Soil Information Requirements for Humanitarian Demining: The Case for a Soil Properties Database

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ABSTRACT

Landmines are buried typically in the top 30 cm of soil. A number of physical, chemical and electromagnetic properties of this near-surface layer of ground will potentially affect the wide range of technologies under development worldwide for landmine detection and neutralization. Although standard soil survey information, as related to conventional soil classification, is directed toward agricultural and environmental applications, little or no information seems to exist in a form that is directly useful to humanitarian demining and the related R&D community. Thus, there is a general need for an information database devoted specifically to relevant soil properties, their geographic distribution and climate-driven variability.

A brief description of the various detection technologies is used to introduce the full range of related soil properties. Following a general description of the need to establish a comprehensive soil property database, the discussion is then narrowed to soil properties affecting electromagnetic induction metal detectors - a problem of much restricted scope but of immediate and direct relevance to humanitarian demining. In particular, the complex magnetic susceptibility and, to a lesser degree, electrical conductivity of the host soil influence the performance of these widely used tools, and in the extreme instance, can render detectors unusable. A database comprising these properties for soils of landmine-affected countries would assist in predicting local detector performance, planning demining operations, designing and developing improved detectors and establishing realistic and representative test-evaluation facilities. The status of efforts made towards developing a database involving soil electromagnetic properties is reported.

Keywords: landmine detection, humanitarian demining, soil electromagnetic properties, world soil database, soil magnetic susceptibility, soil electrical conductivity

1. INTRODUCTION

Human suffering caused by antipersonnel (AP) landmines left over from previous conflicts has received considerable public exposure in the past few years. By some accounts [1], the problem of landmines and other unexploded ordnance (UXO) affects some 90 countries spanning Africa, the Americas, the Asia-Pacific, Europe and Central Asia, and the Middle East and North Africa. Although estimates of the severity of the problem vary, there are many publications that describe this global problem. The nature, the extent and the impact of this problem can be found in the Landmine Monitor [1], which provides a particularly extensive discussion.

In this paper we will be concerned with only a small but crucially important aspect of the landmine problem, namely, their detection and the effect of soil properties on present and proposed detection technologies. We will

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first describe the nature of the problem in general terms in order to underline the difficulty in detecting landmines. A brief description of the various detection technologies is then used to introduce the full range of related soil properties. Following a general description of the need to establish a comprehensive soil property database, the discussion is narrowed to soil properties affecting electromagnetic induction metal detectors - a problem of much restricted scope but of immediate and direct relevance to humanitarian demining. A knowledge of these soil properties in diverse landmine-affected areas will thus be of significant importance to landmine detection efforts both in the development, testing and selection of equipment as well as in predicting their performance in a given region.

2. LANDMINE DETECTION PROBLEM

Although research on how to detect and deal with buried landmines was initiated before the Second World War, the search for solutions still continues.

Landmine detection is part of a more general problem, namely, the detection and neutralization of buried unexploded munitions, which also includes the detection of unexploded ordnance (UXO). UXO items include artillery shells, bullets, mortars, bombs and other such ammunition, and are relatively large metallic objects usually made of steel. Landmines are of two broad types: larger antitank (AT) landmines and smaller AP landmines, both of which can have nonmetallic (wood or plastic) or metallic cases. AT landmines, which are designed to damage tanks and vehicles, can be up to 35 cm in diameter and may contain several kilograms of explosives. AP landmines are meant to injure people and are small, containing from a few to several hundred grams of explosives. The common explosive fill in landmines is TNT, but RDX and other compounds are used as well. There are hundreds of varieties of landmines. Whereas UXO could be buried as deep as 10 m, landmines are usually buried in the first 30 cm of soil.

Although countries with landmine problems usually have significant UXO problems, most current UXO detection activities are aimed at clearing domestic land previously used as military training ranges. Landmine problems comprise two distinct scenarios: (1) peacekeeping and countermine, which involve dealing with landmines in a military environment; and (2) humanitarian demining, which deals with clearing land for civilian use. Despite some common characteristics, the three problems (UXO clearance, countermine and humanitarian demining) have many differences and warrant different approaches to their solution.

The reason that the search for solutions to landmine detection still continues is due to the very complex nature of the problem and the high degree of effectiveness required. Typically, very poor or no records are kept of where landmines were buried; this is particularly true in the case of humanitarian landmine problems where the conflict has been nonconventional warfare. Since landmines are designed to maim or kill, extreme care is needed in interacting with them, which makes invasive detection techniques difficult and demands near 100% accuracy in detection. Landmines, even those laid on the surface, can easily blend into the background vegetation. The problem is further exacerbated by the fact that the soil is a very complex medium. The contrast between properties of a landmine and those of the soil are often very low, particularly for so-called “plastic” landmines (mines with very small amounts of metal). The soil is lossy to many probing energy forms and it is inhomogeneous on the scale required for landmine detection. Added to these is the presence of vegetation and other natural and man made clutter which can produce many false targets.

3. LANDMINE DETECTION TECHNOLOGIES

This section gives a brief background of technologies which have been considered for landmine detection. Landmine detection techniques can be divided into two general categories: (1) techniques to detect the casing (certain physical properties of its explosive content may also have some influence) and (2) techniques for direct detection of the explosive contents. Techniques investigated to implement these two general approaches span almost the entire electromagnetic spectrum and a wide variety of other technologies. Detailed reviews of these technologies can be found in [2–6]. In the rest of this section, we will briefly describe the operating principles of the various detection technologies proposed to date indicating, where appropriate, the particular properties of the soil that may have an effect on their operation. A list of the technologies along with soil properties that could potentially affect their operation is given in Table 1.

3.1. Detection Technologies Which Do Not Detect Explosives

The first major group of landmine detection methods includes those that do not specifically detect explosives, but rather attempt to identify the munition based on properties of the entire landmine or portions of it, such as its casing. Frequently, this is equivalent to void/anomaly detection, that is, detection of the absence of or discontinuity in a soil property.

3.1.1. Magnetostatics and Electrostatics

In magnetostatic techniques which are also known as magnetic anomaly detection, the disturbance caused by ferrous objects in the earth's relatively uniform and static magnetic field are measured by magnetometers of various designs. Since the technique can only detect ferrous metal, it is not suitable as a landmine detection method because many landmines have only nonferrous or stainless steel parts. However it is very relevant for UXO detection. Magnetic properties of soil will affect the operation of this technique.

In analogy with magnetostatics, electrostatic techniques would measure the anomaly caused by objects in the ambient electrostatic field. Hence the technique should be able, in principle at least, to detect both metallic and nonmetallic objects. It is thought that this method would not be viable for this purpose because the ambient electrostatic field near the ground is expected to be very inhomogeneous. Because of this, there appears to have been very little research effort in this area.

3.1.2. Direct Current (DC) Conduction Methods

DC conduction methods (also called resistivity method or surveying) are active techniques and involve measuring an effective electrical impedance of the host medium, by injecting current into the medium and measuring surface potentials. Impedance tomography or conductivity imaging is an extension of the resistivity method where surface potentials, at points on a grid, corresponding to a number of current injection sites (analogous to the number of "views" in X-ray tomography) are measured. This ensemble of surface potential measurements are then used to solve the associated electromagnetic inverse problem to estimate the underlying impedance distribution (an image, in other words) which could have caused the measured potentials. Soil conductivity will influence the operation of this approach, which is still in an early research phase.

3.1.3. Electromagnetic Induction Techniques

Metal detectors, together with the mechanical prodder and the dog, are the only detection devices widely used in demining operations. Metal detectors use the principle of electromagnetic induction in which objects are detected by sensing the eddy currents induced in metal by an external time-varying magnetic field. It is known [7–11] that magnetic properties of the soil and, to a lesser extent, its electrical conductivity affect the operation of metal detectors. Characterisation and measurement of these properties and their effect on metal detectors will be discussed in a latter section.

3.1.4. Microwave Techniques

Active: One of the most extensively researched topics in the detection of buried landmines is the use of active microwave systems which are discussed in the literature under various names such as ground probing/penetrating radar (GPR), subsurface radar, ultrawide band radar and so on. Active systems of various designs (e.g., impulse, continuous wave (CW), frequency modulated continuous wave (FM-CW), step frequency, separated aperture or waveguide beyond cutoff, balanced bridge and so on) have been developed over more than three decades for the detection of buried landmines. Although these systems can detect buried antitank nonmetallic landmines under certain conditions and form a part of some multisensor military systems [12], the detection of antipersonnel landmines under realistic conditions continues to be one of the most difficult problems for this technology and no operationally satisfactory system exists. Soil inhomogeneity, low target contrast, uneven soil surface, vegetation and nuisance targets, such as rocks, are some of the basic problems. A number of multisensor handheld systems incorporating a GPR and a metal detector are currently under development.

Passive: Passive microwave, or microwave radiometric techniques, involve the measurement of natural blackbody radiation, in the microwave band, coming from an object or region of interest. In simple terms, detection of buried landmines with radiometric techniques relies on the assumption that the presence of a landmine causes a temperature anomaly at the surface of the host medium of uniform emissivity or that the soil disturbance causes an emissivity and/or temperature change. Reflection of sky radiation can also be used to detect surface laid landmines. However, because of their better success, convenience and lower cost, passive infrared techniques have almost completely superseded research in passive microwave for landmine detection.

Soil electromagnetic properties of relevance to both active and passive microwave techniques are permittivity, conductivity and, to a lesser degree, magnetic susceptibility. Permittivity and conductivity will depend strongly on soil moisture content. There has been extensive work on the characterization of soil properties as they relate to the performance of GPR in detecting buried objects. A review of soil electromagnetic properties and their impact on GPR performance can be found in [13]. As well, it should be noted that a GPR suitability map of the United States has been recently developed using existing information on soils [14]. Although this map may have only limited application in UXO detection activities in the United States and none in humanitarian demining, the process followed in developing the map would be very useful in any effort to develop similar maps for the landmine-affected countries of the world.

3.1.5. Optical Technologies

Since the penetration of optical wavelength electromagnetic radiation in opaque materials is less than 1 mm, the only optical techniques to consider are those which measure a soil surface property that is affected by the presence of the buried landmine.

Infrared (IR) Infrared detection or infrared radiometry relies on measuring the change, compared to undisturbed soil, in spectrum or intensity of infrared radiation emitted or reflected by the soil over a buried landmine. The change in radiation is usually quoted as an equivalent change in surface temperature. The cause of the radiation change is the alteration of the heat flow by the landmine and disturbed soil and the change in surface emissivity of the disturbed soil. Infrared imagers of sufficient temperature resolution ($\sim 0.1^{\circ}$C) and spatial resolution to detect the anomalies due to a landmine are commercially available and are used in some multisensor military systems [12]. Soil parameters relevant to the operation of IR systems include thermal resistivity, thermal diffusivity and specific heat capacity, all of which are expected to depend on soil moisture content. An excellent discussion of characterization of thermal properties of soil and the development of a database of these properties for Canadian soils can be found in [15].

Visible Wavelengths Visible wavelengths will measure surface optical properties, such as reflectance or polarization characteristics, of the disturbed ground above a landmine which may differ from the properties of undisturbed soil. In addition, vegetation growing above buried landmines may have different spectral characteristics than that growing above undisturbed soil. The signal due to thermal emission is negligible compared to reflection at these wavelengths.

Current research in detection using optical technologies is directed towards hyperspectral imagers which have many more and much narrower spectral bands than older multispectral imagers. It may be possible to use pattern recognition methods with such imagers to distinguish between disturbed/undisturbed soil and to detect vegetative changes. Research is in the early phases and no specific soil properties are considered for inclusion in the envisioned database.

Ultraviolet (UV) Measurement of UV reflection from the ground surface, using either solar radiation or artificial sources, will measure only surface properties of the ground. These properties may differ between disturbed soil over a landmine and undisturbed soil, but the effect should decrease with burial time. The magnitude of the difference and the rate of decrease of the effect is unknown. The signal due to thermal emission is negligible compared to reflection at these wavelengths. As for visible wavelengths, the research is in the early phases and no specific soil properties are considered for inclusion in the envisioned database.

3.1.6. Acoustics/Seismic

Active acoustic methods are based on injecting acoustic energy into the ground and then measuring reflections of acoustic energy caused by the difference between the acoustic impedance of the landmine and/or disturbed soil and that of the surrounding undisturbed soil. Current research efforts measure ground vibrations over a buried landmine as an approach to detecting it. Acoustic techniques have had mixed success to date.

Since acoustic impedance depends on mass density and bulk modulus, knowledge of these properties of soil will be relevant to acoustic techniques. These properties will also depend on soil moisture content. Although there is a need for characterisation and information on these properties of soils, to the authors' knowledge there has been little related work in this area.

3.2. Detection Technologies Which Detect Explosives

Explosives detection methods are classed as either bulk detection or trace detection methods. Bulk detection, which includes radio frequency resonance absorption (with the exception of microwave molecular absorption) and nuclear radiation methods, look for a property present in explosives which is not present in natural soil or vegetation. Explosives have a much higher percentage of nitrogen (10 to 40%) than soils ($< 0.1\%$). Also, the effective atomic number of explosives is between 5 and 7, which is similar to organic material, as compared to 11 to 12 for soil. However, typical mass density of soil (1.0 to 2.5 g/cm^3) and of explosives (1.6 to 1.8 g/cm^3) are similar. Trace detection involves identifying the specific explosives molecules themselves by sampling the air or soil in the vicinity of the landmine. This technology involves sensing particles emanating from the buried landmine and then separating the constituent molecules, atoms or ions for identification. A viable method must have sufficient sensitivity to explosives and sufficient selectivity to reject particles from naturally occurring materials.

3.2.1. Radio Frequency Resonance Absorption Spectroscopy

Radio frequency resonance absorption spectroscopy (RRAS) methods all involve selective absorption of energy from an electromagnetic field due to resonances formed by interactions between the electric or magnetic moments of nuclei or electrons of atoms and external or internal fields. There are four basic methods: nuclear magnetic resonance (NMR); nuclear quadrupole resonance (NQR); electron paramagnetic resonance (EPR); and microwave molecular absorption (MMA). Of these, the only one being seriously considered for landmine detection at present is NQR, which can uniquely identify a specific explosive. Since the NQR technique involves interaction, through soil, of bulk explosives in landmines with electromagnetic field in the hundreds of kHz to MHz range, soil properties having the most influence would be magnetic susceptibility, electrical conductivity and, to a lesser degree, electrical permittivity. Other attributes of soil that may affect the operation of NQR are the quantities of piezoelectric (e.g, quartz) and magnetostrictive materials present in soil.

3.2.2. Nuclear Radiation Methods

Since the 1940s, an enormous amount of research has been performed on nuclear detection of landmines. Nuclear techniques look at a return radiation characteristic of nitrogen or an intensity change of a noncharacteristic scattered radiation, which is a function of a parameter that differs between soil and explosives. Noncharacteristic radiation methods are essentially anomaly detectors, that is, they detect inhomogeneities in the medium and inclusions in addition to landmines. Examples of noncharacteristic radiation techniques are X-ray Backscatter and Neutron Moderation. Thermal Neutron Activation (TNA) is based on detecting γ-rays characteristic of ^{14}N. While X-ray Backscatter and Neutron Moderation techniques are at a research stage, a vehicle-mounted TNA device is already a part of a fielded military system [12].

Soil properties of relevance to X-ray Backscatter will include effective atomic number, weight, and mass density. Since Neutron Moderation detects landmines by detecting hydrogen content anomalies, a property of direct relevance will be the moisture content of soil. Because of the potential effect on the background signal and possible interference with the γ-line due to ^{14}N, contents of elements such as Fe, Ti, Cd, B, Gd, O, C, N, Si in soil are important for landmine detection by TNA.

3.2.3. Nonbiochemical

There are many nonbiochemical detection technologies that can be used to detect explosive vapours. These include mass spectrometry (MS), ion mobility spectrometry (IMS), laser/optical techniques, gas chromatography (GC), solid state detectors (resistive film, metal oxide field effect transistor or MOSFET), differential Raman spectroscopy and photothermal deflection spectroscopy. There are also combined detectors such as GC/MS, MS/MS and IMS/MS.

3.2.4. Biochemical Detection

Biochemical detection is a trace explosive detection method which uses chemical processes derived from biological systems. Biochemical detection can be divided into two general classes - *in vivo* and *in vitro*. Examples of *in vivo* detectors include animals, bioluminescent bacteria and plants.

The success of all trace element detection systems, biochemical as well as nonbiochemical, will depend on the amount of explosive available for detection at or near the soil surface over a landmine. The soil parameters needed to model the migration of explosives through the soil will be of interest. To the best of the authors' knowledge, such modelling is relatively new [16–18] and it is not possible to produce a definitive list of relevant soil parameters. However, such parameters will likely include factors related to porosity, moisture content, organic matter content, cation exchange capacity and so on.

3.3. Mechanical Detection Technologies

To date, mechanical systems for dealing with landmines usually have been machines to unearth and move the landmines (ploughs) or trigger and detonate them (flails and rollers). There appears to have been little work done on mechanical systems for landmine detection without moving or destroying the landmine. The current technology employed for the mechanical detection of buried landmines is limited to the use of a prodder, inserted manually into the ground at about 30 degrees. The operator virtually "feels" around with the prodder for buried objects. As such, the parameters that may indicate the ease with which a prodder could be inserted in a given soil will be relevant to the operation of the prodder. The standard prodder relies on the dexterity of the operator. With instrumentation, the prodder could make acoustic or electromagnetic measurements during insertion. The return signal would give information about the mechanical impedance of the material near (or in contact with) the tip, making discrimination between rock, wood, plastics and metal possible. Such a device has been under development with considerable success [19].

In addition to the parameters that may indicate the ease of inserting a prodder in a given soil, depending on the auxiliary sensors used, other parameters such as acoustic and electromagnetic properties of soil would be relevant to the operation of an instrumented prodder.

4. GENERAL REQUIREMENT FOR INFORMATION ON SOIL PROPERTIES

Landmines are buried typically in the top 30 cm of soil. From the foregoing discussion and Table 1 we have seen that various physical, chemical and electromagnetic properties of this top layer of ground will potentially affect landmine detection as well as other technologies devised to deal with landmines. Thus as much information as possible on these properties of soil would be beneficial to the development and operation of landmine detection technologies. To the best of the authors' knowledge, such information is not available. Although there is information related to conventional soil classification which addresses agricultural and environmental issues, such as the FAO-UNESCO soil map of the world [20], little or no information exists in a form directly relevant to landmine detection and other demining technologies. Thus, there is a general need for the development of an information database and maps of such soil properties. Such an information database will serve the following purposes:

1. It will help demining organizations select equipment and predict its performance in their particular environment.

2. It will help equipment developers and researchers assess the potential of their proposed technologies in various parts of the world.

Table 1. Landmine detection technologies and relevant soil properties. Many of the soil properties (e.g., permittivity, thermal and acoustic properties) will depend strongly on soil moisture content and their values may have to be specified at a number of selected moisture contents.

Detection Technology	**Main Relevant Soil Properties**
Magnetostatics	Magnetic susceptibility
Electrical Impedance Tomography	Electrical conductivity
Electromagnetic Induction	Magnetic susceptibility Electrical conductivity
Nuclear Quadrupole Resonance	Magnetic susceptibility Electrical conductivity Electrical permittivity Piezoelectric materials (e.g. quartz content) Magnetostrictive materials
Active and Passive Microwaves	Electrical permittivity Electrical conductivity Magnetic susceptibility
Infrared	Thermal resistivity Thermal diffusivity Specific heat capacity
Thermal Neutron Activation	Content of elements such as Fe, Ti, Cd, B, Gd, Si, O, C, N, H
X-ray Backscatter	Effective density Effective atomic number and weight
Neutron Moderation	H Content
Trace Explosives Detection	Porosity and moisture content Cation exchange capacity Other chemicals and parameters affecting absorption and adsorption of explosives
Acoustic/Seismic Techniques	Density and bulk modulus
Prodders	Hardness Acoustic and electromagnetic properties

3. It will help researchers develop test facilities that simulate realistic demining environments existing in different parts of the world.

We should note that a number of databases exist on the landmine targets themselves. The proposed database will complement this information.

Even if we consider only the landmine-affected countries, the task of obtaining information on all the properties discussed above would be almost impossible. With this in mind, we describe below a potential initiative of much reduced scope but of immediate and direct use to both humanitarian demining operations and the research community.

5. SOIL ELECTROMAGNETIC PROPERTIES DATABASE

In spite of the many technologies being researched and developed as previously discussed, the metal detector remains one of the most commonly used detection tools in humanitarian demining. The operation of the metal detector is based on the principle of electromagnetic induction. The signal produced in a detector by a metal object depends on many factors including the object's size, shape, orientation, material and parameters of the detector electronics. One of the other important factors that has an the effect on this signal is the host soil. As already mentioned, soil magnetic properties and, to a lesser degree, electrical conductivity influence this signal [7–11] and thus have an effect on the depth of detection of buried objects.

The adverse effects of some soils on metal detectors were known as early as the Second World War [10, 21]. But the user community seems to have forgotten this in the intervening period. Users are once again finding that certain soils (1) can reduce the sensitivity of detectors to an extent that they cannot detect targets to desired depths; (2) can cause false targets and (3) in extreme cases can render some detectors totally unusable. This so-called "Soil Problem" may be much more severe at the present time than during previous conflicts. This is because antipersonnel landmines, which contain a minimal amount of metal, are presently very common and are widely used. Although it is generally known that certain soils are a problem, there is much confusion in the user community and even in the research community about what causes the problem or how to characterize it. One often hears people use terms like "conducting soil", "lateritic soil", "red soil", "iron bearing soil", "mineralised soil" and so on to describe the problem. In an attempt to characterize the effect, investigators often carry out only a texture and chemical analysis of the soil, instead of measuring the electromagnetic properties.

Currently a large variety of metal detectors on the market are being aimed at the humanitarian demining community. The capability and performance of these detectors vary widely. Some of the better detectors (less than 5 in total) can adequately detect small landmine targets in "problem" soils. This is an area of detector performance which is currently of great importance and impacts heavily on the selection of new detectors by demining organizations and by the military. Manufacturers are competing to design detectors that can deal with "problem" soils in a better way.

Work in the following interrelated areas is needed to clarify and advance our understanding of the effect of soil properties on the functioning of metal detectors. This will generate, in the process, information on soil properties that would be of direct and immediate benefit in humanitarian demining.

1. **Scientific Research:** Rigorous scientific studies on how soil electromagnetic properties (magnetic properties in particular) affect the operation of metal detectors and how to mitigate the effect without sacrificing detector performance seem to be lacking. Most of the recent knowledge in this area appears to rest with detector manufacturers, only some of whom (e.g., [8]) have publicly divulged their findings. Results of related earlier work [10] are also not widely available. Although there has been some related work in geophysics [22] which may be useful in understanding metal detectors, the problem of soil appears to have been largely ignored by researchers in metal detection techniques until very recently [23]. Thus, there is a need for analytical and experimental research to clarify which electromagnetic properties are important and to what extent they affect the performance of metal detectors of various designs, employing continuous wave as well as pulse induction principles. Often the effect of soil is quantified by simply measuring the absolute value of its magnetic susceptibility at one or two frequencies along with its d.c. or low frequency conductivity. These measurements alone may not be adequate to predict the performance of metal detectors in all

cases. In general one would need to measure both the real and imaginary components of these constituent parameters over a suitable band of frequencies. Such measurements may need to be complemented by measurements in the time domain, for example, of magnetic viscosity effects.

2. **Instrument Development:** Only very limited number of suitable instruments are available to measure soil electromagnetic properties both in the field and in the laboratory. This is particularly the case for instruments to measure magnetic properties of soil. For example, there does not appear to be any commercial instrument that can measure the complex magnetic susceptibility of soil over a frequency band or any that can measure decay of soil magnetization. There is a need for developing new instruments, adapting existing instruments, and to develop measurement protocols to characterize the relevant soil properties both in the field and in the laboratory.

3. **Validation:** Using the results of research and instrument development described above, one would need to develop and validate a methodology to relate performance of detectors of various designs to measured values of suitable soil properties. This work should include putting a previously employed empirical but clever method [10, 11] on a more rigorous scientific base. In this method, which seems to have been independently discovered some 50 years apart, the effect of the soil is quantified by measuring the distance of the sensor head to the ground surface at which a chosen metal detector, which does not employ any soil compensation, produces a preselected level of response.

4. **Database:** Information on properties, as identified in the previous steps, of soils present in the landmine affected regions should be gathered and integrated into a database and/or soil maps. This information, in conjunction with the work described above, will help predict and compare detector performance in the types of soil to be expected worldwide. Organizations that plan demining operations, such as the United Nations and the demining organizations in the landmine-affected countries, could use this information in their planning and equipment selection. Manufacturers of detectors could also use such information in improving the performance of their detectors in various parts of the world. Organizations which are engaged in research, test and evaluation, would benefit from such data for developing detectors as well as for designing realistic tests and test soil lanes representative of conditions in different parts of the world. Although the information on soil electromagnetic properties would be of immediate benefit to the development, test and evaluation, and application of metal detectors, such information is also needed for other technologies being researched (Table 1).

As already indicated, a comprehensive database of properties of soils of the world would be beyond the resources likely to be available to the demining research community. In the following we present some issues, specific to the humanitarian demining problem, that may help reduce the magnitude of the task while still providing some useful data.

1. **Parameters:** The number of soil properties on which information is gathered will strongly influence the scope of the work. Since soil magnetic properties have the most dominant effect on metal detectors, the database could be initially restricted to magnetic susceptibility data only. This parameter is also expected to be relatively independent of soil moisture content and short term climatic variations, thus reducing the number of variables to take into account.

2. **Areas and Spatial Resolution:** Initially, information requirements could be restricted to those landmine-affected countries which are expected to have strongly magnetic soils. The amount of surface area to include can be reduced if a country can be divided into areas of "representative" soil types. The desired parameters of a number of these representative areas could then be characterized at an affordable spatial resolution. It may be possible to further reduce the number of areas to be surveyed by focusing on areas expected to have strongly magnetic soil. The degree of local spatial variation of magnetic susceptibility has an effect on the performance of a metal detector. Hence, at each survey site within the representative areas one should gather some high resolution (of the order of a few cm) data over a relatively small area (a few square meters). Such complementary high resolution data may provide an adequate idea of the expected spatial variation of magnetic susceptibility in a given country.

An alternative area reduction approach would be to concentrate only on the known and suspected mined areas of a country and characterize soils typical of those areas only. As well, initial work could consider only a very small number of countries as a pilot project.

The idea of representative soil areas may also be applicable in some cases across country boundaries. This would allow any available information on soils of one country to be used to deduce information about soils from another.

3. **Existing Resources:** It may be possible to draw upon the existing infrastructure and resources of the mine action centres in the various landmine-affected countries, to assist in the gathering of data. As well, national organizations responsible for geological and soil surveys in landmine-affected countries may be approached for assistance and any existing data. Soil scientists as well as other earth scientists may be able to point to existing data from which the sought information can be derived, thus reducing the need for data collection. There may be other on-going international initiatives, an example being the one described in [24], on which we could "piggyback" to obtain the required information with incremental effort. As well, it may be possible to add a soil properties component to the on-going Global Landmine Survey initiative currently being managed by the Survey Action Center[*].

6. STATUS

The work envisioned would involve enormous effort, technical expertise and international cooperation. Various organizations have expressed an interest in the project and to date, the following activities have been undertaken.

1. Some scientific organizations have been approached to make them aware of this unique requirement for information on soil properties. A presentation [25] on this proposed initiative was made to the Council of the International Union of Soil Science in an effort to solicit interest and co-operation from the international soil science community.

2. A pilot project is currently being planned under the auspices of the International Test and Evaluation Program (ITEP) to measure the electromagnetic properties of archived soil samples and produce a metal detector suitability map of Bosnia-Herzegovina (BiH). These soil samples were collected as a part of conventional soil surveys.

3. As a part of another international agreement, a model based on the concept of pedotransfer functions[†]is being developed at the University of Liverpool, UK, to predict electromagnetic properties of soil from a knowledge of conventional soil classification data, geological data, climatic data and so on. It is intended that this model and the measured data from BiH will complement each other. If a successful model is developed from these efforts, it can be used to predict electromagnetic properties of soils in other regions, possibly reducing the effort required for direct measurements.

4. Laboratory analysis [26] of soil samples from areas with "problem" soils has been conducted. Such analysis will help identify and understand mechanisms that contribute to the electromagnetic properties of soils and as such may help in the development of predictive models for such properties.

5. Magnetic susceptibility (absolute value only) of soils at a number of locations in some landmine-affected countries has been measured. Some sample values are given in Table 2 which shows the range of values obtained at the locations measured. It must be emphasized that these measurements of opportunity were taken at sporadic locations. Nonetheless, based on previous experience [9] which has shown that susceptibility values as low as 140×10^{-5} SI units can degrade the performance of many detectors, these measurements can give a general indication of the degree of interference to be expected from the magnetic soils in these countries. This emphasizes the need and utility of a database of such properties.

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[*] Information about the initiative can be found in http://www.icbl.org/lm/2001/appendices/sac.html

[†] This is a technique in Soil Science, where unknown soil properties are predicted from *a priori* knowledge of related factors such as soil type, geology and climate.

[‡] One sample only, location unknown

Table 2. Sample values of magnetic susceptibility measured at sporadic locations of opportunity in landmine affected countries.

Country	**Range of Values** (10^{-5} SI units)
Cambodia	150 - 3000
Yemen	150 - 2000
Ethiopia	20 - 1000
Mozambique	$150^{\ddagger}$
Colombia	20 -1100
Lebanon	50 - 300
Syria	700 - 2500

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