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LANDFORM CLASSIFICATION USING ASTER GDEM AND OPTICAL HIGH RESOLUTION SATELLITE IMAGES OF SOFIA CITY DISTRICT

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Abstract

The morphologic and morphometric landform information plays a significant role in the spatial and temporal analysis and modeling of the landscape and affects the course of the natural processes. The geoinformation technologies provide for performing digital terrain analysis and extraction of a series of morphometric parameters and landform elements. The compound geomorphologic analysis and interpretation can be performed through various algorithms incorporated in the GIS software product. The objective of the present study was to classify the landform elements and to describe landform complexity of Sofia City District based on ASTER GDEM and satellite images. TPI-based algorithm for landform classification will be applied and the terrain heterogeneity of the study area will be assessed. As a result of the performed spatial analysis maps of the topographic position index and landform classification map were elaborated.

Introduction

Relief is one of the major components of each landscape, which plays an important role in the spatial distribution of the surface water runoff and determines the exogenic processes (denudation, accumulation, erosion, etc.). The landform information is essential for the modeling and understanding of many physical processes [1]. The term *landform* is defined as "*any physical feature of the Earth's surface having a characteristic, recognizable shape*" [2]. From the geomorphometric point of view a landform is "*a terrain unit created by natural processes in such a way that it may be recognized and described in terms of typical attributes where ever it may occur*" [3], [4].

Digital terrain modeling, also known as geomorphometry, integrates methods from earth sciences, geoinformatics and geostatistics. It studies the quantitative and qualitative description and measurement of landform [5], [6] using various approaches, including classification of morphometric parameters, filter techniques, cluster analysis, and multivariate statistics. Terrain analysis for landform classification has been applied by many authors dating back to 50-ties of the XXth century [7]. A large number of automated techniques and algorithms for DEM/DTM processing and extraction of landform elements has been developed and applied [8], [9], [10], [11], [12]. Many of these algorithms has been implemented into GIS software (e.g ESRI and the open source products such as SAGA, GRASS, gvSIG, etc.), whereas others were developed as stand-alone programs and software packages (MICRODEM [13], LandSerf [10], TAPES set [12], DiGeM [14] [15], TAS GIS [3], etc.)
The landscape differentiation can be performed by extraction of different landform elements through parameterization of digital elevation model (DEM). Various classifications of landforms have been proposed according to the morphometric variables which are used as a basis for their characterization and description. Among the well known algorithms are those developed by Hammond, Wood, Conrad, etc [15], [10], [16], [17]. The object-oriented approach for landform classification has been applied for territories with different relief types [18], [19], [20], [21], [22].

Objective

The objective of this study was to classify the landform elements and to describe landform complexity of Sofia Municipality based on ASTER GDEM and satellite images. We apply and test the TPI-based (topographic position index) algorithm for landform classification developed by Conrad and assess the terrain heterogeneity of Sofia City District.

Study area

The Sofia (Metropolitan) Municipality, which in the term of territorial scope is identical with the Sofia City District, is located in Western Bulgaria. It includes 38 settlements - 1 city (Sofia), 3 towns (Bankya, Novi Iskar and Buhovo) and 34 villages. According to the data obtained from CORINE land cover 2006, its territory is occupied by urbanized territories (13.5%), agricultural land (37%), forest areas (30%), scrubs and open spaces with little or no vegetation (9.4%), mining and quarry areas (1.6%), transport and infrastructure facilities (5.5%) and water areas (3%). From the point of view of physical geography its location is analyzed with respect to the main morphological structures (structural units). Sofia Municipality occupies part of the Sofia hollow (field), and parts of the surrounding mountains - Mala and Sofia Mountains in the northern part, and Vitosha, Plana, Lyulin and Lozenska Mountains in its southern part (Fig.1). The landscape of Sofia Municipality is characterized by varied relief and relatively mild climate, part of the moderate-continental climatic region of Bulgaria. The relief is represented by flat areas, foothills, valleys and mountain areas, which are changing from mountain areas in north to flat areas in the middle of territory and again mountain areas in the southern part. The average altitude of Sofia hollow is approximately 550 m a.s.l. and in its periphery the elevation rises gradually. The average altitude for the whole municipality is calculated to 1386 m, while the maximum and minimum elevation values vary from 450 to 2241 m. Due to the high rate of urbanization, the natural relief is significantly complemented and transformed by the anthropogenic factor as a result of which a number of anthropogenic landforms have been created - artificial reservoirs (such as Iskar Dam, Pancherevo Dam, Passarel Dam), transport and industrial infrastructure, quarries, embarkmends, etc.

The available geological information and the studies conducted over the years by Kamenov, Georgiev, Frangov on the area of Sofia Municipality show that the Sofia hollow is young, Neogene-Quaternary tectonically active graben structure [23], [24], [25], [26]. Detailed geomorphologic studies of Sofia region including surrounding mountains have been conducted by Hristov, Georgiev, Kanev ([27], [28], [29], [30], [31], [32]), and the anthropogenic relief has been discussed by Vlaskov and Simeonov in 1992 [33]. Digital terrain analysis of the relief for geoecological studies of Sofia Municipality has been performed by Choleev and Popov in 2005 [34].

The main elements of the hydrographic network in Sofia Municipality are the rivers and water reservoirs and lakes. The main drainage artery is the river Iskar with its asymmetrical tributary network, represented mainly by short tributaries. Most of them are left-handed, which spring from from Vitosha Mountains (the river Bistritsa, Perlovska, Vladayska) and from Lyulin Mountains (e.g. river Suhodolska), as well as the river Blato. The most significant right-hand tributary of Iskur river is Lesnovska (as knows as Stari Iskur). Based on the landscape diversity (determined by the natural characteristics of the territory) and the altitude-based zoning the natural landscapes of Sofia Municipality can be divided into three major types: Mountain landscapes, Foot-hill landscapes, Plane landscapes.

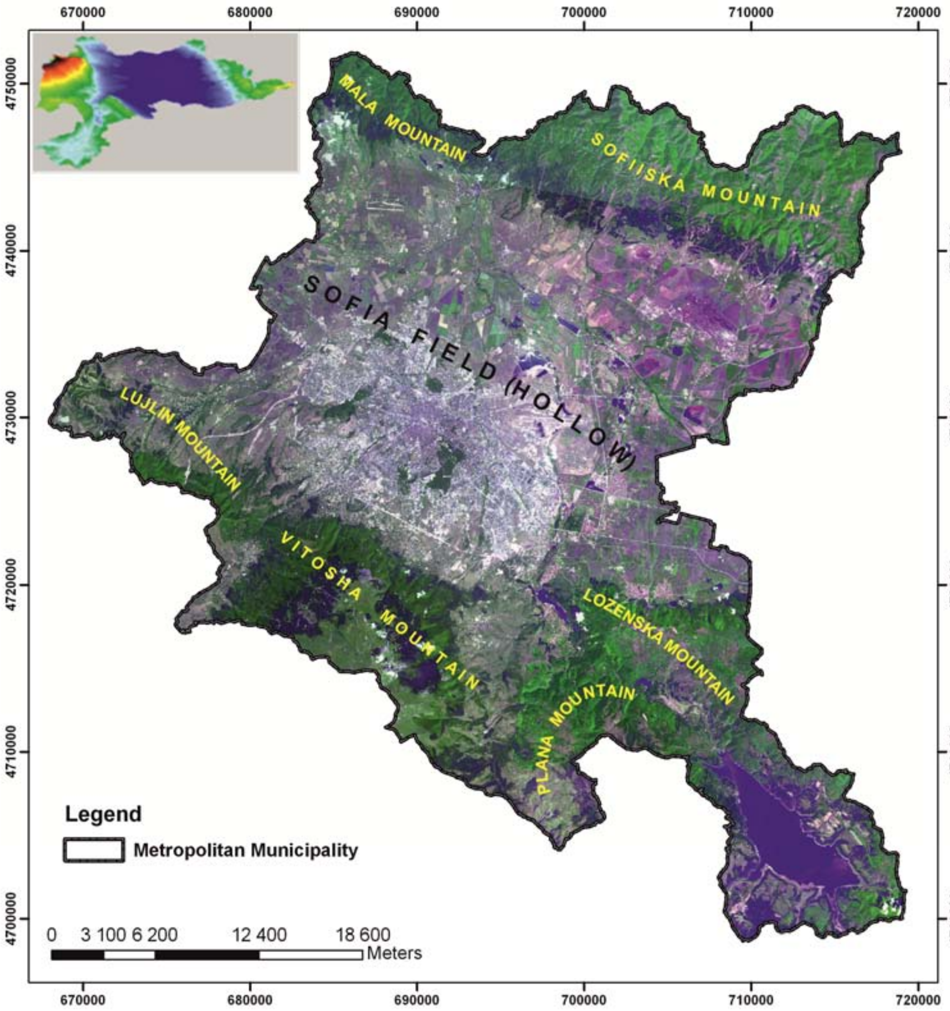

Fig. 1. Overview of Sofia City District (Metropolitan Municipality)

Methodology

Data sources

The main data source for the present study is ASTER GDEM (ASTER Global DEM) with resolution 30 m. ASTER GDEM is a satellite product provided by METI and NASA and download by WIST web portal of NASA. The missing data and error of the DEM was filled through spatial analyst tools of ArcGIS, and then converted in ascii grid file.

Digital terrain analysis

The present work is focused on some morphometric parameters and derivatives. The chosen morphometric parameters for characterization of the structural elements of the relief are the topographic position (TPI) and topographic ruggedness indexes (TRI), the Multi-resolution index of valley bottom flatness and TPI-based landform classification. The calculations were performed using SAGA GIS modules and algorithms for terrain analysis, developed by Conrad [35] (table 1).

The **TRI** reveals the terrain roughness and serves as an objective measure of the topographic heterogeneity and diversity [36]. It is calculated for every grid based on the change of the elevation and the mean of the elevation for the neighboring cells within 3x3 pixel grid.

The **TPI** is defined as a difference between the elevation of a specific cell and the average elevation of the neighboring grid cells. It compares the elevation of each cell in a DEM compared to the mean elevation of a specified neighborhood around that cell.

The multi-resolution index of valley bottom flatness calculates two morphometric parameters - multi-resolution index of valley bottom flatness (MRVBF) and multi-resolution index of the ridge top flatness (MRRTF). The first of them classifies valley bottoms as flat, low areas using slope and elevation (DEM), while the second index uses the opposite algorithm for identification the ridge tops [37].

The classification approach which is applied in the present study is known as TPI-Based Landform Classification, developed by O. Conrad (2011).

Table.1. Morphometric parameters and indexes applied for the territory of Sofia City District

Morphometric parameter/index	Input data	Algorithm author/references
MRVBF	DEM	*Algorithm:* O. Conrad (2006)
MRRTF	DEM	
TRI	DEM	*Algorithm:* O. Conrad (2010)
TPI	DEM	*Algorithm:* O. Conrad (2010)
Landform Classification	DEM	*Algorithm:* O. Conrad (2011)

Results

Maps of the morphometric parameters and landforms of the Sofia City District were elaborated. The result were correlated and compared to ASTER satellite image of the Sofia Municipality with spatial resolution 18 m.

The valley bottoms of Sofia City District were classified through the multi-resolution index of valley bottom flatness, where the highest value indicates the low flat areas (Fig. 2). The lowest part of the Sofia hollow is well distinguished and it coincides with the valleys of Iskur river, Blato and Leskovska.

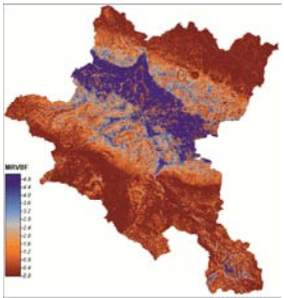

Fig. 2. Map of the multi-resolution index of valley bottom flatness (MRVBF) of Sofia City District

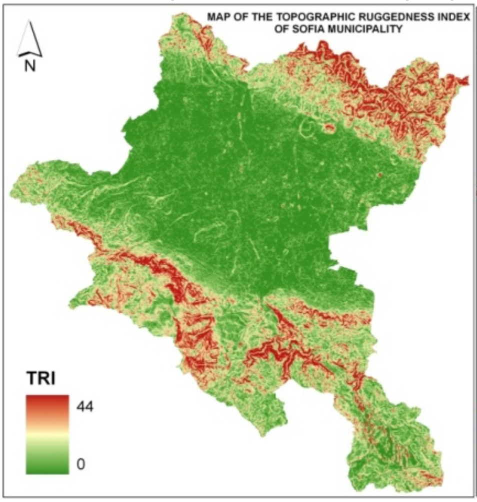

Fig. 3

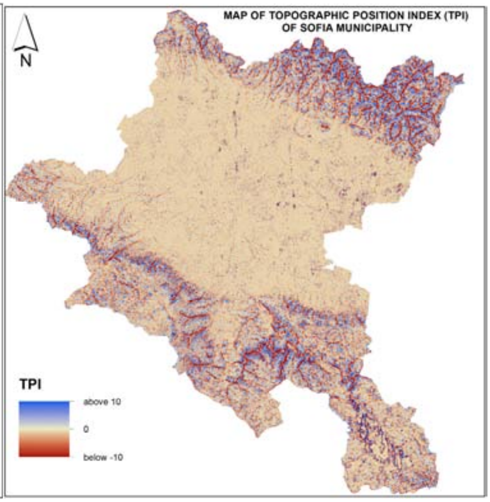

Fig.4

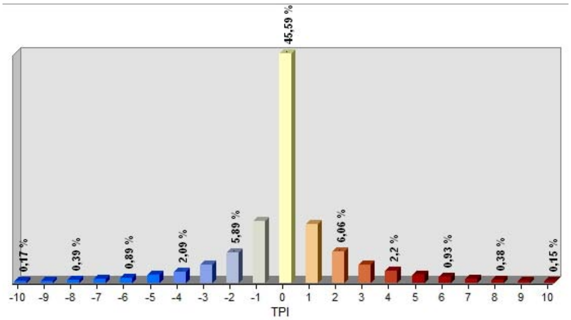

Fig. 5. Histogram of the TPI values for the territory of Sofia City District

The areas with most fluctuations of the elevation correspond to the areas of highest values of TRI. The lowest TRI values are observed in the Sofia hollow and in some areas in the southern part of the Sofia City District – Vitosha plateau and parts of Lozenska and Plana mountains. The highest rate of heterogeneity is registered in the mountainous areas in the northern and southern part of the District (Fig. 3). The terrain heterogeneity is an important morphometric parameter and variable for analyzing the landscape heterogeneity and diversity.

The TPI values for the territory of Sofia vary between minus 10 to plus 10 (Fig.4 and 5). The positive TPI values are associated with locations that are higher than the average of their neighborhood surroundings and they are defined as ridges, while the negative represent locations that are assigned with values lower than their surroundings and are classified as valleys. The flat areas are calculated with values near zero, whereas when the slopes are greater than zero. Almost 50% of the territory of Sofia City District has TPI value 0, and is classified as flat areas.

The topographic position index is used for differentiation of the main landform classes. The calculations are performed in SAGA GIS environment using the TPI-based algorithm.

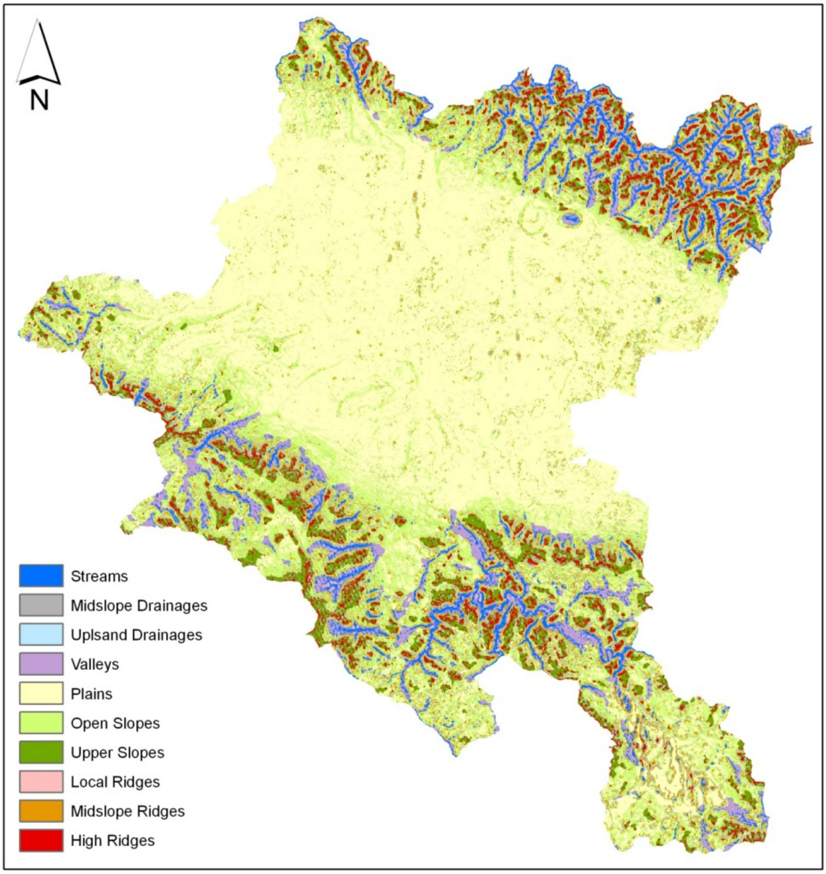

Fig. 5. Landform map of the Sofia Municipality using the TPI-based landform classification algorithm

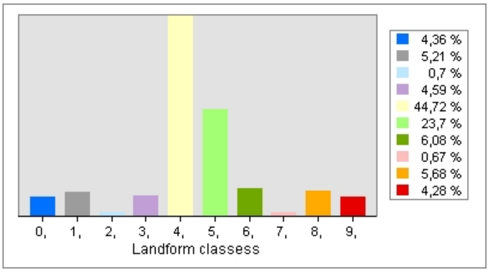

Fig. 6. Histogram of the landform classes of the Sofia City District, calculated in percent

The main landform classes for the study area are the plains and the slopes, respectively with 45% and 30% (Fig. 5 and 6). The ridges and the valleys are presented almost equally and they are distributed mainly in the northern and southern part of the study area.

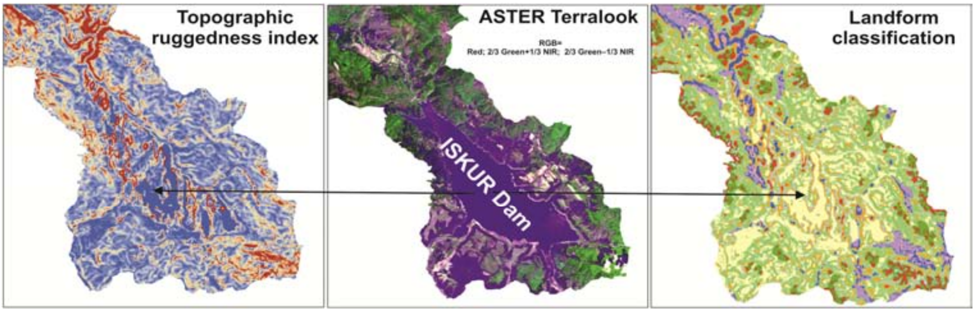

Fig. 7. Anomalies in ASTER GDEM

Some discrepancies and visual anomalies in the ASTER GDEM are observed in water bodies (Fig. 7). The anomalies in the water bodies of the ASTER GDEM are described also by Guth, who assess and compare the geomorphometric characteristics of ASTER GDEM to SRTM DEM [38].

Conclusions

The present study attempts to describe and classify the landforms of the Sofia City District using remote sensing data and GIS technologies. The obtained results will be further analyzed and compared to the outputs form the same classification procedure using various data sources (SRTM DEM and DEM from topographic maps). The data will be used also for landscape planning of the territory.

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КЛАСИФИКАЦИЯ НА ФОРМИТЕ НА ЗЕМНАТА ПОВЪРХНОСТ С ИЗПОЛЗВАНЕ НА ЦИФРОВ МОДЕЛ НА РЕЛЕФА ASTER GDEM И САТЕЛИТНИ ИЗОБРАЖЕНИЯ С ВИСОКА ПРОСТРАНСТВЕНА РАЗДЕЛИТЕЛНА СПСОБНОСТ ЗА РАЙОНА НА ОБЛАСТ СОФИЯ ГРАД

В. Найденова, Ст. Стаменов

Резюме

Морфологичната и морфометрична информация за формите на земната повърхност играят важна роля в пространствения и времеви анализ и моделиране на ландшафта и оказва влияние върху хода на протичане на природните процеси. Геоинформационните технологии дават възможност за извършване на цифров анализ на терена и извличане на серия от морфометрични параметри и елементи на формите на земната повърхност. Геоморфоложкият анализ и интерпретация могат да бъдат извършени чрез различни алгоритми, интегрирани в ГИС софтуерните продукти. Целта на настоящето изследване е да се извърши класификация на формите на земната повърхност и да се опише тяхната хетерогенност за територията на област София-град на базата на цифров модел на релефа ASTER GDEM и сателитни изображения. Приложена е TPI-базирана класификация на формите на земната повърхност и е оценена хетерогенността на терена за изучаваната територия. В резултат на извършените пространствени анализи са съставени морфометрични карти и карта на класовете форми на земната повърхност.