Remote Sensing of Illegal Black Sand Mining in the Philippines

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CEGA Behavioral Sensing Challenge 2014
What is black sand?

- Black sand, or magnetite, is a type of iron ore.
- Often used in steel production.
- High demand in rapidly developing countries, such as China.
- Naturally occurs in riverbeds and on beaches in the Philippines.

source: indexmundi.com
Black Sand Mining

Black sand extraction:
• Offshore – ships that siphon sand from ocean floor.
• Onshore – “quarrying,” or digging up sand and loading onto trucks.
• River – “dredging,” siphon sand from river bed.
• Sand is processed on ships or at processing plants on land.
Black Sand Mining

Effect on local livelihoods:
• Erosion; communities on the coast.
• Disturbs local marine ecosystem; threat to fisheries.
• Allows saltwater to penetrate water table; freshwater less suitable for drinking and agriculture.
Black Sand Mining

Increased vulnerability to natural disasters:

- Land subsidence and erosion → flooding
- Climate change → more extreme weather
Black Sand Mining

**Illegality:**
- Philippine Mining Act 1995: illegal to mine within 200 m of coastline.
- Since 2006, illegal black sand mining has been on the rise in Luzon.
- Local politicians receive bribes from foreign mining firms.
- Incumbent politicians then use these rents to bribe citizens for votes.
Black Sand Mining

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• Incumbent politicians then use these rents to bribe citizens for votes.

Information based on interviews conducted in each province, September 2014

<table>
<thead>
<tr>
<th>Province</th>
<th>Number of Bgy with mining</th>
<th>Before 2007</th>
<th>2007-2010</th>
<th>2010-2013</th>
<th>2013-present</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cagayan</td>
<td>1</td>
<td>1</td>
<td>27</td>
<td>18</td>
<td></td>
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<tr>
<td>Ilocos Norte</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Ilocos Sur</td>
<td>6</td>
<td>17</td>
<td>13</td>
<td>4</td>
<td></td>
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<tr>
<td>La Union</td>
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<tr>
<td>Pangasinan</td>
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<tr>
<td>Zambales</td>
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<td></td>
<td></td>
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<td>1-2*</td>
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</table>
Project Aims

Explore potential for using remote sensing to measure the scope of illegal black sand mining and its environmental impacts in the Philippines.

1/ Use Landsat/Google Earth optical images to identify mining sites.
2/ Use ALOS InSAR to identify land subsidence.
3/ Combining subsidence rate and elevation, evaluate the time to permanent flooding.
4/ Verify sites and mining methodologies, and collect local election results.
Data and Method

Optical (Visible/IR) satellite imagery
-> “reflectivity map”: how well different colors of light are reflected: depends on the property of the surface (wavelength absorbed)

Data: Landsat (30 – 60 m) & freely available (Google Earth)

RADAR (microwave) satellite imagery
-> how well radio waves reflect and scatter, determine the range.
Advantages: day & night, not affected by clouds, penetrates trees

InSAR
Measure the phase difference of two radar images of the same area acquired at different times

Data: ALOS 2007-2011 globally observing satellite & L-Band: signal unaffected by vegetation

C-Band interferogram $\lambda = 5.8$ cm
L-Band interferogram $\lambda = 23$ cm
Data and Method

InSAR Time Series

- Inversion of many interferograms to extract the displacement through time
-> Averaged velocity maps, remove atmospheric noise, identify small amplitude deformation

Why InSAR time series for detection of mining related subsidence?
- Remote sensing: no ground access
- High precision and high spatial coverage:
  InSAR can resolve deformation at the size of a pixel (10 m) but also covers hundred of km²
- Can resolve deformation as small as 1 cm/yr

How to separate mining from natural subsidence in InSAR TS?
- Each process causing subsidence result in deformation with characteristic rates & extent
  (natural: large scale & slow/ mining: local & fast)
Identification of mining sites with satellite optical images

Identification of 19 illegal black sand mining sites.
Identification of mining sites with satellite optical images
2/ InSAR for land subsidence identification

- Processing of 14 ALOS frames with each 9-25 acquisitions
- 40 to 250 interferograms per track

- ALOS data
- Mining sites from optical images
2/ InSAR for land subsidence identification
2/ InSAR for land subsidence identification
2/ InSAR for land subsidence identification

![Map with InSAR velocity and mining sites marked]

- Red diamonds: Mining sites from InSAR
- Light blue diamonds: Mining sites from optical images
2/ InSAR for land subsidence identification

- Mining sites from InSAR
- Mining sites from optical images
Zoom on south Area

- 1.2 cm/yr
- 1.3 cm/yr
- 2.6 cm/yr
- 3.5 cm/yr
Zoom on center Area

- 3.9 cm/yr
- No subsidence
- 4.3 cm/yr
- 4.6 cm/yr

Ascending LOS velocity (cm/yr)
Summary

- Optical images enable identification of some illegal mining sites.
- 7 mining sites have no coherence in InSAR images – biggest limitation of InSAR (too much change in properties – too recent development? too much subsidence?)
- 5 sites show no subsidence: subsidence likely depends on the amount of mining/pumping and timing.
- **13 sites show subsidence**
  - 6 not originally identified with optical images
  -> InSAR can further help identify areas of high risk
  - Pattern ~ 100 time larger than mining site (mining 0.05 km² / subsidence 5-10 km²)
  - Subsidence up to 7 cm/yr in coastal area
  -> Increases the threat of flooding

<table>
<thead>
<tr>
<th>Site</th>
<th>Subsidence (cm/yr)</th>
<th>Adding sea level rise (1.3 cm/yr - NOAA)</th>
<th>Elevation above sea level (m)</th>
<th>Time before land is below sea level (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candon 10</td>
<td>3.6</td>
<td>4.9</td>
<td>2-4</td>
<td>41-82</td>
</tr>
<tr>
<td>Sta Lucia 13</td>
<td>5.2</td>
<td>6.5</td>
<td>2-4</td>
<td>31-62</td>
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<tr>
<td>Aringay</td>
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<td>6.0</td>
<td>4-6</td>
<td>67-100</td>
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<tr>
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<td>5.5</td>
<td>6.8</td>
<td>2-4</td>
<td>29-59</td>
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<tr>
<td>Lingayen 2</td>
<td>5.2</td>
<td>6.5</td>
<td>2-4</td>
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<tr>
<td>Candelaria 8</td>
<td>2.2</td>
<td>3.5</td>
<td>2-4</td>
<td>57-114</td>
</tr>
</tbody>
</table>
Next Steps

- Incorporating election and census data.
- Further evaluation of land use and water extraction near high subsidence sites.
- DigitalGlobe imagery grant – two high-resolution images of one site.
- Partnership with Big Pixel Initiative, Calit2 @ UCSD + DigitalGlobe, to explore magnetite ID and/or land use classification in high-resolution satellite data.
- Field experiment in 2015 to test effect of monitors equipped with smartphones and apps to report illegal mining in real time.
- ALOS-2 launched summer 2014.
Acknowledgements

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