetland, nature parks etc. | High |
| Protected forest | Officially protected forest, nature parks etc. | High |
| Urban areas | Urban areas not directly using surface water | Medium |
| Agricultural land | Areas used for agriculture using surface water for irrigation | Medium |
| Industrial areas | Areas for industry | Low |
| Forest | Areas covered by forest | Low |
| Transportation | Roads, railroads | Low |
| Mining areas | Areas within the mining companies with no residents and few offices | Low |
| Waste land | Areas unused | Low |

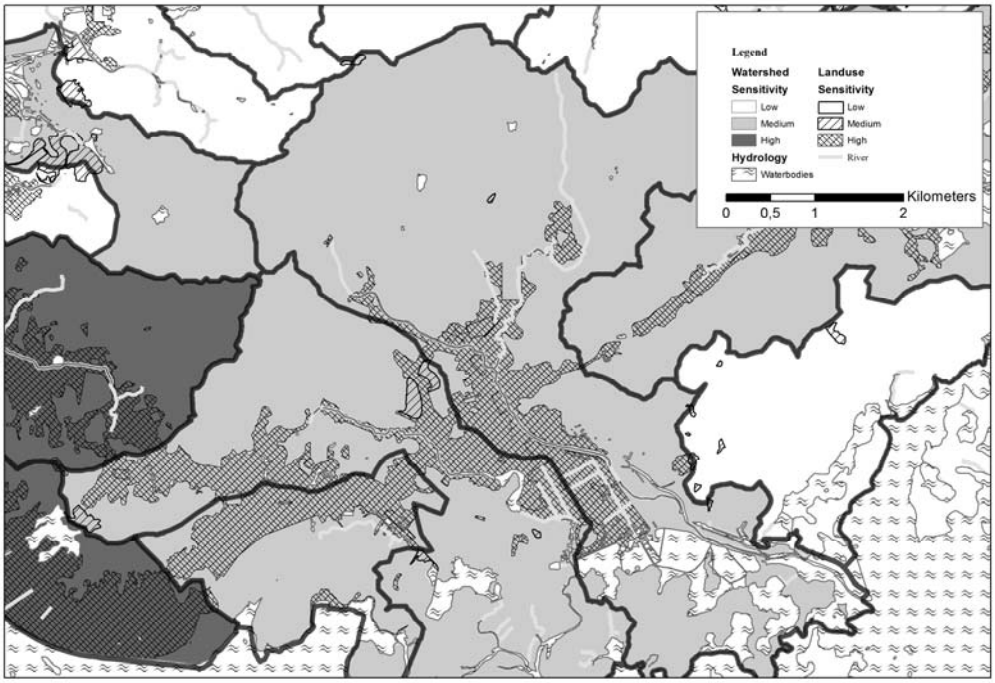


**Figure 1: Example map on environmental sensitivity classification for surface water**

The second parameter for prioritizing measures is the environmental pollution. The current status of the pollution is described and analysed for the corresponding field of activity in the next part of the environmental report. The environmental pollution is classified based on data on pollution sources, environmental measures and monitoring results. The summarized information is visualized in a map (Figure 2).

After a short general overview the pollution sources in each MU are described. The pollution

sources are determined by using existing CAD drawings, analysis of satellite images, existing data from mining companies and direct GPS mapping in the field. Point as well as area sources are included. All pollution sources are stored in a cadastre separate for every year. This allows identifying potential contaminated sites after the mine site is closed and is prepared for rehabilitation. Each pollution source in the cadastre contains additional attribute data beside the spatial information. Additional attributes are e. g. the pollution load per year, relevant substances causing the pollution, a short description of the process causing the pollution, information on environmental measures if existing already etc.

Already existing environmental measures are determined by using existing CAD drawings, analysis of satellite images, existing data from mining companies and direct GPS mapping in the field. Additionally, information from investment reports and detailed design drawings are used. Attribute data for existing measures are e. g. the type of measure implemented, the parameters treated, the treatment capacity, the treatment technology, the implementation status etc.

Important indicators for environmental pollution are the monitoring results in the reporting period. These results can come from permanent monitoring points where monitoring takes place regularly always at the same location. An even better solution would be permanently installed monitoring devices. Permanent monitoring points are defined in places where pollution is likely to occur or in points with sensitive landuse. Additional, there can be measurement results from temporary points. They are used for investigation purposes or during the conceptual phase for an environmental measure. All monitoring points with the corresponding monitoring data are stored into the geodatabase. In order to ensure the unique attribution of monitoring data each monitoring location gets an ID. Like this different and sometimes only slightly changed monitoring locations cannot be mixed up even they have a similar geographic description. The analysis of monitoring results in one location at different times gives important hints on either the growing impact of a pollution source or the effectiveness of environmental measures.

The next step is to classify the environmental pollution for each MU. As for the sensitivity three classes are defined: high, medium and low environmental pollution. Depending on the availability of data different evaluation methods are available. Here a method was chosen which considers the cumulative pollution load in the MU and relates it to the area of the MU. The pollution load is determined from data on pollution sources, monitoring data and process data. In case exact data are not available the pollution load has to be estimated by using data from similar situations and processes or literature data. The informative value of the cumulative pollution load can be further improved by using different weighting factors for different pollution parameters. The weight is increased with the level of hazardousness of a substance. Specific legal regulations and demands from stakeholders should be considered, too. The resulting classified environmental pollution is visualized in a map which also shows pollution sources, existing environmental measures and monitoring points (Figure 2).

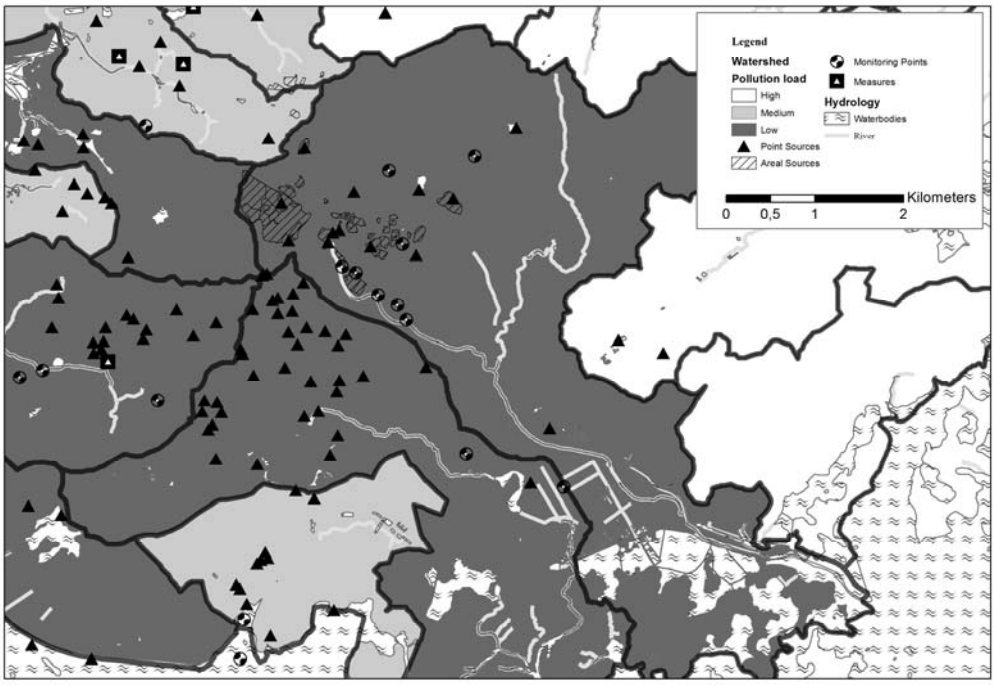


**Figure 2: Example map on environmental pollution classification for surface water**

Based on the derived classifications for environmental sensitivity on the one hand and environmental pollution on the other hand finally the environmental impact is determined for each MU in order to identify priority MUs for the recommendation of environmental measures. As the mining sector still is in the beginning phase of implementing environmental measures here the focus is put on MUs where a high environmental sensitivity is combined with a high environmental pollution. The corresponding MUs are selected as high priority MUs, visualized in a map and further described in detail in datasheets. Such a datasheet summarizes all relevant information on environmental sensitivity, pollution sources, existing environmental measures, monitoring results, environmental pollution and environmental impact. At a glance the reader can understand why the MU is a high priority MU and where potential mitigation measures should be implemented.

In high priority MUs the pollution sources are examined in regard to possible mitigation measures. Pollution sources with hazardous substances and high pollution loads should be treated first. Based on estimated investment costs for the measures a cost/benefit ratio is determined. The measures with a high cost/benefit ratio are the recommended measures and are displayed in a map.

Furthermore, recommendations for adjustments of the monitoring network are given. Main criteria for adjustments are priority MUs, areas with high environmental sensitivity and areas with missing data about environmental pollution. The suggested adjustments of the monitoring network are displayed in a map.

The algorithm described above is performed for each field of activity in a similar way. First, the environmental sensitivity and the environmental pollution are analysed and classified. Based on this the environmental impact is determined and priority MUs are identified. For them mitigation measures and adjustments in the monitoring network are recommended.

After implementing the report in the second year the effectiveness of implemented measures has to be checked carefully in order to decide whether to continue implementing the same type of measures or to readjust and recommend a different type of measures. This applies also

for the location of recommended measures. The report is a tool for environmental management and planning which controls itself and has to be adjusted regularly to the requirements of the reality.

*Organization, Organization Development and Communications*

This part of the environmental report deals with organizational issues in environmental management in order to inform the reader of the report about the environmental management structure in the company but also to make suggestions if necessary. The human resources, roles, responsibilities and authorisations related to environmental management are described and explained. Internal communication between all management levels and inside them as well as external communication of environmental issues play an important role and are fixed in the report. Rules and requirements on the documentation of environmental management and environmental information are described. Furthermore, conducted and planned capacity building measures as well as organization development plans are described.

*Overview on relevant GIS applications*

There are several GIS applications used for the generation of the environmental report described above. All spatial data included in the report are stored in a *relational geodatabase*. A relational geodatabase has the advantage that data are consistent, clearly arranged and easily updated. The *analysis of high resolution satellite images* is used to update existing topographic maps, to derive landuse and landuse changes, to identify pollution sources and environmental impacts. Due to a large number of satellites for environmental and other purposes offering image data the prices for high resolution satellite data nowadays are quite affordable. Usually, in the existing image databases from previous flights suitable images can be found, so the much more expensive image data on request are not necessary. As for the field of activity water the natural catchments have to be determined, the *ArcGis ArcHydroTool* was used to delineate catchments which represent the MU. Other tools for the analysis of environmental data include *erosion risk assessment, pathway analysis* and *hot spot analysis*. For the comparison of the situation between two different reporting years GIS offers also a *change detection* tool.

## *3 Conclusion and Outlook*

The GIS based environmental report that has been developed, allows aggregation of spatial and non-spatial data in a plain way. The division of the reporting area in management units (MUs) that can differ for each field of activity allows a flexible environmental management based on natural and administrative boundary conditions.

The developed reporting system not only displays monitoring data, but evaluates emission, immission and the environmental impact in the reporting area. Based on this information a prioritization of management units (MUs) is done which is followed by a prioritization of pollution sources within the management unit. The prioritization of pollution sources for mitigation measures directly supports decision makers in managing environmental issues and assigning investment to those environmental projects that have the highest positive impact. After the implementation of measures for pollution mitigation their effectiveness can be evaluated and easily assessed and visualized in maps.

The proposed methodology has a great potential to contribute to improving the environmental situation in the mining sector. Especially in those countries that face the challenge of making decisions in the field of environmental protection with limited data sources and limited financial sources.

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