The significance of soil characterisation for metal detector and ground-penetrating radar tests for landmine detection

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Influences on the detectability of targets

- Probability of detection
  - Detection technique
  - Human factor
  - Target characteristics
  - Man-made clutter
  - Environmental conditions
    - Soil
    - Weather etc.
### Soil influence on sensors for landmine detection

<table>
<thead>
<tr>
<th>Metal Detector</th>
<th>Ground-Penetrating Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical parameters</td>
<td></td>
</tr>
<tr>
<td>- magnetic susceptibility $\kappa$</td>
<td>- dielectric constant (permittivity) $\varepsilon$</td>
</tr>
<tr>
<td>- frequency dependence of magnetic susceptibility</td>
<td>- electric conductivity $\sigma$</td>
</tr>
<tr>
<td>- electric conductivity $\sigma$</td>
<td></td>
</tr>
<tr>
<td>Soil parameters</td>
<td></td>
</tr>
<tr>
<td>- mineral compound</td>
<td>- soil moisture</td>
</tr>
<tr>
<td>- soil moisture</td>
<td>- soil texture etc.</td>
</tr>
<tr>
<td>- soil texture etc.</td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity of the parameters
Heterogeneity of a natural soil

Spatial variability of magnetic susceptibility on a site in Mozambique

magnetic susceptibility
- mean: 1648 SI*10^{-5}
- coefficient of variation: 14.4 %
- correlation length: 1.2 m
6 Test lanes and 4 different soil types with different textures

Lane 1.1: Laterite
Lane 1.2: Laterite
Lane 2.1: „Magnetite“/Sand
Lane 2.2: „Magnetite“/Sand
Lane 3.1: „Humus“ - low gravel content
Lane 3.2: „Humus“ - high stone content
Soil magnetic properties – Field measurements

1.3 Laterite

- Magnetic susceptibility:
  - Mean: 2977 SI*10^-5
  - Coefficient of variation: 8.4 %
  - Correlation length: 0.35 m

2.3 Magnetite

- Magnetic susceptibility:
  - Mean: 3324 SI*10^-5
  - Coefficient of variation: 7.4 %
  - Correlation length: -

3.3 Humus

- Magnetic susceptibility:
  - Mean: 18 SI*10^-5
  - Coefficient of variation: 38.9 %
  - Correlation length: 0.26 m
Soil magnetic properties – Frequency dependent susceptibility

1.3 Laterite

Frequency dependence = 290 SI*10^{-5} (6 %)

2.3 Magnetite

Frequency dependence = 7 SI*10^{-5} (0.1 %)

3.1 Humus

Frequency dependence = 5.3 SI*10^{-5} (7 %)

3.3 Humus

Frequency dependence = 1.3 SI*10^{-5} (1 %)
Frequency dependence of the electric conductivity

- **Humus 3.1** 0.5%
- **Humus 3.3** 5.7%
- **Laterite** 8.0%
- **Magnetite** 4.8%

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Electric Conductivity [S/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>0</td>
</tr>
<tr>
<td>0.01</td>
<td>0.004</td>
</tr>
<tr>
<td>0.1</td>
<td>0.008</td>
</tr>
<tr>
<td>1</td>
<td>0.012</td>
</tr>
<tr>
<td>10</td>
<td>0.016</td>
</tr>
<tr>
<td>100</td>
<td>0.016</td>
</tr>
<tr>
<td>1000</td>
<td>0.016</td>
</tr>
</tbody>
</table>

- Humus 3.1: 0.5%
- Humus 3.3: 5.7%
- Laterite: 8.0%
- Magnetite: 4.8%
GPR performance – measurement with GSSI equipment (1.5 GHz)

Magnetite

Laterite

Humus 3.4
Soil moisture distribution – Field measurements

1.3 Laterite

soil moisture
mean 25.6 %
coefficient of variation 12.8 %
correlation length 1.35 m

2.3 Magnetite

soil moisture
mean 7.5 %
coefficient of variation 6.9 %
correlation length -

3.3 Humus

soil moisture
mean 30.3 %
coefficient of variation 10.0 %
correlation length -
Modelling of GPR performance

Model

FD-Simulation
## Classification of soil properties

<table>
<thead>
<tr>
<th></th>
<th>Laterite (Lane 1.1-1.4)</th>
<th>Magnetite (Lane 2.1-2.4)</th>
<th>Humus (Lane 3.1)</th>
<th>Humus with high stone content (Lane 3.2-3.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa$</td>
<td>very high</td>
<td>very high</td>
<td>very low</td>
<td>very low</td>
</tr>
<tr>
<td>$\kappa(\omega)$</td>
<td>very high</td>
<td>very low</td>
<td>large</td>
<td>very small</td>
</tr>
<tr>
<td>$\varepsilon$, $\theta$</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>$\varepsilon(r)$</td>
<td>large</td>
<td>very small</td>
<td>large</td>
<td>very large</td>
</tr>
<tr>
<td>$\text{MD}$</td>
<td>very severe</td>
<td>moderate</td>
<td>neutral</td>
<td>neutral</td>
</tr>
<tr>
<td>$\text{GPR}$</td>
<td>moderate/severe</td>
<td>neutral</td>
<td>moderate</td>
<td>very severe</td>
</tr>
</tbody>
</table>

$\kappa$ : Magnetic susceptibility  
$\kappa(\omega)$ : Frequency dependence of magnetic susceptibility  
$\varepsilon$, $\theta$ : Permittivity (dielectric constant), water content  
$\varepsilon(r)$ : spatial variation of permittivity
Relation of soil classification and discrimination performance (GPR)

<table>
<thead>
<tr>
<th></th>
<th>Laterite</th>
<th>Magnetite</th>
<th>Humus Lane 3.1</th>
<th>Humus Lane 3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAR reduction</td>
<td>60 %</td>
<td>56 %</td>
<td>61 %</td>
<td>56 %</td>
</tr>
<tr>
<td>POD loss</td>
<td>6.6 %</td>
<td>2.5 %</td>
<td>7.8 %</td>
<td>11.2 %</td>
</tr>
</tbody>
</table>

**Difficult soil:**
- Higher POD loss

**Easy soil:**
- Lower POD loss
Conclusions

- Soil properties can have a considerable influence on detection performance.
- Different soils with different textures and electromagnetic properties determine different detection results.
- Main soil parameters are easy to measure.
- Soil characterisation is useful for comparison of test results from various regions.
- Knowledge on soil characteristics can be used for the choice of proper detection technique for demining activities.
- Conclusions hold for metal detectors and GPR technique as well.