# VEGETATION STRESS DUE TO MINING IMPACT IN KARABASH USING TSA OF SPOT-VGT

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## ABSTRACT

The South Urals of Russia have been a centre for mining and metals production for well over 3000 years which has left a catastrophic environmental legacy. One of the most polluted areas is within and around the town of Karabash, which contains a number of abandoned mines and waste dumps and is centred on a Cu smelter which emits high levels of $SO_2$ and metal-rich particulate. A 14 year time series of 10-daily Normalized Difference Vegetation Index images from SPOT-Vegetation has been analyzed. The 10-daily time series was smoothed and monthly maximum value composites were created. To remove seasonal vegetation changes and thus facilitate the interpretation through the historical record, a Standardized Difference Vegetation Index (SDVI) was calculated for each pixel and for each record of the time series. Linear least squares trend analyses of SDVI depict a general tendency of increasing photosynthetic activity in the area 10-50 km distance from the smelter, which is confirmed by other authors and can be related to climate change. However, with closer proximity to Karabash (< 10 km), the trend gradually decreases, reaching a steady-state situation on the outskirts of Karabash town. This relative impediment is strongly related to the distance to the smelter and to Pb concentrations observed in lichens. Red-edge positions, derived from 32 in-situ ASD vegetation spectra, correlate with the slope of the SDVI trend over time, confirming vegetation stress hampers the increase in photosynthetic activity which is observed at larger distances from Karabash.

## INTRODUCTION

Remote sensing is an important and common tool in the Earth and environmental sciences, including environmental monitoring. The strength of remote sensing techniques lies in their ability to provide both spatial and temporal views of environmental parameters that are typically not obtainable from in situ measurements. The objective of the ImpactMin project (EC-FP7, contract 244166) is to develop new methods and a corresponding toolset for the environmental impact monitoring of mining-related operations using Earth observation. The three principal stages in metals production – mining, minerals processing and metallurgical extraction (often based on smelting) – all produce wastes which may pose a threat to the environment (1). The main impact of smelting is the release of gaseous and particulate pollutants, including oxides of sulphur, nitrogen and carbon, and metal-rich and sometimes radioactive particles.

Sulphur dioxide ($SO_2$) emissions can be responsible for acid deposition on the vegetation and other surfaces and the occurrence of winter smog episodes (2). The spatial scale of airborne pollution related to mining, and particularly smelting activities, is typically quite large. Depending on substances and particle sizes, the area affected can range from a few hundred square meters to thousands of square kilometers. A number of studies have used satellite remote sensing to analyze the secondary effects of atmospheric pollution related to mining activities, especially vegetation stress. Vegetation stress factors have repercussions on plant photosynthesis, transpiration, and metabolism (3), and often induce changes in the plants' leaf pigment composition, the plants' water holding capacity and the synthesis of secondary metabolites. This can result in foliar physiological changes and visible symptoms such as chlorotic or darkened spots on leaves. However, accumulation of stress-induced compounds may not always be visible. (4) and (5) monitored the changes in land cover induced by atmospheric pollution ($SO_2$) in the Kola Peninsula, Russia, using Landsat images. In the same area, (6) compared Landsat reflectance data with a mathematical model of $SO_2$ concentration in ambient air around a metallurgical complex, and concluded that the strong statistical correspondence as well as the nature of the spectral change indicate that the airborne pollutants were the major factor causing forest vegetation decline.

The objective of this study is to analyze impact of mining on the vegetation in the surroundings of an intensive mining area in the Orenburg region in the Russian Urals, through time series analysis of low resolution Normalized Difference Vegetation Index (NDVI) images derived from SPOT-Vegetation.

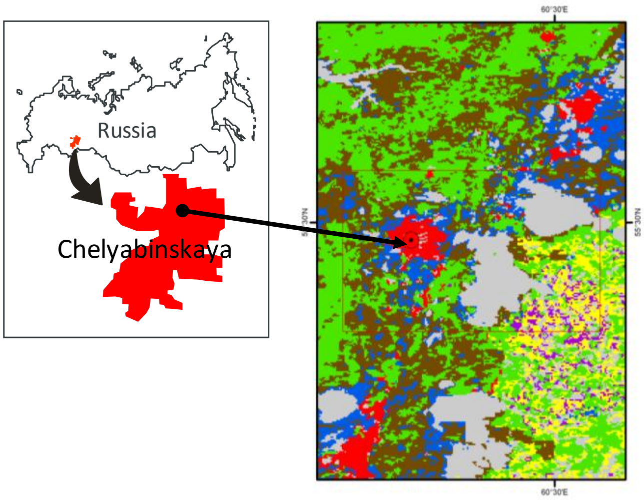
The objective of this study is to assess the impacts on vegetation of smelter operations around the Karabash Cu smelter in the South Urals of Russia, through time series analysis of low resolution Normalized Difference Vegetation Index (NDVI) images derived from SPOT-Vegetation.

## STUDY AREA

Karabash is located in the Chelyabinsk district of the South Urals of Russia (Figure 1). Mining is known to have occurred in the Urals for at least 3000 years, but was greatly intensified in the early to mid-20th century (7). The area around Karabash is extensively forested apart from small agricultural plots and the conspicuously de-vegetated (smelter-facing) western slopes of the nearby Karabash ‘Mountain’ (8). Following the closure of a number of smaller operations, in 1910 a copper smelter was built close to the centre of the town, which specializes in the production of ‘blister copper’. Since its opening, the smelter has produced around 30 million tons of metallurgical slags and other wastes. However, in 1991, following the collapse of the Soviet Union, the smelter, a nearby beneficiation mill and the last mine were closed. The loss of jobs caused such extreme economic hardship that the smelter resumed operations in 1997. In 2006, the Russian Copper Company modernized the smelter. Ausmelt Ltd, which provided the technology, claims that the smelter is now one of the most up-to-date and environmentally safe Cu smelters in the world (9). Nevertheless, the environmental impacts of past mining activities in Karabash are extremely severe. Karabash was described in 1992 by the United Nations Environment Programme (UNEP) as one of the most polluted towns in the world. (10) characterized the area as an ‘ecological disaster zone’, based on chemical analysis of soil samples. Karabash and the surrounding areas are affected by gaseous and particulate emissions from the smelter, acid drainage from the abandoned mine workings and leachates and dusts from waste dumps (7). Several studies have looked into the environmental effects of atmospheric pollution in Karabash (8, 11, 12, 13). Lichens were shown to be heavily impacted in an area of many kilometres distance from the smelter due to acid rain and the fallout of metal–rich particulate from the smelter (8, 13).

## DATA AND METHODS

A time series of 10-daily NDVI images from SPOT-Vegetation (S10 January 1999 to December 2011 at 1km² resolution, http://www.vgt.vito.be/) was analyzed. In order to account for missing values and undetected clouds affecting the observations, the 10-daily time series was smoothed to S10s (14) and monthly maximum value composites (S30) were created (15). As a reference dataset, the GlobCover land cover map was used (16). To remove seasonal vegetation changes and thus facilitate the interpretation through the historical record, a Standardized Difference Vegetation Index (SDVI) was calculated for each pixel and for each record of the S30 series. The SDVI is a z-score representing the deviation from the mean in units of the standard deviation (17): $SDVI = (NDVI_{ijk} - \mu_{ij}) / \sigma_{ij}$ where $NDVI_{ijk}$ is the monthly maximum NDVI value for pixel i during month j for year k, $\mu_{ij}$ is the mean NDVI for pixel i during month j over the time series, and $\sigma_{ij}$ is the standard deviation of pixel i during month j over the time series. Next, a linear least squares trend analysis was applied on the monthly SDVI.



| Class name | Color |
|---|---|
| Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%) | Yellow |
| Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%) | Purple |
| Closed (>40%) broadleaved deciduous forest (>5m) | Green |
| Open (15-40%) needleleaved deciduous or evergreen forest (>5m) | Blue |
| Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m) | Brown |
| Sparse (<15%) vegetation | Red |

*Figure 1: Location of the study area in the South Urals of Russia and GlobCover land cover classification (16).*

## RESULTS

The NDVI profiles (S10, S10s and S30) of three individual pixels in the direct surroundings of Karabash in Figure 2 show a clear seasonality and differences between three different GlobCover classes. The linear trend analysis over time of the S30 SDVI series, indicates a weak trend of increase of photosynthetic activity for the open resp. closed forest pixels over the last 12 years.

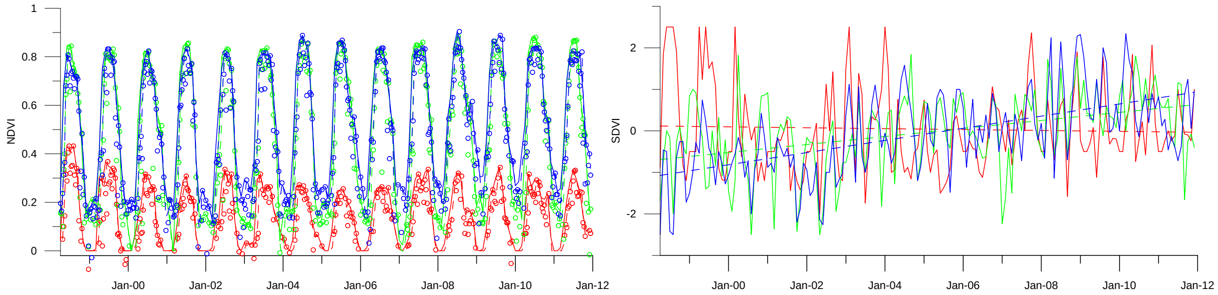


*Figure 2 Left: NDVI profiles derived from SPOT-Vegetation for three individual pixels in the Karabash area. Circles: 10-daily observations. Dashed line: smoothed profile. Solid line: monthly composites. Right: Trend analysis based on SDVI profiles derived from S10s NDVI from SPOT-Vegetation for the same pixels. Land cover types derived from the GlobCover dataset (16), for colour coding see Figure 1.*

In general, pixels in the wider area (10 to 50 km) around Karabash show a positive trend over time, indicating an increase of photosynthetic activity (Figure 3A). This is in accordance with other authors (e.g. 18 and 19) who attribute this general trend to climate change. Nevertheless, pixels in closer proximity (< 10 km) to Karabash show a decrease of the slope towards the smelter. There is a linear relation between the slope of the linear trend of S30 SDVI and the distance to the smelter, for distances smaller than 10 pixels (roughly 10 km). This is especially clear for the sparsely vegetated pixels (Figure 3B).

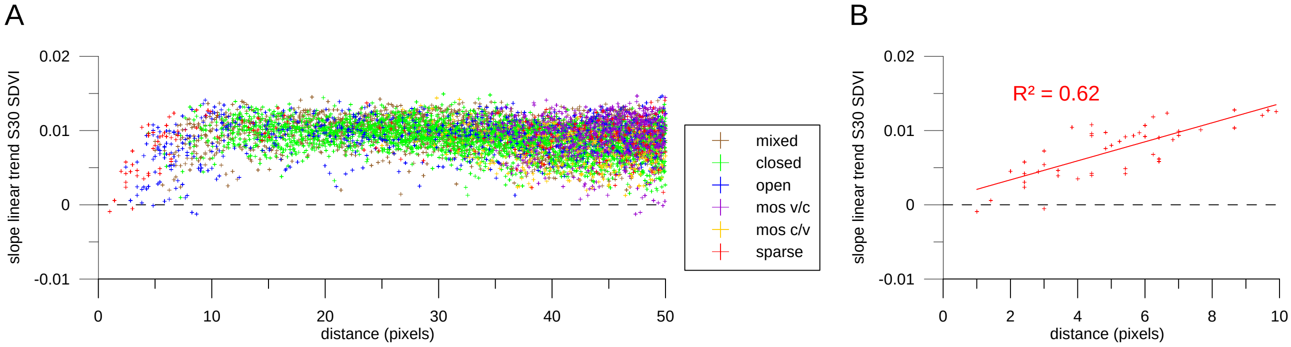


*Figure 3 A. Relation of the slope of the linear trend over S30 SDVI and the distance to the smelter. Land cover types derived from the GlobCover dataset (16), for colour coding see Figure 1. Figure B. focusses on the area up to 10 km from Karabash, for the 'sparse vegetation' class.*

In order to relate this relative impediment of increase in photosynthetic activity over time with the effects of environmental stress on vegetation, the slope of the linear trend was related to red-edge position (20), which is an indicator for vegetation stress, derived from 32 in-situ ASD measurements of Birch leaves. The results show a clear indication of the relation between a tendency of greening of vegetation (or not) and vegetation stress (Figure 4), and is in clear accordance with the results from studies observing the Pb concentrations in lichens in the area (8, 12, 13).

## CONCLUSIONS

This study focused on the use of low resolution NDVI time series analysis for environmental impact assessment of airborne pollution related to the smelter at Karabash. Linear least squares trend analyses of SDVI depict a general tendency of increasing photosynthetic activity, at 10-50 km distance of the mining area. This confirms observations by other authors and can be related to climate change. However, with closer proximity to Karabash (< 10 km), the trend gradually decreases, reaching a steady-state situation at Karabash town. This relative impediment is strongly related to the distance to the smelter and follows the same general trend as for Pb concentrations in lichens (8, 12, 13). Red-edge positions derived from in-situ ASD vegetation spectra correlate with the slope of the SDVI trend over time, confirming vegetation stress hampers the increase in photosynthetic activity which is observed at larger distances from Karabash. Further research should include the time series analysis of different phenological parameters, such as start, end and length of the vegetative season, since the increase in photosynthetic activity due to climate change is probably the result of an increase in the length of the vegetative season, while trees in the town are reported to show premature autumn colours. Also non-parametric methods for trend analysis should be tested.

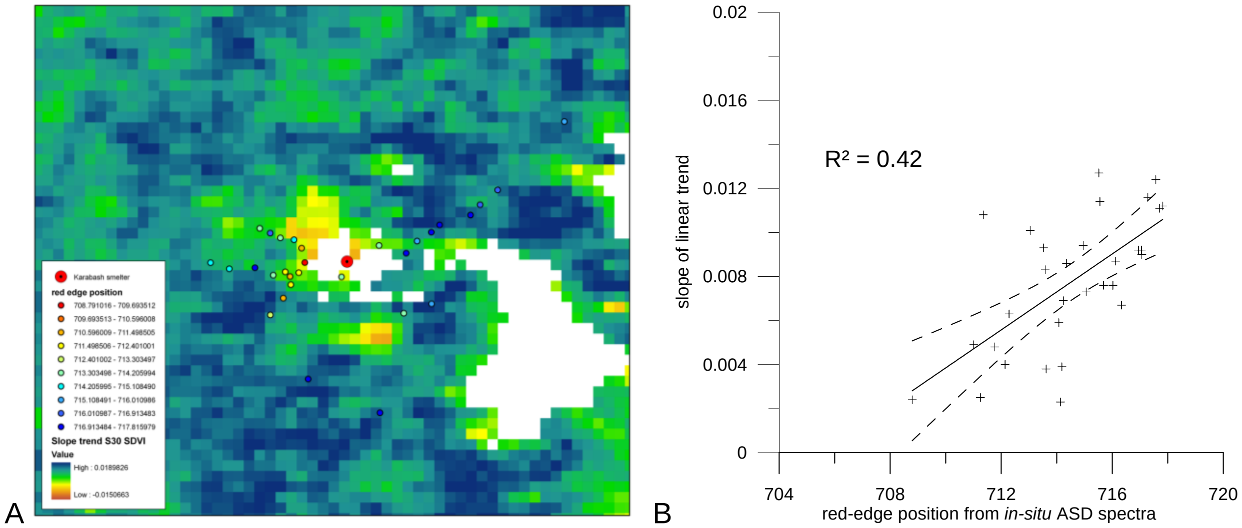


*Figure 4 Relation between the red-edge position measurements derived from in-situ ASD measurements and the slope of the linear trend of S30 SDVI.*

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