Application of GIS and Remote Sensing Techniques in Multi-temporal Analyses of Soil Properties in the Foreland of the Carpathians

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Abstract. The paper presents a spatial and temporal analysis of the distribution of the soil salinity and its pH level of south-east Poland depending on selected environmental factors. The area under examination (Carpathian Foredeep, Carpathians flysch) is distinguished by its specific hydrological and geological conditions (the Vistula and the San valley). The research works were performed in relation to parameters that had been measured in-situ in 1995, 2000, 2005, and 2010. Using specialist GIS software, proper interpolation procedures were performed, which enabled visualization in the form of raster and vector maps for the spatial distribution of the examined soil properties. Moreover, an analysis of remote sensing data was completed. Based on the analysis, it was discovered that the biggest changes in all examined soil parameters took place in 2010 - changes in the soil salinity and its pH level, as well as in the content of potassium (K) and sodium (Na). Those changes occurred mainly in the north and south parts of the examined area. The underlying reason for those changes might have been the flood, which hit the region in June 2010.

1. Introduction

Salinity is one of the factors that influence changes in soil properties and productivity. The process of accumulating easily soluble inorganic salts in soil is triggered by natural climate or anthropogenic conditions through incorrect watering and fertilizing. The natural sources of soil salinity are, in the first place, mineral waters. The anthropogenic sources include fossil salts, chemical fertilizers, as well as industrial waste and sewage. These are high concentrations of sodium and potassium that exert a substantial impact on soil salinity levels. High concentration of potassium results in soil salinity, which is harmful to plants, especially at their sprouting phases and during water shortage periods. The soil salinity and impact of this phenomenon on the environment is widely described in the literature [1-4].
An important indicator of soil fertility is soil acidity, expressed in pH values as a concentration of hydrogen ions in soil solution (1 mol KCl/dm³). Soil acidity results from the concentration (activity) of H⁺ and OH⁻ ions. The level of acidity is determined by such elements as, type of bedrock, soil building process, as well as process of washing out of calcium from upper soil layers. Also climate conditions, prevalence of precipitations over evaporation, acid rains and use of incorrect amounts of nitrogenous fertilizers substantially contribute to soil acidity levels.

Methods of quantitatively mapping and monitoring soil salinity at regional to global scales are essential for providing information about the state of natural environment. From the literature, mapping methods are known such as ANCOVA (Analysis of Covariance) that involves in-situ measurements of soil electrical conductivity (ECA) as an indicator for soil salinity [8, 9]. The alternative and much cheaper techniques of mapping soil salinity can be GIS and remote sensing [6, 7, 10].

Integration of in-situ measurement data, satellite and aerial images, as well as data gathered in spatial databases enable an optimal utilisation of information on the environment, which further makes it possible to comprehensively investigate and monitor changes in selected elements of the environment [9, 11].

This research presents a way of integration of data in a process of a multi-temporal analysis of spatial distribution of soil properties (as measured in-situ) on the basis of raster maps, which have been prepared using GIS techniques and satellite images.

2. Data and Methodology
2.1 Research Area
The research area is located in the Carpathian Foreland in the southeast part of Poland (Figure 1), within the range of two geological units. The north part belongs to the Pre-Carpathian Foredeep, while the south one to the Flysch Carpathians. The Foredeep area is filled with Miocene formations, mainly clays, sandstones, and sands. The Flysch Carpathians in the examined area are built of alternating formations of the types of sandstones, limestones, conglomerates and schists, which form flysch layers. This diversification of geological composition is reflected in the area hypsometry. The north part of the area is from an upland nature (over 300 m a.s.l.), while the south one is of a mountainous nature (over 500 m a.s.l.). Prevailing agricultural lands belong to the cleanest ecological regions in Poland.

![Figure 1. Study area](image-url)

2.2 Data collection
The basis for investigating soil environment variability in terms of soil salinity was provided by the data gathered by the Institute of Soil Science and Plant Cultivation in Puławy, Poland (IUNG) in the form of
an attribute database within the framework of the programme of "Monitoring the Chemism of Arable Soils in Poland" financed from resources granted by the National Fund for Environmental Protection and Water Management [12]. For the research purposes, 14 out of 216 sampling points (their depth ranging from 0 to 20 cm, surface areas about 100 m²) located within the examined area were selected (Figure 1). Samples were collected in 1995, 2000, 2005, and in 2010.

Moreover, an analysis of remote sensing data was performed. For that purpose, satellite images Landsat 5 TM were used (available online on USGS servers), recorded in years 2005, 2010, in which the in-situ samples were collected.

2.3 Methods
On the basis of sampling point coordinates, a numerical grid of sampling points was prepared. In order to enable a thorough situational analysis, the created grid of 14 sampling points was superimposed on a digital terrain model available as Web Map Service.

Next, using RST (Regularized Spline with Tension) interpolation algorithm [13, 14, 15], which has been implemented into the GRASS system, map compositions of salinity levels, soil acidity, as well as potassium and sodium concentration levels were made for particular annual data sets (Figure 2).

The RST method employs an interpolating function, which is the aggregate of the trend and local variability function. In this way, raster maps have been obtained, constituting a two-dimensional model of soil parameters in the examined area (that is of salinity, acidity, and Na and K contents).

The data analysis concerned soil salinity and acidity, as well as overall contents of macroelements (sodium and potassium). The processes of charting and analysing of spatial distribution of examined soil parameters were performed using the open-source QGIS/GRASS system.

On the basis of Landsat spectral channels of the obtained satellite images, false colour composite (FCC) of infrared channels were created (Figure 3c), as well as vegetation index (1) (NDVI - Normalized Difference Vegetation Index) (Figure 3a, Figure 3b). For calculation and analysis purposes, channels recorded in visible (RED) and in near infrared (NIR) ranges were selected.

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NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}
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Analyses were performed only for the area confined within the boundaries of area of interest (Figure 1).

3. Results and Discussions
The analysis of multi-temporal maps demonstrates that in four consecutive years of 1995, 2000, 2005, and 2010 changes in soil parameters were moderate, except for the southwest part of the area, where noticeable transitions from inert and slightly acidic soils to alkaline ones (pH\textsubscript{max} = 7.8) were observed in 2000 and in 2010 (Figure 2b). Additionally, in 2010 in the central part of the examined area, an increase in soil pH levels occurred from 6.7 to 7.7, while in the north of the area a substantial decrease in soil acidity levels, from pH = 5.7 to pH = 4.1, was observed (Figure 2b).

On the basis of analysis of spatial distribution of examined soil parameters, the highest levels of salinity, ranging from 25 [mg KCl*100g⁻¹] in the year 1995 (Figure 2a) to even as much as 46 [mg KCl*100g⁻¹] in the year 2010 were noticed in points located on the border of the Flysch Carpathians and the Carpathian Foredeep (points nos. 381 and 447) and in point no. 441, located in the Beskids mountains (Figure 2a).

As regards soil salinity in 1995, one can notice high concentration levels in the prevailing part of the research area (ranging from 20 to 40 mg KCl*100g⁻¹). In subsequent years, the area of saline land decreased, and in 2010 it was present only in zones of sampling points nos. 381, 447, and 441, located in the central part of the examined area (Figure 2a).
The biggest changes in levels of salinity and in those of other examined soil parameters occurred in 2010. Those changes took place mainly in the north and south parts of the examined area. The results of the analyses indicate significant changes in the levels of sodium (Na), potassium (K), acidity, and salinity of soil (Figure 2a). One of the main reasons for those changes might have been the flood in 2010, which inundated the major part of the area under consideration. Those terrains are situated within the inundation zones of three rivers, namely the Vistula, the San, and the Wislok (Figure 3). The major part of land was underwater then, and the results of the flood have substantially affected soil properties (Figure 3).
Figure 3. The satellite maps with boundaries of area of interest: a) NDVI 2005, b) NDVI 2010 and c) false colour composite FCC (554) - flooding area (in blue), vegetation (in green)

The comparative analysis of the obtained raster maps and of multi-temporal satellite images with their derivatives (vegetation indexes) (Figure 3a, Figure 3b) confirmed that the above-referenced changes in soil properties might have been caused by periodical inundation of the examined area. Clearly visible on satellite images are the inundated areas (FCC colour composite) (Figure 3c), while the vegetation index NDVI clearly shows extensive vegetation changes for the whole research area, being the direct results of the flood.

Precise analysis of that area in relation to other, determined soil properties allows discerning certain dependencies between those properties, and the level of salinity.

4. Conclusions
Using specialist GIS software, proper interpolation procedures were performed, which enabled visualization in the form of raster and vector maps for the spatial distribution of the examined soil properties. On the basis of the obtained maps of spatial and temporal distribution and processed satellite images, it was noticed that the biggest changes in all examined soil parameters had taken place in 2010. In the case of soil salinity, one can notice high concentrations in the prevailing part of the research area in 1995. In subsequent years, the area of salinity land decreased, and the year of 2010 recorded a significant decrease in soil salinity levels. The comparative analysis of the obtained raster maps and of multi-temporal satellite images with their derivatives (vegetation indexes) confirmed that the above-referenced changes in soil properties might have been caused by periodical inundation of the examined area. The results of the analyses indicate big changes in the levels of potassium (K), sodium (Na), pH, and salinity of soil. Those changes took place mainly in the north and south parts of the area under examination. The reason behind the noticed changes might have been the flood, which hit the region in June 2010.

The use of GIS spatial analyses and remote sensing images made it possible to examine correlation between soil salinity level and soil reaction, and factors affecting soil properties (Na and K contents, land inclination) over a period of 15 years.

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