E3S Web of Conferences **435**, 03006 (2023) https://doi.org/10.1051/e3sconf/202343503006
REC-2023

Urban environment monitoring in industrial city using remote sensing of snow cover

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Abstract. The dynamic development of modern cities requires new solutions to urban planning and management by local regional authorities. The paper focuses on ecological indicators based on Earth Remote Sensing Data (ERSD) of the snow cover with the purpose to evaluate the city and to plan ecological environment protection strategy. The paper deals with the method of using space images to assess the snow cover pollution of Chelyabinsk, a large Russian industrial city. The assessment of the snow cover of Chelyabinsk was carried out by comparing the heavy metals concentrations with the Landsat 8 data. The spectral indices were calculated for fourteen sites evenly distributed over the urban area of four types: courtyards, car parks, industrial zones and roads. We found a statistically significant difference between the Swirl/Green index and the site type and a correlation with the concentrations of dissolved and suspended forms of heavy metals in snow cover. Snow cover indices can be used as ecological indicators of urban environment.

Key words: Urban environment; Remote sensing; Urban environment indicators; Urban environment protection strategy.

1 Introduction

Cities currently occupy less than 2% of the world's land area, but they account for 80% of the world's gross domestic product and more than 70% of carbon emissions [1]. Until the 1950s, Russia remained a country with a predominantly rural population. The 1959 census showed that more than half of all residents lived in cities. Today, about 75% of Russians live in cities [2]. Currently, there are over 1,000 cities in Russia. Most of them have a population of up to 50,000 people. The population of 16 cities exceeds 1 million people. Cities are the front line of the ecological disaster looming over us. Therefore, they should be at the forefront

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of the fight against pollutants. But it cannot be denied that densely populated cities with developed public transport lines, shops and various household services consume fewer resources. And cities emit fewer pollutants than scattered households. Compactness reduces the negative impact. Thus, it cannot be denied that urban density is an effective way to achieve environmental sustainability. Cities are making progress, but they remain a harsh and ruthless environment. Russia's industrial cities give residents a chance for higher incomes and a better education, but they cripple our souls and clog our lungs. Urbanization requires effective governance by national and local authorities which can be one of the modern solutions for sustainability.

The concept of a “smart city” is becoming one of the most modern and innovative solutions for sustainability. Ecology in a smart city involves not only a network of sensors measuring pollution in real time. First of all, a smart city is, the use of the most modern monitoring methods and the adoption of smart decisions. Modern tools, including remote sensing, can be used to develop effective ecological environment protection strategy of Russian industrial cities [3]. The open archive of Landsat can be useful to study urban areas. The unique combination of fine spatial details and high temporal resolution of Landsat images allows for temporal assessments of individual urban areas at a relatively low cost [4].

Chelyabinsk is one of typical Russian industrial cities with millions of people. There are several metallurgical plants and a developed transport network. It is characterized recent rapid growth of urban construction and the reconstruction of transport infrastructure. The city residents are worried about the black sky regimes. It is well known that air pollution is one of the health risk factors. For example, it was shown that there is correlation between emissions of metals and their compounds on cancer incidences in the population of Sverdlovsk region [5].

Monitoring of the urban environment, including urban air pollution monitoring, helps to assess the reduction of risks to public health and to form a sustainable urban environment

[6]. In recent years, remote sensing technology has become widely used in digital near real-time monitoring of urban areas pollution. [7-10]. However, these studies have usually focused on long and widely used indicators as the Normalized Difference Vegetation Index (NDVI) or the land surface temperature (LST). It was suggested the Remote Sensing-based Ecological index (RSEI) integrated the primary land surface components and the climate [11] and Remotely Sensed Urban Surface Ecological index (RSUSEI) by integration of surface greenness, moisture, dryness, heat, and imperviousness using Principal Components Analysis (PCA) [12]. The total snow cover pollution index is widely used for ecological researches of urban areas [13]. But research based on remote sensing of snow cover in the city is extremely limited. It was studied snow cover of the Tyumen by the method of cluster analysis (k-means) [14] however, a universal indicator was not proposed in this work. It was developed a Water-Resistant Snow Index (WSI) as one of the cutting-edge approaches in the binary snow mapping [15] but this index is poorly applicable to the urban area.

This study is the first integrated approach using state-of-the-art methods and Landsat satellite data of snow cover state. Mathematical modeling method and physico-chemical analysis were also used to cover the main problems and to search for solutions and give useful recommendations on the modern organization of urban planning for city authorities.

2 Methods

2.1 Study area

Snow cover is a reliable indicator of urban pollution [16-18]. To assess snow cover pollution over large areas, a large number of ground-based laboratory measurements are needed. Such studies are both time-consuming and costly. Therefore, the use of satellite images and establishing the relationship between spectral images and pollution is an effective solution for assessing pollution in a large city. Russian scientists are mainly engaged in research on snow cover pollution [19].

This paper presents the main approaches to assess snow pollution with the integrated use of ERSD from the city. The analysis of the snow cover was carried out during the period of the beginning of snowmelt on open flat areas not subject to snow removal. We selected fourteen sites of four types evenly distributed over the territory of Chelyabinsk city: courtyards of residential areas (sites 1, 4, 8), car parks (sites 9, 12-14), industrial areas (sites 2, 5, 6, 11) and roadside areas (sites 3, 7, 9). Figure 1 shows the study sites.

Fig. 1. Locations of study sites.

2.2 Earth remote sensing data

We used Landsat 8 OLI (Operational Land Imager) images for February and early March 2022 and the ENVI 3.2 software. All the necessary channels of the selected image were subjected to radiometric calibration and the conversion of the brightness values into the values of the reflectivity of the underlying surface. Landsat 8 images were downloaded from the free site https://earthexplorer.usgs.gov/. We used QGIS 3.16 software to study snow cover pollution and identify the qualitative content of substances. Channel combinations were made using the Raster Calculator tool.

For a comprehensive account of all factors affecting the state of the snow cover, and to assess the level of snow pollution, snow quality indices were used [20]:

$$\frac{Swir1}{Green} \text{ and } \frac{Nir}{Green}, \quad (1)$$

where *Swir1, Nir, Green* are reflection coefficients in the mid-infrared, near-infrared and green channels of the Landsat scanner.

2.3 Chemical composition of snow cover

The snow samples were collected in study sites. Snow samples were melted and filtrated through blue ribbon and membrane filters with a pore diameter of 2 and 0.45 µm, respectively. The content of solid particle matter less than 2 and 0.45 µm (PM_2 and $PM_{0.45\text{-}2}$) in snow meltwater was determined. The concentrations of metals in the snow cover in dissolved and suspended forms were analyzed using Varian 720-ES inductively coupled plasma spectrometry (ICP-AES).

3 Results and discussion

Table 1 shows the ranges of snow cover pollution indices for sites of various types; no statistically significant differences were found for the Nir/Green. The Swir1/Green was minimal for the yard area, and the maximum values were typical for car parks. The main snow pollution in car parks is associated with tire wear, engine exhaust and brake wear.

At the same time, the *Swir1/Green* ratio is the highest in the north (Fig. 2). The wind regime of the region is characterized by the predominance of the south and south-west winds with an average speed of 3-4 m/s from January to May. This leads to regional transport of pollutants in northern and eastern directions. Moreover, Chelyabinsk is a "heat island" created by industrial enterprises.

Table 1. Values of snow cover pollution indices for different types of sites in the city (mean ± SE, a, b, c - statistically significant differences, p=0.95).

Index	Industrial areas	Courtyards	Car parks	Roadside areas
Nir/Green	1.07±0.09a	1.08±0.12a	1.07±0,14a	1.03±0.11a
Swir1/Green	0.64±0.08a	0.51±0.06b	0.73±0.08c	0,69±0.07a

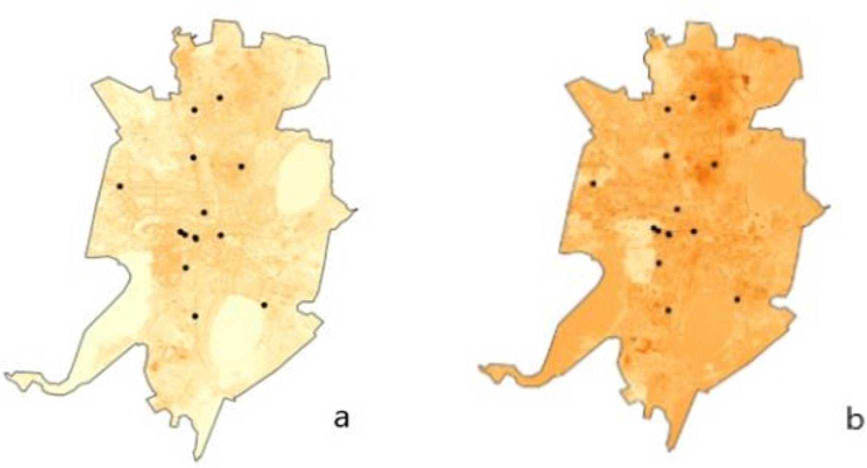

Fig. 2. Map of changes in *Nir/Green* (a) and *Swir1/Green* (b) indices.

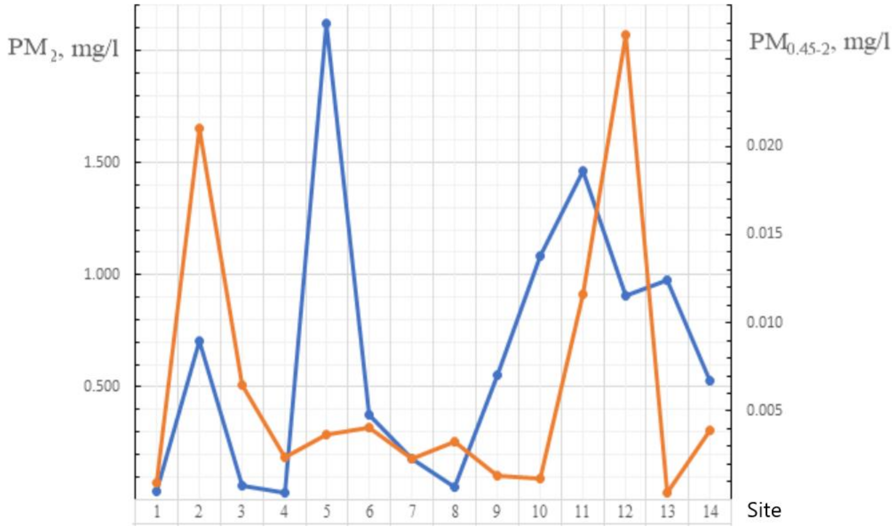

Fig. 3. The content of solid particles (PM_2 and $PM_{0.45\text{-}2}$) in snow meltwater for different sites.

Most of the PM was discovered for industrial areas, and the least for residential areas (Fig. 3). It was found that the content of PM and heavy metals in the snow sampled in selected areas is statistically significantly correlated with the *Swir1/Green* index (p=0.95).

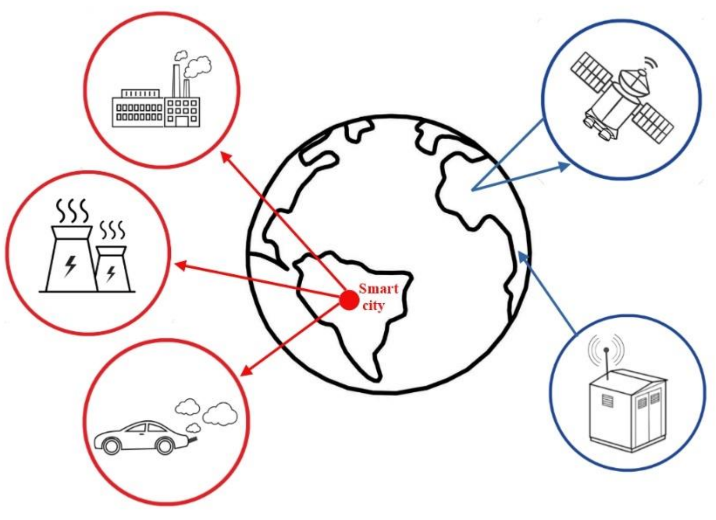

Fig. 4. Environmental monitoring in a smart city at the regional level (red) and global level (blue).

Remote sensing can be successfully integrated into environmental monitoring in a smart city. Monitoring at the regional level makes it possible to identify such pollution sources as energy, industry, and transport. Construction of the digital twin and model is carried out at the urban level. The regional level implements a bottom-up approach. The global level combines ground measurements and remote sensing. It allows you to build a model of the state of the atmosphere based on global observations. Global monitoring implements a top-down approach. Combining the two approaches allows to develop the best urban environment protection strategy. The physico-chemical characteristics of snow cover collected at selected sites of urban area (regional level) are a traditional indicators of air pollution in Russian industrial cities. *Swir1/Green* index is calculated using remote sensing. It is a new urban environment indicator. Remote sensing offers the ability to quantify the spatiotemporal dynamics of snow cover in urban areas where such measurements are impossible or very limited for the monitoring and mapping. It allows to monitor air pollution in near real-time during winter time.

4 Conclusion

Developing cities in a sustainable manner require proper knowledge of recent changing scenarios in the urban-environmental conditions of the city. Our considered indices based on remote sensing can observe urban environmental conditions very efficiently and require less time, money, and resources than phisico-chemical analysis of snow cover. This paper has defined the indices which should be adopted as urban indicators. It proved that Earth Remote Sensing data can be a useful tool. Snow cover urban environment indicators can fit into urban management.

Acknowledgments

This study was supported by grant from the Russian Science Foundation, project number 22-17-20006 (https://rscf.ru/project/ 22-17-20006/) and Chelyabinsk oblast.

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