INTEGRATED ENVIRONMENT FOR DATA MANAGEMENT OF MINING WASTE DISPOSALS

M. Gracia Manca, A. Bertacchi and C. Matzuzzi

CSGM-CNR, Geoengineering and Mineral Processing Study Centre of the C.N.R.
University of Cagliari
Piazza D'Armi, 09123 Cagliari, Italy
Phone: + 39 070 6755513, Fax: + 39 070 6755523
e-mail: mgmanca@vaxca1.unica.it

ABSTRACT

Researchers at the Geoengineering and Mineral Processing Study Centre of the Italian Research Council, have developed a database system integrated with a GIS (Geographical Information System), for data collection on operational or closed waste disposal sites. This paper describes the objectives of the system, the data organisation, the structure of the database, the characteristics and functionality of the GIS.

INTRODUCTION

For many decades, before the heightened environmental awareness of today's society, a short-sighted attitude considered waste disposal sites as a necessary evil inherent in economic growth and at the most it was their visual impact that caused concern.

In actual fact, waste disposal sites can pose a serious problem in that the release of possible toxic substances, also in the long term, may put both the personnel that work there and the neighbouring populations at risk and create an environmental hazard.

In a correct approach to the problem, the environment should be construed as a system of relationships between the natural component (groundwater, air, climate, geology, geomorphology, etc.), the human component (land use, socio-economic system, traffic) and the waste disposal system (plant, type of treatment, type of waste). The analysis of these components points to those factors that characterise the system of relationships and that could be used for risk assessment.

Data collection on waste disposal sites and the surrounding territory is a basic preliminary step for a better approach to the formulation of environmental protection programmes. Nevertheless, it is essential that the raw data collected are organized such that they can be processed and converted into useful information for assisting waste management and pollution prevention and for supporting the decision making process regarding human health and environmental protection.

The aim of this work is to develop a software system in which these factors are organised in such a way that they are able to represent the situation of the waste disposal site, and its relationship with the surrounding environment. This representation is managed by means of interaction between the database and a Geographical Information System (GIS) that permits the descriptive (alphanumeric data) and/or representative data (vector and raster data) to be viewed from different perspectives.

The use of this technology has a major effect on the analysis of data relevant to environmental protection planning by natural processes. In particular, with such a system it is possible to realise an information base in digital format, at different management levels (local, provincial, regional), that are of support in:

- identifying higher risk waste disposals sites;
- planning action to be taken in the event of accidents that could constitute a threat to the population;
- formulating operational control and prevention planning.

In order to achieve the above mentioned objectives, the work was organised into distinct phases:

- definition of characteristics of the entities to be studied;
- identification and choice of some samples of waste disposal sites in Sardinia;
- planning of the database structure of a relational type;
- GIS organisation;

- data acquisition;
- construction of a prototype system, easy and fast to use, by means of commercial software tools;
- simulation of database use as an aid in hazard or risk assessment.

DEFINITION OF ENTITIES

The interrelation between the geographical and environmental features and waste disposal technology plays an important part in mining waste problems. In particular, the analysis of the different factors, which exert their influence in diverse ways, starts from the definition of four principal entities, namely:

- waste;
- landfill;
- site;
- land.

Analysis of these entities allows the delineation of their characteristic parameters organised according to a territorial representation model, considered as the result of interactions between natural and human components. In these terms, especially for mining waste disposal, site characterisation is essential. In particular the main factors are:

- *Geological and geotechnical.* They are essential for evaluating interactions and chemical-physical exchange that occur between substances contained in the landfill and derived from mineral processing techniques. For example tectonic or stratigraphic discontinuities could favour the infiltration of pollutants, such as heavy metals, into the aquifer underlying the mining waste site. Equally significant are the geotechnical and geomechanical properties since they affect the site stability directly;
- *Morphological.* They govern the stability of the area and influence the landforms with processes of tectonic-structural origin, by water flows, karst, action of wind and ice and human intervention. In particular, areas undergoing active geomorphological processes like solifluction, diffused runoff and linear erosion and the alluvial zones are to be considered areas "at risk";
- *Hydrological and hydrogeological.* The evaluation of possible interference between the accumulation of mining waste and surface and groundwaters is very important. In particular for vulnerability assessment of aquifers a knowledge of the main geometric characteristics (water table, aquifer thickness) and chemical-physical proprieties (permeability, infiltration capacity, ion exchange, adsorption, degradation, etc.) is important;
- *Pedological.* Soil classification and the study of its properties allows to define safety measures and to plan reclamation and environmental rehabilitation of mining sites. The necessary elements for a complete description and for soils characterisation are various and they concern both the soil profiles and the site features (surface with homogeneous soil properties);
- *Meteoclimatic.* They influence waste disposal sites with respect to nearby populated area. Rainfall and its intensity and direction of dominant winds are the most important features. In particular, the wind action could contribute to dispersing the particles contained in mine tailings and the sludge in settling ponds;
- *Land-use.* A knowledge of human activities in the neighbourhood of mining waste sites, could be of aid not only in environmental impact assessment, but also for evaluating the risks connected with possible diffusion of pollutants.

WASTE DISPOSAL SITES

In the past the economy of Sardinia relied heavily on its mining industry, with the extraction of lead-zinc, copper and other metallic sulphide ores, fluorite, barite, talc, etc. This long and intense mining activity has left visible scars on the landscape, with enormous pits, underground voids, and also numerous waste sites of a different nature (processing tailings and mine waste, mineral stocks, etc). These waste dumps contain mineral residues or other substances that could trigger the transfer of pollutants into the soils and waters.

In view of this situation, and having examined a number of the main waste sites existing in the south of the island in the Province of Cagliari, we selected, one from each category, to achieve the established objective.

INTEGRATED ENVIRONMENT MODEL CONSTRUCTION

The integrated environment consists of a relational database that runs sharing data and activities with a Geographical Information System. The latter system is an effective means of data management because it takes advantage of combining the capacities of data acquisition and storage, typical of databases, with the description and representation of various territorial situations. The difficulties connected with integrating a database, containing alphanumerical data in particular, with a tool of representation and spatial analysis, are overcome by defining a common structure between the two systems. Therefore the facilities of this integrated system will allow to significantly improve the data acquisition, management and analysis phases, identification of the spatial relationships and the creation of thematic maps.

Planning of the database structure

The relational database was designed on a conceptual data model based on the defined entities of territorial system. The key feature of the model is the subject area: a set of interrelated data on a specific entity. In our domain we have defined four subject areas (Figure 1):

- *waste*: consists of characteristics of the waste material in relation to the industrial process that generated it, to its main constituents, to its risk characteristics, to dumping and to sampling;
- *landfill*: all data related to the operational status of the waste disposal sites, to the engineering aspects and to the pollution control;
- *site*: consists of information about the main features of the site area such as geological, geomorphological, hydrogeological, geotechnical and pedological;
- *land*: consists of the data pertaining to geographical or regional aspects at different scales.

Figure 1. The database form structure (subjects areas).

Primary Tables	Secondary Tables	Main Fields
Waste	Characterisation	European code, category, hazard, constituents,...
	Sampling	Sample identification, date, analysis parameters,.....
Landfill	Identification	Name, company, address, type, status, lifetime, ...
	Permits	Authority, license number, expiry date, authorised capacity,..
	Technical aspects	Stability, morphology, cover, drainage, etc...
	Location	Latitude, longitude, maps of site location
	Accesses	Type of road, denomination, Km.....
	Security	Alarm, fire system, equipment....
	Emissions	Type, entity, monitoring, control, ...
	Inspections	Authority, date, check,...
	Accidents	Description, date,...
Site	Characteristics	Stability, erosion, morphology, slopes, ...
	Hydrogeology	Average depth, hydraulic gradient, flow direction, uses, ..
	Rocks	Rock type, thickness, weathering, discontinuities,..
	Ground	Thickness, cohesion, aggregation,...
	Pedology	Profile, texture, fabric, erosion description,...
Land	Characteristics	Geology, geomorphology, seismic activity, land use,..
	Hydrography	Hydrographic element, denomination, discharge, ..
	Meteoclimate	Average temperatures , wind speed and direction,...
	Cities	Denomination, population, facilities,..

Table 1 – Primary and secondary tables and fields contained in subject areas.

The model of the database is organised as follows (Table 1):

- *primary tables*: contain the subject areas (waste, landfill, site, land). These relational tables interact by different links: static and dynamic. The relation between the key fields of two different tables defines the static link and it is a component of the database structure. An important key is "ID_Landfill" which is the key component in the construction of dynamic links. These connections are defined between tables from time to time especially when querying the datasets. Dynamic links are created on the basis of the static links according to different procedures determined by the query rules of the database;
- *secondary tables*: organise the data referred to a specific area subject in the according to different topics;
- *auxiliary tables*: complementary to primary and secondary tables and support data entry and processing activities.

The database carries out two main functions:

- *data entry and updating*, requiring the development of forms for data management and control;
- *data consultation*, by means of specific forms for interrogating the datasets.

The first activity has required the definition of a user interface consisting of a graphical module divided into different forms related to primary and/or secondary tables, depending on the subject area to be considered, making data entry and the updating easy and friendly. Moreover it enables specific information to be directly obtained.

The development of a user interface for data consultation has simplified the process of interrogating the datasets. A main and auxiliary forms (Figure 2) form the interface.

In the main form the database framework and the tools for constructing queries in an interactive way are visualised. The user can query the database by selecting, through the subject areas, the fields related to information to be acquired or by choosing among predefined queries classified on the basis of type of environmental phenomena connected with influence of the landfill on the territory (Figure 3). The results of queries can be elaborated in tables of interchange with the Geographical Information System.

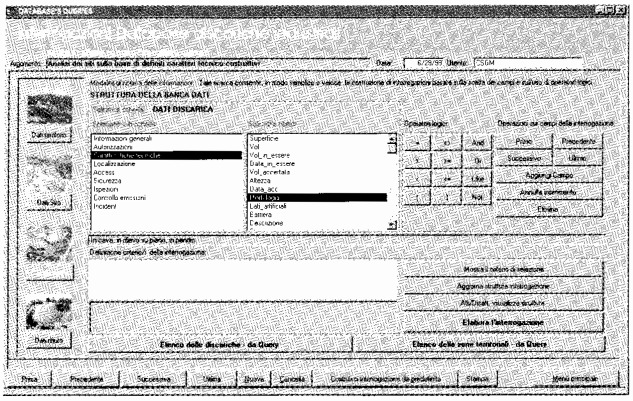

Figure 2. Query user interface (main query form).

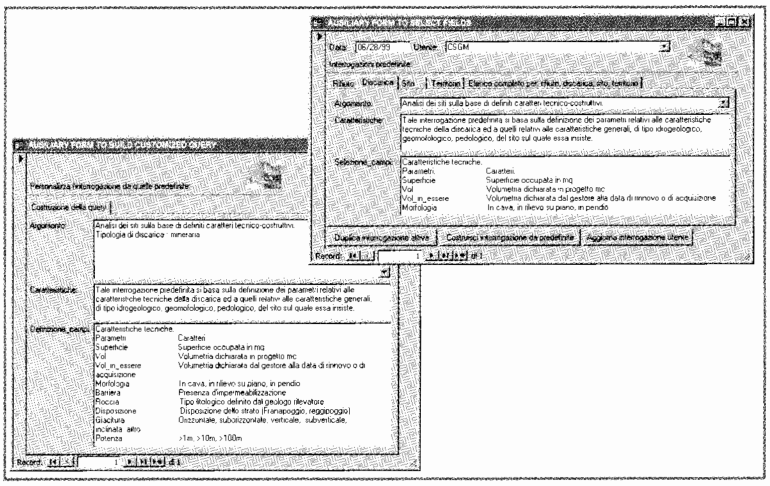

Figure 3. Auxiliary forms allow to construct customised queries.

Geographical Information System organisation

The GIS was developed on the basis of database structure to manage the representative aspect of the alphanumerical data as regards the different thematic maps that describe the territorial space surrounding the waste disposal site. The processing of the geocoded information, improved by typical GIS functions allows to study those phenomena which may be a cause of risk. A geographical space, based on subject areas, is defined for the representing the territorial situations consisting of:

- *Primary zone ("Land")*. The aim of the primary zoning is to define the geographical land units. These zones are defined on the basis of regional waste disposal plans. The boundaries are represented in a map which also indicates orographic and hydrologic features, infrastructures, built-up areas, waste disposal sites.
- *Secondary zone ("Site", "Landfill")*. Each primary zone is divided into secondary units. They will represent the most significant spatial entities for studying the environmental phenomena caused by landfills. The secondary zone boundaries are defined on map base of higher level and on the detailed site and landfill maps.

The thematic territorial bases are represented on this geographical spatial model, both large scale and detailed thematic views. The representation scale is carefully chosen in relation to local situations and to specific investigations associated with the waste disposal area. More in particular three levels of representation have been defined:

- *Large scale* – this allows location of waste disposal sites over a large geographical area. Accordingly it is possible to highlight and analyse those situations that require a global perspective of the territory. The scale of representation ranges from 1: 25,000 to 1: 10,000.
- *Small scale* – locates the landfill and allows specific analysis. This level provides more details on information drawn from the general picture. The scale of representation ranges, according to the local situations, from 1: 10,000 to 1: 2,000.
- *Detail* – this allows a detailed analysis of the landfill, indicating for instance zoning of the main area, size of waste body, internal access ways and the structural features of the site. The scale of representation ranges from 1: 5,000 to 1: 1,000. In this phase a further level of detail is envisaged, resorting to graphics and images.

FUNCTIONALITY OF SYSTEM

All alphanumeric information, related to territorial data, is defined in the Geographical Information System by a dynamic link between the query module of the database and a representation module developed in the GIS. This module extends the basic functionality of the GIS to the visualisation and analysis of the results of the database queries.

The GIS allows the datasets to be queried either singly or in combination, using both spatial and non-spatial queries. In particular, interrogating data from the database, through a query of attributes, the results can be displayed either graphically or in report form. In Figure 4 the interaction between the database query and the corresponding visual presentation in the interface of the GIS are shown.

Interaction between the database and GIS's GUI (Graphical User Interfaces) allows visualisation of the zones located on the map base by dynamic construction of the views. This enables access to alphanumerical landfill data and visualisation of detailed and thematic maps generated for the various levels of analysis. On the other hand, it is also possible to build spatial queries related to components of the geographical space.

The system has been developed as a PC based system using two different commercial programs chosen for their compatibility, diffusion and possibility to develop owner programs.

CONCLUSIONS

The definition of an integrated environment based on GIS architecture has allowed to develop an information base for a broad set of environmental and anthropic parameters that are essential for analysing the various territorial scenarios conditioned by the presence of waste disposal sites. Based on the potential of this integrated environment and its future developments it will be possible to obtain a picture of the different situations created in areas of mining activity, the result of which may generate hazards to the environment.

ACKNOWLEDGEMENTS

The work described herein has been funded by the CNR's (Italian Research Council) National Research Group for Protection from Chemical-Industrial and Ecological Hazards.

REFERENCES

Agus, M., A. Bertacchi, A. Bortolussi, S. Fadda, M. Fiori, S. Grillo, M.G. Manca, P.P. Manca, G. Massacci, A. Marcello, C. Matzuzzi, S. Pretti, P. Saba and C. Tilocca, 1998. Il controllo ambientale di discariche industriali e minerarie utilizzando una banca dati. Convegno Nazionale AMS, Cagliari 9-11 Ottobre 1998 (in press).

Allegri, T.H., 1986. Handling and management of hazardous materials and waste. Chapman and Hall Ltd, London.

Carty, G. and M. Crowe, 1997. Development of a National Wate Database for the Republic of Ireland. Proc. Sardinia 97, Sixth International Landfilling Symposium, CISA, Cagliari, Vol.V, pp. 241-252.

Colombo, A.G., et al., 1996. An analysis of Environmental Impact Studies of installations for the treatment an disposal of toxic and dangerous waste in the EU. Final Report, Joint Research Centre European Commission, EUR 16389; CL-NA-16389-EN-C.

CTD, 1997. Linee guida per le discariche controllate di rifiuti solidi urbani. Editor CISA, Centro Ingegneria Sanitaria Ambientale, Cagliari.

Dawson, G.W. and B.W. Mercer, 1986. Hazardous waste management. John Wiley and Sons.

Lewin K., et al., 1997. Development and use of a national landfill GIS. Proc. Sardinia 97, Sixth International Landfilling Symposium, CISA, Cagliari,Vol.V, pp. 233-240.

Petersen. H., 1997. Commission of the European Communities: Proposal for a council directive on waste landfilling. Proc. Sardinia 97, Sixth International Landfilling Symposium, CISA, Cagliari, Vol.V, pp. 25-46.

Pitea, D., A.L. De Cesaris and G. Marchetti, 1998. Criteri per la realizzazione di impianti di stoccaggio di rifiuti residuali. Fondazione Lombardia per l'Ambiente. Vol.I.II.III.

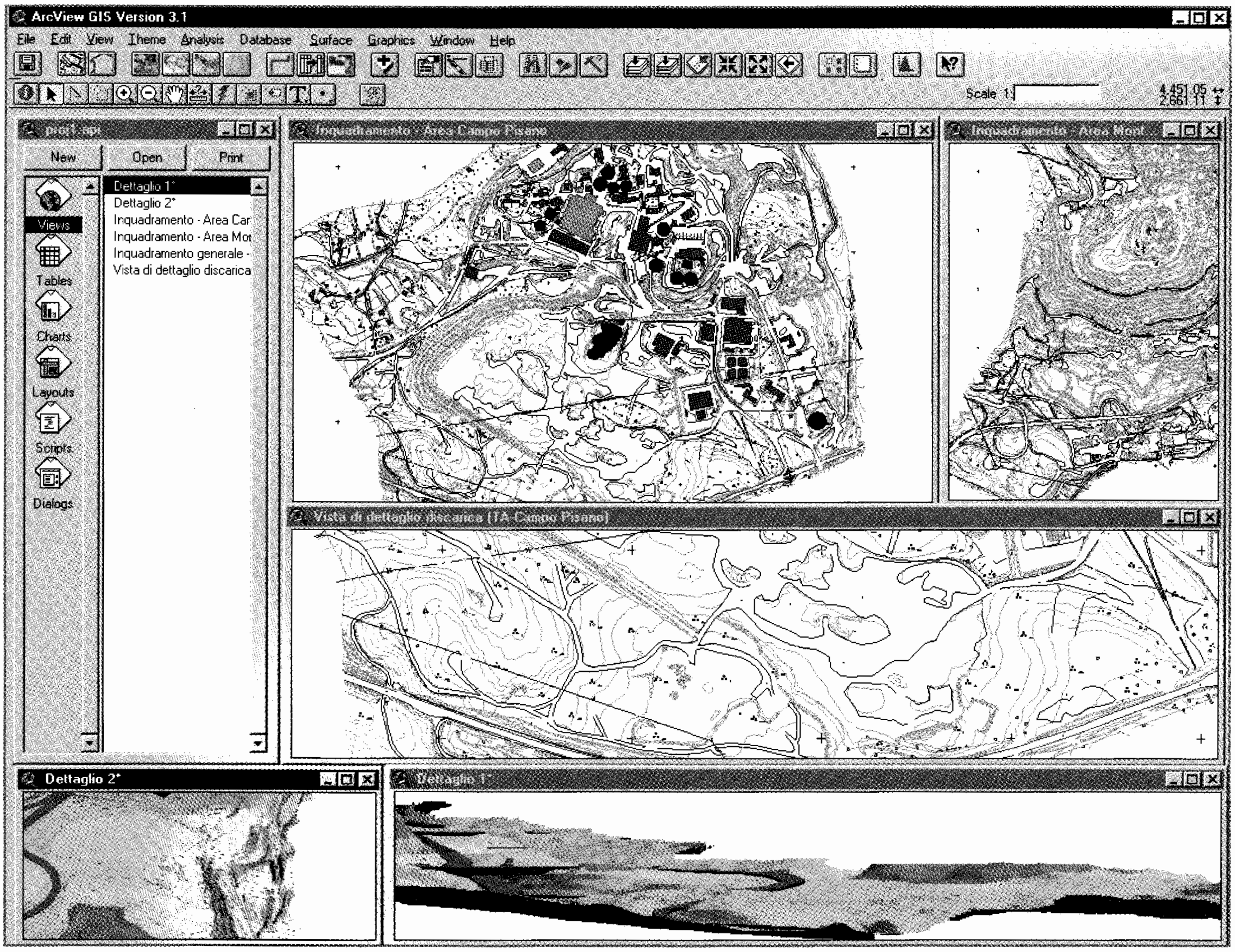

Figure 4. User GIS's GUI