ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF WATER, SOIL AND WASTE
Detailed-Scale Mapping of Soil Moisture and Landslide-Proneness Using Spaceborne Sensors

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Introduction

- Remote sensing is a major source of data which can be used for soil studies such as:
  - Soil erosion
  - Soil moisture
  - Mass movements
1. Soil Moisture
Soil Moisture

- Soil moisture is the water that is held in the spaces between soil particles.
- Surface soil moisture is the water that is in the upper 10 cm of soil.
- Root-zone soil-moisture is the water that is available to plants, which is generally considered to be in the upper 200 cm of soil.
Why Soil Moisture?

• Estimating soil properties, including soil moisture, is important for many water-budgeting processes, and for meteorological and agricultural applications (Verhoest et al., 2008).

• Soil-moisture information can also be used as an indicator for the prediction of natural disasters, such as flooding and droughts, and for environment changing, such as dust storms and erosions (Nied et al., 2012).

• However, measuring accurate in situ soil moisture is too expensive because it requires a repeated sampling process to analyze the periodical changes in soil moisture. Moreover, the sampling itself may introduce problems, making the sampled data unreliable (Lakhankar et al., 2006).

• The emitted electromagnetic radiation (in the passive remote sensing case) or the reflected microwave radiation (in the active remote sensing case) from the soil surface to the sensor represents the only measurement for studying the soil properties remotely (Nichols et al., 2010).
Agricultural Production is becoming increasingly important as the world demand increases. By 2050, world population ~> 9 billion (*)

70% increase in global food production is required (*)

- Climate Change (temperature, rainfall)
- Water Scarcity
- Land Degradation (25% of the earth’s lands)

• Irrigation Management
• Crop Yield Prediction,
• Subsidy Control
• Flood, Hydrology

Challenge of providing sufficient food
Improving irrigation management & water-use efficiency

- Natural resource bottlenecks are increasingly felt
- Competition for land and water

Texture Analysis
Classification
SM Mapping

Land Cover Map
Soil Moisture Map

Synthetic Aperture Radar (SAR) data (spatial, temporal-resolution)
Field-Boundary Maps (due to the advantages in GI-Science)

The Role of Remote Sensing in Soil Moisture Mapping

- Thermal infrared techniques
- Microwave
  - Active
  - Passive
- Optical (visible/near infrared)
The Role of Remote Sensing in Soil Moisture Mapping

- Microwave measurement strongly dependent on dielectric properties of soil water
- Basis for microwave remote sensing of soil moisture is contrast in dielectric constant of water (80) and dry soil (<5), causing emissivity contrast of 0.4 for water and 0.95 for dry land (Schmugge et al., 2002)
- Research concludes surface layer smooth can be determined to about ¼ wavelength, i.e. 0-5 cm layer using microwave $\lambda = 21$ cm.
- Longer $\lambda$ better for increased depth, less noise
Soil-Moisture Mapping using TerraSAR-X Data

- Land Cover Map
- Measured SMv
- TSX Data

- Speckle Filtering
- Backscattering Coefficient
- SNR / ENL
- Conv. 3x3

- Regression Analysis
- User Selection

- Regression Equation
- Soil Moisture Extraction

- Soil Moisture Map
- Backscattering Coefficient
- Speckle Filtering
- Visual Evaluation
### Extraction of Soil Moisture

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Date</th>
<th>Regression equations of bare fields</th>
<th>( R^2 )</th>
<th>Regression equations of vegetated fields</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSX</td>
<td>31.05.2010</td>
<td>( m_v = 1.68 \sigma^\circ + 32.47 )</td>
<td>0.82</td>
<td>( m_v = 1.46 \sigma^\circ + 58.59 )</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>17.06.2010</td>
<td>( m_v = 2.87 \sigma^\circ + 50.17 )</td>
<td>0.88</td>
<td>( m_v = 1.07 \sigma^\circ + 30.85 )</td>
<td>0.56</td>
</tr>
<tr>
<td>ALOS PALSAR</td>
<td>31.05.2010</td>
<td>( m_v = 1.41 \sigma^\circ + 37.48 )</td>
<td>0.91</td>
<td>( m_v = 5.22 \sigma^\circ + 121.58 )</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Correlation between the In-situ Soil Moisture and Backscattering Coefficient
Production of Soil Moisture Map

Merged Soil Moisture Map Extracted from TSX Image Acquired on 31.05.2010

Mean Values of Soil Moisture Extracted From TSX Image Acquired on 31.05.2010 of Gottleuba Sub-basins
Soil Moisture Map (on plot-basis)

Extracted volumetric soil-moisture using a subset of the TSX image acquired on 18/04/2011

Average of volumetric soil-moisture at the plot level
Study Site

- 2 soil profiles were dug in each of the selected LULC type
- Profiles were described according to: USDA, 1998 & FAO, 2006
- 21 soil samples were taken to be analysed
Field Measurements of the Soil Moisture

- TDR was applied to measure the volumetric soil moisture for both bare and vegetated fields.

- Eight to twelve measurements were taken at each tested field location at 0 – 5 cm soil depth and subsequently averaged.

- Soil samples were collected from the fields to validate the TDR measurements.

- The laboratory results of the TDR validation samples show that the RMSE is 0.98 which indicates highly precise TDR measurements.
Distribution of the Measured Soil Samples
Integration of Local Population

**Important**: group discussions and individual interviews with local population

Interviewees: e.g. 10 key informants + 41 farmers
2. Mass Movements
Application of Remote Sensing for Mass Movement Applications

- Radar interferometry
Application of Remote Sensing for Mass Movement Applications

- Radar interferometry
- Air photos / satellite imagery
Models: Landslide Susceptibility Assessment

1. Mountainous area
   Hilly area

2. Deforestation

3. Heavy rainfall
   Prolonged rain

Damage to infrastructures
Loss of lives and houses
Models: Landslide susceptibility assessment

- **Extracted factors**
  - Slope
  - Aspect
  - River
  - Soil
  - Lithology
  - Landuse

- **Quantitative prediction models**
  1. Fuzzy
  2. Frequency ratio
  3. Logistic regression
  4. Neural Network
  5. WoE
  6. Neuro-Fuzzy

- **GIS analysis**

Pixel to pixel
Case Study

- Penang Island
Landslide Identification

05/01/2005

19/04/2005

17/04/2006
• Preparation and digitization of landslide inventory
  – Field data
  – Reports
  – Satellite images
  – HRS (Ikonos, Quickbird)
Susceptibility Analysis

- LANDUSE
  - SPOT
    - TOPO MAP (1:25,000)
      - LINEAMENT
        - LITHOLOGY
          - NDVI
            - SOIL MAP
              - SOIL
                - LANDSLIDE INVENTORY
                  - PRECIPITATION MAP (MMD)
                    - SOCIO ECONOMIC
                      - LANDUSE ANALYSIS
                        - UPDATED LANDUSE
                          - SUSCEPTIBILITY ANALYSIS (FUZZY LOGIC MODEL)
                            - LANDSLIDE SUSCEPTIBILITY MAP
                              - EXTREME SUSCEPTIBLE CLASS
                                - RISK ANALYSIS MODEL
                                  - LANDSLIDE RISK MAP
                                    - SLOPE LENGTH
                                      - FLOW ACCUMULATION
                                        - CATCHMENT BASIN
                                          - SURFACE AREA
Thank you for your attention!

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