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INTRODUCION TO RESEARCH PROJECT ORGANIZING FOR CHARACTERIZATION AND MONITORING OF THE ENVIRONMENTAL EFFECT OF PETROLEUM INDUSTRIAL CONTAMINATION IN HUNGARY[1]

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Introduction

There are currently over 20,000 registered contaminated sites in Hungary. The estimated cost of the remediation of these known sites is approximately 2 billion USD. The delineation of the contaminated areas and their associated sources is an extremely complex process due to the different types of contaminants and their associated persistence and migration, as well as the media in which the contamination is present (e.g. in soil, vegetation, and groundwater). These contaminants pose an immediate and long-term threat to the local population, flora, and fauna. This threat is increased by the movement of the contaminants through the soil, surface- and groundwater. In the agricultural regions, heavy metals can be absorbed by cultivated plants. These heavy metals are known to be extremely toxic to humanity and fauna who ingest the plants. Heavy metals are known to bioaccumulate in animals, thus the body burden of these often increases up the food chain. This poses a significant risk for humans.

The proposed research program seeks to clearly identify and locate the suspected and unknown contaminated areas and their corresponding sources. The investigation also will assess the extent of the contamination and it's associated effects on the flora and fauna. The project will utilize state-of-the-art techniques in remote sensing, material science, geostatistics, information management, and cartography.

Research area

The exploration of natural oil and gas began in the mid 1960's in the southern part of Hungary. The Algyõ Oil and Gas Field belongs to the Hungarian Oil and Gas Company Ltd. (MOL) and is the largest oil and gas field in the country. The field is comprised of 24 km^2. This field provides a significant portion of the energy supply to Hungary. There are in excess of 1000 oil wells within this field. *(Fig 1-2.)*

During the intensive drilling operations, various additive materials containing high levels of heavy metals (Cr, Pb, etc.) were utilized. These contaminants were deposited in the area of the existing wells. In one so called „near-well soil disposal" area, varying amounts of

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contaminant material (ranging from 100 to 1000 m^3) were deposited. This method of disposal was used from mid 1960's to 1990 at such wells, which were deeper than 1800 m. To further complicate matters, the locations of the former disposal sites have been forgotten.

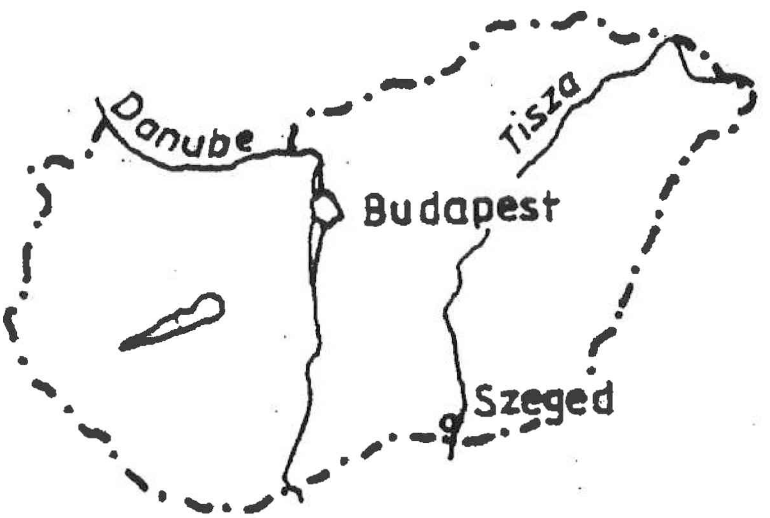

Figure 1 Map of Hungary

MOL is one of the leading integrated oil and gas companies in Central and Eastern Europe. MOL's primary activities include the exploration, production and refining of crude oil and natural gas, the transportation and storage of raw materials and related products, as well as the marketing of their own products.

Environmental protection is an integral part of MOL's business philosophy and practices. MOL's official policy with respect to the environment was quoted as: *"We wish to carry out our activities with the protection of the natural environment, keeping in view that our products and services should be benign to the environment."* In 1995-96 the environmental responsibilities of the Hungarian Oil and Gas Co. Ltd. were evaluated by independent auditing firms prior to the company's initial stock offering. According to the report, one of the most important tasks is remediation of the contaminated regions associated with the near-well disposals (ca. 20 million USD).

One of the most important conclusions of the report was that the environmental impacts of activities must be assessed, regularly evaluated, and monitored over time. The adherence to these recommendations will allow efficient operations while minimizing the impact on the environment.

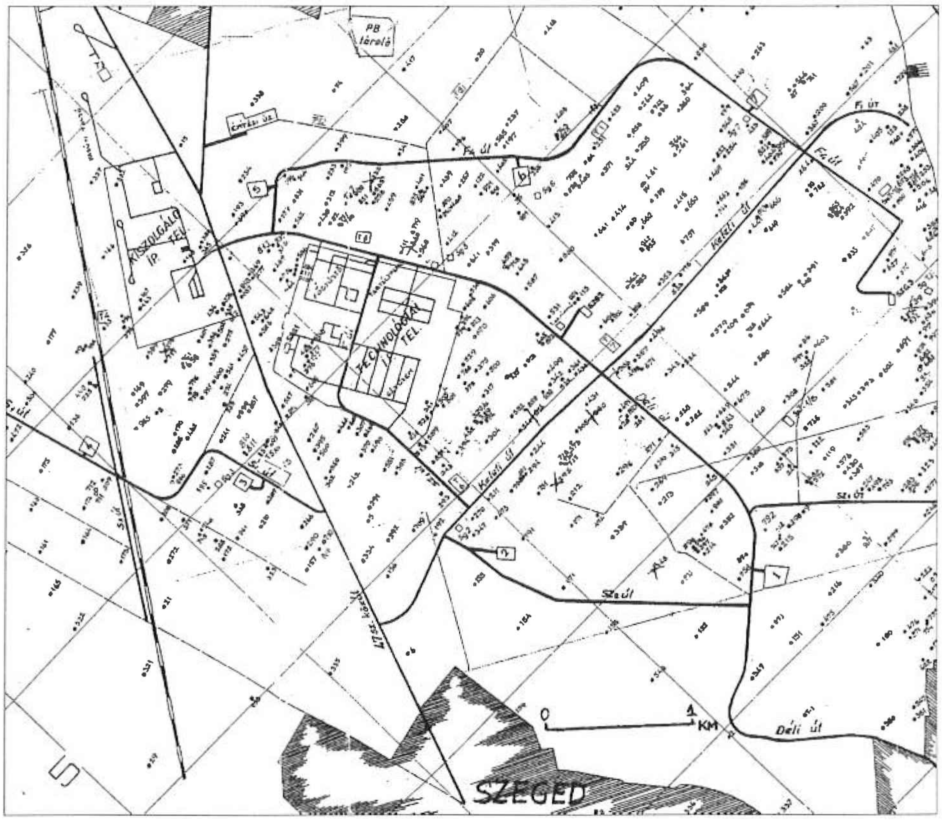

Figure 2 Map of Algyő Oil Field with the oil and gas wells depicted

The City of Szeged's Environmental Plan contains a section pertaining to the remediation of the contaminated regions associated with the near-well disposals. There is a formal agreement between the Hungarian Oil and Gas Company Ltd. and Hungarian Government regarding the location, characterization, and remediation of the disposal areas. The industrial waste disposals are primarily located in agricultural areas and according to previous analysis the heavy metal contents of cultivated plants are much higher than regulatory levels. Due to the geological and hydro-geological conditions of the region, the aquifers are particularly threatened by contamination. The hydro-geological conditions facilitate contaminant transport to the Tisza river (*Fig. 3-4.*).

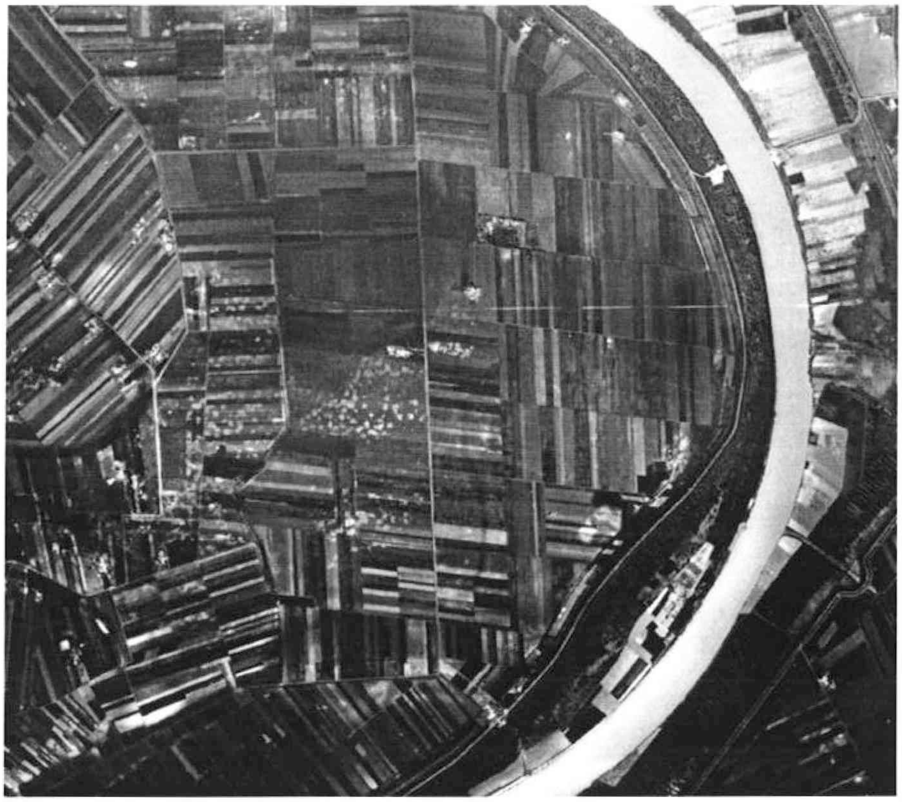

Figure 3 Cultivated area was on the current oil field in 1950 (BW aerial photography – Database of Ministry of Defense)

The goal of the research programme is to identify, locate, and map the positions of the near-well disposals, and to subsequently assess the effects of selected representative (4-5) contaminants by complex analytical methods (remote sensing, geo- and hydro-chemical analysis, GIS based environmental modelling, etc.). These analytical tools and modelling results will then be deployed as a continuous monitoring system covering the entire oil field.

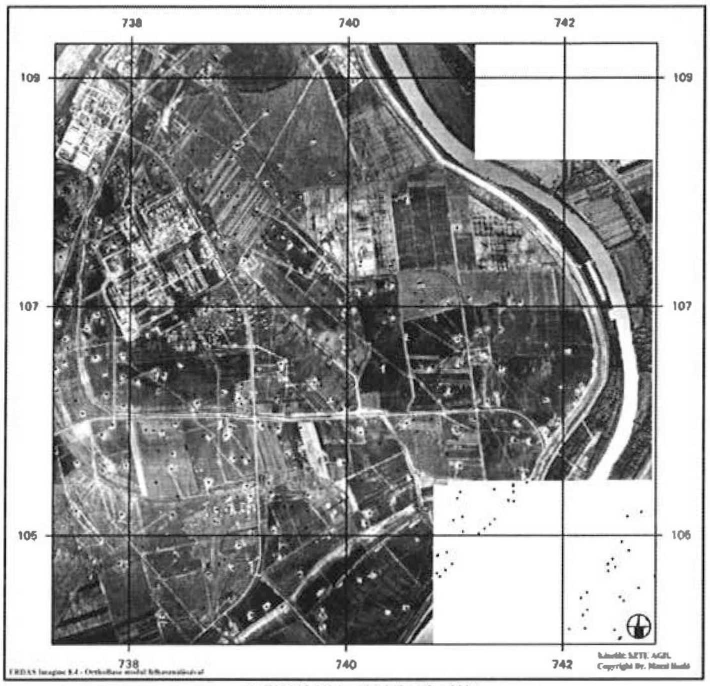

Figure 4 Aerial photography of part of oil- and gas field in Algyő. Ortophotography from BW airphotos (database of FÖMI) developed in the Applied Geoinformatics Laboratory, Univ. Of Szeged

Expected results

1. Contaminant map of study area

The use of aerial remote sensing methods coupled with field data acquisition will allow us to identify contaminated areas in a time- and cost-effective manner. Hyper spectral remote sensing instruments can provide detailed information about the complete spectral reflectance of objects on the earth. A key goal of this project is to determine how to best analyse these data to help researchers differentiate between contaminated and non-contaminated soils and vegetation. The hyperspectral field spectroradiometers and airborne imaging sensors deployed in this research will provide information on the nature and extent of the contamination. This will greatly facilitate and expedite the site characterization.

2. Groundwater and contaminant transport modelling

Depending on the level of funding, between 30 and 50 monitoring wells will be placed in and around the study area. Soil samples will be obtained based on a comprehensive sampling plan. The soil samples will be analyzed using both physical and chemical analytical methods. The testing will be conducted by the Department of Physical Geography. They will measure the contaminant concentration by atomic absorption photometric methods. A detailed soil and surface geological map will be developed based upon these data by the Hungarian Geological Survey.

The contaminant transport modelling will be performed using data from the continuous groundwater monitoring stations set up in the wells. An existing GPS with 1 cm geodetic accuracy will be using for all field data acquisition. The combination of groundwater levels and chemical sampling data will be fed into a contaminant transport model and output into ESRI's ARC/Info GIS software. This will provide information on the concentration and migration of contaminants (i.e. heavy metals) in the groundwater.

In the frame a scientific research programme supported by OTKA (Hungarian Scientific Research Fund) – no. 035121.- 15-20 groundwater monitoring wells can be extended. on Algyő oil field in 2001. The positions of the wells are determined by geologigal and geostatistical methods based on former database of groundwater network located on tankstations of MOL.

3. Remote sensing database

Spectral reflectance will be measured by using a field spectroradiometer (multi-channel – up to 150 channels, 1-2 nm wavelength) in natural field conditions. The data will be further analyzed in the laboratory for radiometric and geometric calibration. The results of these field data studies will be the basis for the analysis of hyperspectral image data provided by aerial imaging spectroradiometers. The changes in spectral reflectance of the vegetation and soil will be measured under different conditions to delineate and characterize the extent of contamination. The results of this process and the spectroradiogram libraries for different pollutants will be published on the Internet, so that other researchers may benefit from our work.

4. Thermal mapping for continuous monitoring

Thermal mapping will require additional equipment due to the fact that a different portion of the spectrum is being measured. The difference between the emittance of natural and contaminated / disturbed soils can be measured by thermal imaging radiometers. In addition to the contamination of the near-well disposals, the other significant source of contamination is the old pipeline system connecting the wells and stations. The pipeline contains various fluids (water, natural oil, etc.) which are under high pressure and temperature, therefore the thermal effect of the outflowing material can be measured prior to the pollutants reaching the surface and causing changes in the spectral characteristics of the soil and vegetation. In a sense, thermal mapping may provide an „early warning" system for the future monitoring of the field.

On the frame of a research programme supported by Ministry of Education (contract no. 00018/2000), an environmental monitoring system and decision making method will be developed based on thermal images and former aerial photographies. The Department of Physical Geography (coordinator László Mucsi associate professor), A.A. Stádium Kft. (repersented by Gábor Dabis engineer) and ERMI Bt. (represented by Mihály Dzsupin) are in the consortium. The 18 months long research program will be finished in 2002.

Figure 5 Aerial photography of underground pipelines on the oilfield. On the bottom right corner basement of an oil well can be seen.

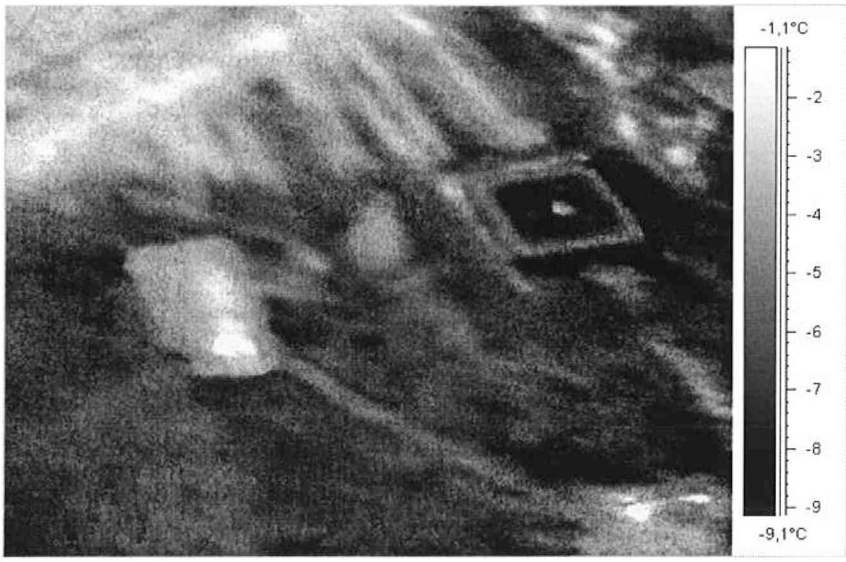

Figure 6 Thermal camera image of an oil- and a thermal water well acquired on February, 2000.

Science and Technology involved

Due to the complex nature of this project, it is essential to utilise interdisciplinary methods and state-of-the-art instruments for the research. The primary focus of the research project is the use of thermal and hyperspectral remote sensing to delineate surface contamination.

Satellite and airborne remote sensing technology has been used to effectively monitor the dynamic changes and disruptions in the environment for over 25 years. Synoptic viewing and short-cycled revisit capabilities of the current satellite sensors allow for effective monitoring and mapping of dynamic changes in the environment. More recently, the miniturization of these technologies has allowed the propagation of field based remote sensing technologies (i.e. portable spectroradiometers). The recent advent of advanced mapping technologies, i.e., Geographic Information Systems (GIS) and the Global Positioning System (GPS), has greatly facilitated the use of remotely sensed data for environmental monitoring. While remote sensing provides an expedited means of GIS data acquisition, GIS and GPS provide increased accuracy and utility of information which is extracted from the analysis of remotely sensed data. These technologies significantly enhance the accuracy and timelines of monitoring and managing the environment and associated natural resources.

Methodology

Remote sensing technologies measure the reflectance and/or emittance of energy from the earth's surfaces. Each material possesses a characteristic spectral signature based upon how much incident energy is absorbed, transmitted, reflected and emitted. In certain wavelengths, uncontaminated soil and vegetation possess distinctly different spectral signatures from their contaminated counterparts. Hyperspectral sensors split the spectrum into extremely narrow bandwidths thus providing detailed information on the nature and state of the surface in question. Data acquired at a high spatial resolution allows the discrimination of relatively small surface objects (i.e. individual plants). The analysis of hyperspectral data should be able to clearly identify those surfaces (soils, vegetation, etc.) which are contaminated with select contaminants (i.e. petroleum, heavy metals, etc.).

Based upon this methodology, the analyses should clearly distinguish the contaminated portions of our test sites. This project will serve as a pilot study to provide a proving ground for this methodology. Based upon the project results, this methodology can be applied to much larger regions. This would be an extremely time and cost effective method of site characterization.

The measurement of the spectral characteristics will be analyzed in four different areas.

1. The soil and groundwater samples will be analysed continuously by utilizing the Atomic Absorption Spectrophotometers of the Department of Physical Geography. This method of analysis will provide measurements of the quantity of accumulated and migrated heavy metals. This will allow the determination of areal impact of the mud-deposits situated near the wells. The existing ground water well-system will be extended by 5-6 m. The ground-water level will be continuously measured and the samples will subsequently be

analysed every second week. This will result in approximately 2000 laboratory analyses over the three year life of the project.

2. Field spectroradiometer AVS-2000 (financed by OTKA) will be used to measure ground spectral reflectance. The use of these multiband instruments will allow us to detect the reflectance of 2,5 nm wavelength regions characteristic of reflectance of the study area's surface (200-1100 nm). The reflectance of soils found in the surrounding area of test waste disposals will be measured *in situ* and in the Laboratory of the Department of Physical Geography. This will establish the background levels. The data will be correlated with the results of the soil chemical analysis. Prior studies have clearly demonstrated that this method can identify and delineate contaminated soils and vegetation.

3. Hyperspectal imaging is not a common method for site characterization due to the high capital costs of the equipment. The large extent of the oil field (6*4 km^2), however, makes it necessary to apply areal remote sensing techniques. There are several government and research agencies who possess the necessary equipment, hence we included such agencies as project partners. The data acquisition is approximately the same cost as standard multi-spectral data. We are planning only two measurement campaigns, at the beginning and at the end of the program, to demonstrate the applicability of this technology. With the current imaging systems we can acheive 3-5 m geometric resolution while spectral imaging provides 1-12 nm resolution.

4. The wells within the oil field and pumping stations are linked by high temperature/pressure pipelines containing hydrocarbons. The pipeline is in poor condition and has developed numerous ruptures resulting in the contamination of several 100 m^3 of soil. The cost of remediating these areas would be in the range of tens of million of forints. The Hungarian Oil Company regularly monitors the pipeline system via the acquisition of aerial video. Unfortunately, this method does not provide reliable results. Therefore, we propose to expand the monitoring to include thermal analysis of the near-well disposals of the pipeline system. This would allow us to accurately monitor the surface temperature with an areal thermoradiometer. These sensors are able to detect 0.1C degree differences in temperature. This would allow the immediate identification of any pipeline ruptures. This would also be able to detect the detioration of wall thickness in surface pipelines.

The development of hyperspectral spectroradiometry includes the development of new sensors, the establishment of calibration systems, and the investigation of the spectral characteristics of soil and vegetation in Europe. Both field and laboratory based radiometric measurements have been used to investigate the potential applications of this technology. An ASD FieldSpec detector was used to measure the spectral reflectance of various contaminated targets in wavelengths ranging from 0,4-2,5 µm in the EGO (European Gonimeter) project. In the IRSA (Institute for Remote Sensing Application), a GER IRIS spectroradiometer was used to measure petroleum contamination in soils. The results of the above-mentioned studies, clearly demonstrated that petroleum contamination of soils can be detected by hyperspectral image processing, particularly in wavelengths surrounding 1.7 µm. There are existing airborne sensors which measure spectral reflectance in this wavelength (DAIS, AVIRIS, MIVIS, etc.). Sensors which measure narrow bandwidths within the reflected infrared spectrum are able to discern between healthy and stressed vegetation. Results from previous applications using the MIVIS sensor were able to detect both petroleum and heavy metals contamination in bare soils and grasslands.

In 1996 the measurements were conducted within the framework of an EGO project under different conditions, which were similar to the parameters of Multi-angle Imaging

Spectrometer (MISR). The MISR will be launched on the American EOS (Earth Observation Satellite) in 1998.

How will the results contribute to the solutions of industrial, environmental or security-related problems?

The expected results of the proposed Research Project will be used to develop a greatly improved method of site characterisation and monitoring. The resulting methodology will allow expedited and cost effective regional characterisation and monitoring. The resulting technology will be useful for: detection and assessment of industrial contamination, detection of former military and industrial operations, determination of impacts from industrialisation and urbanisation, and potentially the location of hazards such as land mines. The immediate contribution will be the characterisation necessary to assess and remediate the largest oil field in Hungary. The project will not only characterise known contaminated areas, but will serve to detect unknown contaminated areas (soil, vegetation, and groundwater) within the study area. The use of remote thermal sensors will allow the detection of leaking pipelines and storage units. This early detection could prevent further contamination due to the unchecked outflow of undetected contaminants into the surrounding media. The project results will include maps depicting the locations and contamination extent of the near-well disposals and detailed GIS based modelling results depicting the above and below surface contaminant transport. The Hungarian Oil and Gas Company Ltd. will use these data sets to develop the most efficient and effective remediation strategy for the contaminated regions. The Hungarian Oil and Gas Company Ltd will finance the site remediation.

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