Monitoring deterioration of vegetation cover in the vicinity of smelting industry, using statistical methods and TM and ETM⁺ imageries, Sarcheshmeh copper complex, Central Iran

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Abstract Simple statistical methods on Normalized Difference Vegetation Index (NDVI) and bands 3 and 4 data of relatively coarse resolution Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM⁺) imageries were used to investigate the impacts of air pollution on the deterioration of the vegetation cover in the Sarcheshmeh copper complex of central Iran. Descriptive statistics and k-means cluster analysis indicated that vegetation deterioration had already started in the prevailing wind directions. The results show that combination of simple statistical methods and satellite imageries can be used as effective monitoring tools to indicate vegetation stress even in regions of sparse vegetation. Despite various possible perturbing factors upon NDVI, this index remains to be a valuable quantitative vegetation monitoring tool.

Keywords Air pollution · NDVI · Statistical evaluation · Remote sensing · Vegetation cover deterioration · Sarcheshmeh copper complex · Iran

Introduction

A major cause of vegetation cover deterioration is air pollution. The smelting industry sector is a well-known air pollutant source worldwide. In the vicinity of nonferrous metal smelters, high concentrations of toxic compounds have been detected in soils and vegetation (e.g. Ettler et al. 2005). Smelting industries have markedly degraded the natural environment around the world. In areas like Kola Peninsula, the reported total industrial barrens around Severonickel Smelter are as much as 200 km² (Kalabin and Evdokimova 1993). The main types of air pollutants caused by smelting industries are noxious gases such as SO₂ and heavy metal particulates (e.g. Ress and Williams 1997; Tommervik et al. 2003).

Inflicted damage to vegetation cover is usually monitored using satellite imagery (Rigina et al. 1999). The reason is the synoptic view and multitemporal sensing of satellite imagery making it suitable for monitoring vegetation health, that is, condition and change through time. According to Mikkola (1996), the application of remote sensing methods can produce a more accurate spatial view
of the phenomenon. Multitemporal image analysis and change detection methods can also give some historical insight on vegetation deterioration. While it is necessary to characterize the nature of the problem and the ranges of magnitude of effects on vegetation through field sampling, it is difficult to determine the geographic extent and locations of the areas affected using conventional methods (Woodcock et al. 2002).

It has been demonstrated that stress and reduced vitality have some effect on the spectral signature of green plants, generally manifested as a decrease in near infrared (NIR) and increase in the visible wavelengths (Hame 1991; Jensen 1996). According to Gupta (1991), healthy vegetation normally has a strong reflection in the near-infrared (NIR).

Vegetation indices are known to correlate with such related physicochemical properties as chlorophyll concentration, leaf area index, foliar loss and damage, photosynthetic activity, and carbon fluxes (Tucker 1979; Asrar et al. 1984; Sellers 1985; Tucker et al. 1986; Vogelmann 1990; Buschmann and Nagel 1993). The most widely used vegetation index for ecological applications is the Normalized Difference Vegetation Index (NDVI) (Garty et al. 2001; Toutoubalina and Ress 1999; Mikkola 1996; Bala et al. 2000; Giannico 2007). Rouse et al. (1974) have defined NDVI as:

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\text{NDVI} = \frac{\text{Near} - \text{Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}}
\]

This index as well as its less popular modifications (e.g. Soil-Adjusted Vegetation Index (SAVI), Transformed Vegetation Index (TVI)) is based on the difference between the maximum absorption of radiation in the red band due to chlorophyll pigments and the maximum absorption radiation in the NIR band due to leaf cellular structure, and the fact that soil spectra, lacking these properties, do not show a dramatic spectral difference (Garty et al. 2001).

NDVI is the most commonly used vegetation index as it retains the ability to minimize topographic effects while producing a linear measurement scale. The higher the NDVI values the higher the probability that the corresponding area on the ground has a dense coverage of healthy green vegetation (Campbell 1996).

In most of the studies which use satellite imageries for assessing the impact of air pollution on vegetation, NDVI evaluations (e.g. Giannico 2007; Garty et al. 2001), image classification techniques (e.g. Mikkola 1996; Ress and Williams 1997), land cover maps with ancillary data (e.g. Tommervik et al. 1998, 2003), or multitemporal change detection technique (e.g. Hanger and Rigina 1998) are used. However, most of these studies deal with dense vegetation cover such as forest and very little research is done on sparsely vegetated areas. The main purpose of this paper is to present a method based on simple statistical approaches on NDVI values and bands 3 and 4 data, for investigating the effect of air pollution on vegetation in Sarcheshmeh, a sparsely vegetated area. In order to serve this purpose, image descriptive statistics and modified soil brightness line plot (Richardson and Wiegand 1977) are used.

**Study area**

Iran ranks 16th among the world’s major copper producers (Edelstein 2003). Sarcheshmeh copper deposit, the largest porphyry copper deposit in Iran is located 160 km SW of Kerman city in Kerman Province (Fig. 1). The Sarcheshmeh orebody along with a number of other porphyry copper deposits occur in the so called central Iranian volcanic belt (Waterman and Hamilton 1975; Forster 1978; Shahabpour and Kramers 1987).

Reverb and converter stacks of the smelting plant release 136,000 and 163,000 m$^3$/h of gas into the atmosphere, respectively. SO$_2$ gas constitutes 2.6% and 4.8% of the emissions, respectively (Ebrahimi and Hakimi 2002).

The region’s temperature varies between $-20^\circ$C in the winter to $+32^\circ$C in the summer (Shirashiani 2004). Average rainfall is 440 mm. Prevailing wind directions based on available meteorological data in the period 1987 to 2000 are NE and N (Sarcheshmeh meteorological station).

Vegetation cover reflects the climatic conditions of the region, i.e., in low-lying plains vegetation cover is mainly bush and desert plants, while