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GIS SPATIAL ANALYSIS OF THE DISTRIBUTION OF SNOW DEPTH: A STUDY OF WESTERN RHODOPES, BULGARIA

Abstract: The aim of the present research is to show the advantages of information technology in investigating the snow cover. The snow data is usually taken from the measurement in meteorological stations which are often sparsely and insufficient. The problem in the analysis of the snow cover is how to present point data spatially and what is the most appropriate model. The area of the present research is the western part of Rhodopes mountain (Southern Bulgaria). The relief is variable from low to high mountainous and the climate is influenced by the high altitude and Mediterranean air advections. The spatial analysis of the distribution of snow depth is done in ArcGIS by application of Spatial Statistics Tools and Geostatistical Analyst. We considered altitude, aspect and slope as explanatory variables that could be used for determination of the territorial distribution of the snow depth. These factors are determined on the base of digital elevation model and the relationship between variables is evaluated by application of regression analysis, ordinary less squares (OLS) analysis and geographically weighted regression (GWR). The high values of R^2 (above 0.7) show the representativeness of the model. A map of spatial distribution of snow depth is created by Map algebra in GIS environment, applying the regression equation of the relation snow depth – altitude. Inverse distance weighted and ordinary kriging interpolation are also carried out. The research shows that spatial presentation of point snow data and its interpretation should be done taking into account the relief and the exposition of the territory.

Key words: snow depth, snow factors, spatial interpolation, regression

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Introduction

Snow is a valuable natural resource with a great importance for the water balance and a main factor for the development of winter tourism. Snow cover influences the Earth surface temperature and snow melting contributes to keep the water level in rivers and dams, which determines the hydrological importance of snow depth. Snow is also a prerequisite for winter tourism and ski sport, and in this relation it contributes to the economic development of regions. Having regard the importance of snow as a natural resource the studying of the distribution of snow depth is topical and could help for rational territorial planning and decision making.

The snow data is usually taken from the measurement in meteorological stations which are often sparsely and insufficient. The problem in the analysis of the snow cover is how to present point data spatially and what is the most appropriate model. In this case it is necessary to determine the main factors for the territorial distribution of the snow depth and to evaluate the type and strength of the relation between independent and dependent variables.

In regard to the above the aim of the present research is to show the advantages of information technology in investigating the snow cover and the factors of snow depth. Geographic information system allows processing of graphic and attribute information and to make spatial and geostatistical analysis, and in this regard it provides opportunities for more detailed study of the snow cover.

The snow cover at Western Rhodopes has been a subject of regional geographical and climatic investigation in Bulgaria. Vekilska (1986) investigates the regime and geographical distribution of the snow cover in the Western Rhodopes. Statistical analysis of the snow data of 30-years period (1950/51 – 1979/80) is done as well as the vertical gradient of the period of snow cover is calculated. The emphasis is on the regime of the snow cover and on the maximal snow depth. The research analyses the average dates of first and last snow cover. Maps of these parameters are elaborated on the base of the analysis of the dependence of the first and last dates of the snow cover on the altitude of the meteorological stations. The influence of solar activity on the regime of snow depth is studied by Yakov (2012). The author analyses the maximal snowfalls, on the base of the data from 19 meteorological stations located in different areas in Bulgaria, taking into account the annual regime of solar activity.

Because of the lack of meteorological stations and complicated relief in mountain regions the spatial presentation and assessment of snow depth in these regions are difficult. In these cases remote sensing, GIS technology and geostatistical analyses show good possibilities. Different interpolation methods are considered by Cansado et al. (2004), Harshburger et al. (2010), Huang et al. (2015). Most of publications about methods of interpolation of snow data give the attention to Kriging and Inverse Distance Weighted interpolations as well as to the importance of snow factors. Harshburger et al. (2010) consider the relationship between physiographic variables (elevation, slope, aspect, clear-sky solar radiation, etc.) and snow water equivalent and conclude that the most important predictor variable of snow water equivalent is elevation. The topographic control of snowpack distribution in a small catchment is analyzed by Revuelto et al. (2014). The authors outline the importance of considering terrain curvature at various scales for explaining the snow depth distribution in mountain environments. Snow accumulates more in small deep concavities, but it is shallower at the end of the season in wider concave areas.

Statistical analyses, multiple linear regression and binary regression tree models are used for studying the snow characteristics and estimating snow cover/snow depth factors (Vevbunt al., 2003; Marchand, 2004; Harshburger et al., 2010; Revuelto et al., 2014). The researches analyze the relation between snow characteristics and environmental parameters as altitude, solar radiation, aspect etc., and most of them consider the altitude as the most important factor. The current research also outlines the importance of the elevation for spatial distribution of snow depth but regarding the nature processes we cannot exclude other environmental factors.

The literature review shows increasing of the publications about the application of remote sensing technology and GIS in snow investigations (Rango,1996; Filipov & Popov, 1998; Filipov, 1999; Chang & Li, 2000; Cansado et al., 2004; Harshburger et al., 2010). Rango (1996) considers the application of remote sensing in snow mapping and in studying other snow variables as temperature, wetness, albedo, grain size. The research presents the possibility of remote sensing technology in mapping snow areal extent using visible and near-infrared sensors and consider snow water equivalent using passive microwave techniques. Huang et al. (2015) analyses the snow distribution on the base of MODIS data and investigates kriging interpolation methods for spatial presentation of snow depth.

Many publications about snow cover/snow depth consider the daily data for determined days of the year and do not consider the snow properties for longer period. The current research presents the snow depth distribution in mountain area by kriging and inverse distance weighted interpolations, and on the base of the regression analyses of morphometric parameters of the area. Average monthly data of 30 years period for the months December – March is used.

Study area

The area of the present research is the western part of Rhodopes mountain, situated in the Southern Bulgaria (Fig. 1) and it takes approximately 7500 km^2. The relief is variable from low to high mountainous with a dense river network. The climate is influenced by the high altitude and Mediterranean air advections. The area is adjacent to the trajectory of southern cyclones that originate in the western part of the Mediterranean. The number of days with snowfall is relatively high in the high parts of the investigated area which causes formation of thick and lasting snow cover on the flat ridges of the mountain. The number of days with snow cover increases to the higher parts in the range of 3-6 months (Nam, 2003). The local orography determines also the wind characteristics. Foehn is often phenomena on the northern slopes the Rhodopes in spring, which is a prerequisite for fast melting of the snow cover.

Data and Methodology

The problem in the analysis of the snow cover and its characteristics is how to present point data spatially and what is the most appropriate model. In this case it is important to determine factors which influence the snow depth. The data from 19 meteorological stations (Fig. 1) is used to present the distribution of the snow depth. The average snow depth data for the period December – March (1950/51 – 1979/80), published in meteorological year books (National Institute of meteorology and hydrology, BAS) is used (Tab. 1). Because of lack of published new data about the whole investigated region and difficulties in receiving unpublished data from Bulgarian Institute of meteorology and hydrology we chose the above period. Having regard the statistical characteristics of the data we consider that this 30-years period is enough reliable for the aim of the research, i.e. to show the possibilities of GIS technology for spatial analysis of snow data.

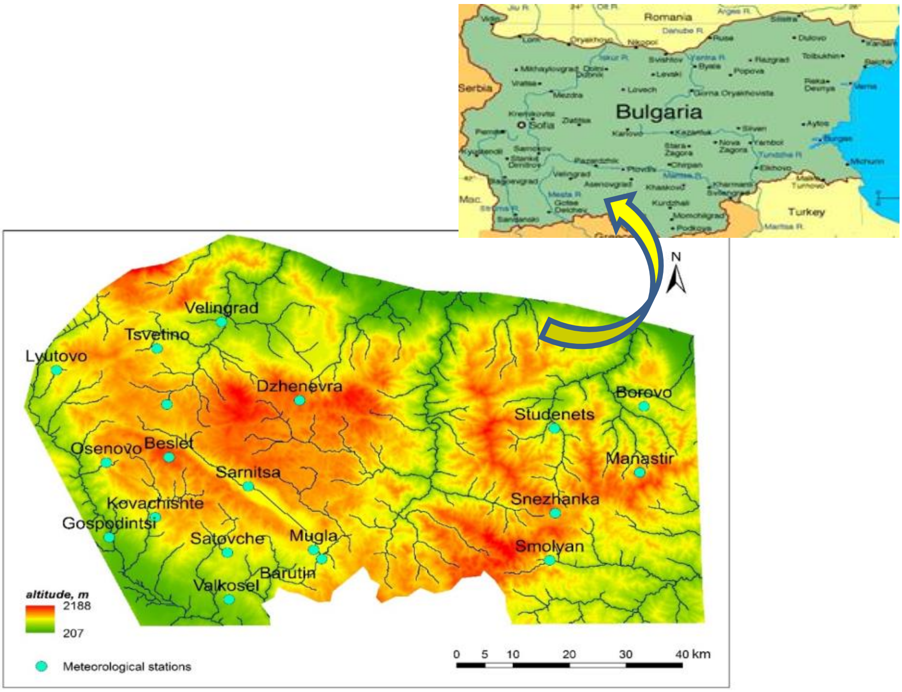

Fig. 1. Study area – Western Rhodopes, Bulgaria

Regarding the characteristics of the modelled phenomena (snow cover/snow depth) we determined altitude, aspect and slope as explanatory (independent) variables that could be used for determination of the territorial distribution of the snow depth. To evaluate the relation between these factors and snow depth regression analysis was carried out using Excel data Analysis Tools and also ArcGIS Spatial Statistics Tools (Geographically Weighted Regression (GWR) and Exploratory Regression) are used for modelling spatial relationships. We applied the regression analysis first between the snow depth measured in the meteorological stations and relief (altitude of the respective station), and repeated the analysis by adding other explanatory variables to assess separately the following relations: 1) snow depth – altitude; 2) snow depth – altitude, slope; 3) snow depth – altitude, aspect; and 4) the combined effect of the three factors: snow depth – altitude, aspect and slope.

Tab. 1. Meteorological stations and average snow depth for the period December – March (1950/51 – 1979/80)

Meteorological stations	Altitude of meteorological stations, m	Snow depth, cm
Barutin	1097	11.0
Beslet	1226	14.2
Borovo	1031	11.2
Tsvetino	1050	9.9
A. Ivanov	1700	36.3
Dzhenevra	1660	29.0
Gospodintsi	545	7.3
Studenets	1737	62.9
Kovachishte	1010	9.8
Lyutovo	1200	9.4
Manastir	1450	19.3
Mugla	1360	15.1
Osenovo	1070	10.1
Satovche	990	7.0
Smolyan	1175	13.7
Sarnitsa	1240	15.1
Velingrad	755	8.2
Snezhanka	1980	67.5
Valkosel	760	6.5

The altitude of meteorological stations is taken from meteorological yearbooks (National Institute of meteorology and hydrology, BAS). The other hydro-morphometric features of the study area are delineated on the base of SRTM digital elevation model, DEM (Jarvis et al., 2006) and using Hydrology tool of ArcGIS. Slope and aspect are also calculated in GIS environment on the base of the DEM. In this case Spatial analyst tools (Surface) are applied. Slopes are calculated in degrees and slope map is elaborated. Having regard the morphometric features of the area slopes are divided in 7 classes as follow: 0-3; 3-12; 12-20; 20-30; 30-45; 45-55 and 55-65. This scale is used taking into account the morphometric and morphographic features of the topographic surface: 3° is accepted as a limit of horizontal areas; 12 and 20 ° are important for delineation of mountain areas (Pantic, 2015), slopes in the interval 20 – 30° are considered as sloping; 30 - 45 ° - steep and above 45 ° - very steep (Konstantinov, 1986). For more detailed analysis the last interval is divided in two ones: 45-55° and 55-65°. The percentages of the different classes is given in Tab. 2.

Aspect (slope exposition) is also derived from DEM in 8 directions and presented in degrees. The analysis of the slope exposition shows that there is not prevailing direction of the slopes (Fig. 2), which is an indicator for complicated mountain relief and could be a reason for change of local climate conditions. The percentages of the areas in the each one of the 8th directions are between 11.11% (total area of slopes with north-western exposition) to 13.42% (north-eastern exposition).

Tab. 2. Areas of slope classes

Slope (in degrees)	**Area, %**
0 - 3	5.67
3 - 12	35.72
12 - 20	33.30
20 - 30	24.10
30 - 45	1.17
45 - 55	0.04
55 - 65	0.002

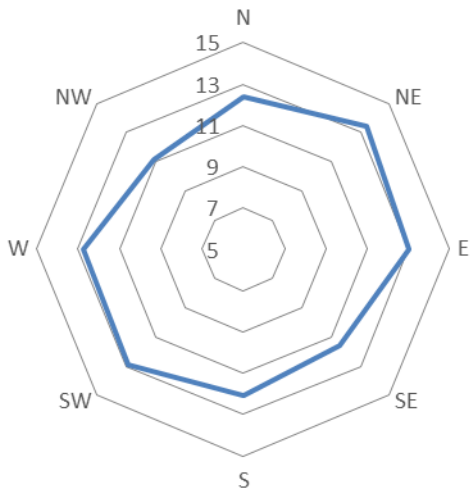

Fig. 2. Percentage distribution of areas according to the slope exposition

Taking into account the coordinates of each meteorological station and generated slope and aspect maps we extracted the values for slope and aspect of the location of each one of the 19th meteorological stations in the study area, which are used in the regression (multiple regression) analysis. The dependent variable is the average monthly snow depth for the winter period (December-March), measured in the meteorological stations and independent variables are altitude (elevation), slope and aspect of the location of each one of the stations.

For spatial presentation of snow depth two methods are used: interpolation and map algebra (ArcGIS Spatial Analyst Tools). The data is modeled by Inverse Distance Weighted (IDW) and Ordinary Kriging interpolations. Other option for spatial presentation of snow depth is to use the regression equation to calculate the snow data for each cell of the terrain raster, taking into account environmental factors. In this case we recalculated DEM by Map algebra, using the regression equation of regression analysis of the relation snow depth – relief (altitude). As a result a raster surface is received presenting the distribution of the snow depth.

Results

Statistical analysis of the relation between snow depth and explanatory variables (altitude, aspect and slope) shows high values of correlation coefficients. Considering the dependence of snow depth on the altitude and other morphometric parameters (slope and aspect) there is not significant difference in the model if we add slope and aspect to the altitude (Tab. 3).

Tab. 3. Regression statistics of the dependence snow depth values on the morphometric parameters

Regression statistics	Altitude	Altitude, slope	Altitude, aspect	Altitude; aspect; slope
Multiple R	0.8516	0.9083	0.8510	0.8539
R Square	0.7252	0.8250	0.7243	0.7291
Adjusted R^2	0.7090	0.7981	0.6875	0.6710

The high values of the R^2 (above 0.7) show the representativeness of the model. The results are confirmed by GWR and Exploratory Regression. The highest coefficient is obtained for received at multiple regression with altitude and slope but applying OLS analysis and explanatory regression show statistical significance of the relationship between snow depth and altitude only.

The snow depth is calculated on the base of the DEM by Map algebra. Each cell in the relief raster is recalculated according to the regression equation of the relation between snow depth and altitude. The results are presented on Fig. 3a. The highest values are on the watersheds and the lowest at the areas with the altitude less than 650 m, and particularly in wider river valleys which could be related to the advection of warm air.

Two interpolation methods are also used to present point data in continuous type – Ordinary Kriging and IDW. The Kriging interpolation shows the highest values of the snow depth in the area of Studenets and Snezhanka, stations with highest altitude (Fig. 3b).

IDW interpolation (Fig. 3c) shows similar results as Kriging, regarding the highest values of the snow depth. Considering the interpolation results and morphographic features of the region, and also analyzing the errors of the interpolation, we could suggest that the IDW interpolation is more appropriate method for the investigated snow depth, and additional investigations are needed in this direction having regard the limited number and unevenly distribution of available meteorological stations.

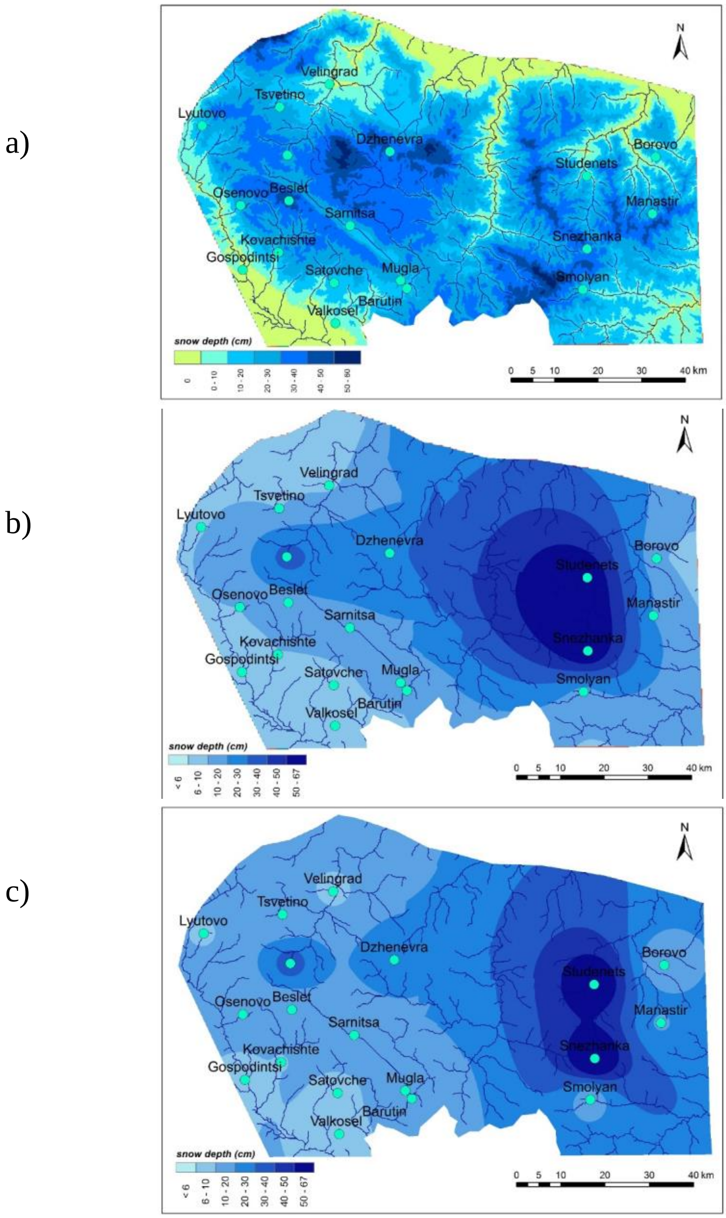

Fig. 3. Spatial distribution of snow depth in the Western Rhodopes

a) Snow depth calculated on the regression analysis snow depth – altitude;
b) Snow depth by Kriging interpolation;
c) Snow depth by Inverse Distance Interpolation

Conclusion

The comparison of the above three methods for presenting the snow depth shows that using regression equation is more logical approach particularly in complicated mountain areas. In the current research modelling of spatial relationship between snow depth and explanatory variables - altitude, slope and aspect shows statistical significance of the relation snow depth – altitude. The uncertainties of the regression analysis is in the limited number of meteorological stations in the study area (in this case – 19) which determines the length of the data row. To solve the problem of data limitation many researchers use virtual stations for snow-free pixels. Entering virtual snow stations with a zero snow depth value (Foppa et al., 2005; Huang et al., 2015) gives good results at analysis of snow cover for selected days but when the analysis covers average data for longer period the problem is more complicated.

The both methods of interpolation, used in the current research (Kriging and IDW), show that the interpretation of the results should be done taking into account the relief and the exposition of the territory. Interpolation methods could give better results at low relief or if the set of meteorological stations is denser.

The investigation of snow depth/snow cover shows that future studies should be focused in finding the most proper way for removing data imperfections and spatial presentation of point data from sparsely and insufficient meteorological stations in complicated mountainous relief (including consideration of other environmental factors, for example air temperature, solar radiation, forest vegetation).

GIS technology allows processing of large amount of spatial data and various tools for presenting point data in continuous spatial information. In this relation raster data format is more appropriate for spatial analyses and the details of the results strongly depends on the resolution of the input raster. Disadvantage in this case would be the size of the raster files which could slow down the performance of the analysis. Entering data in digital format in GIS environment allows easily finding of spatial relations between investigated phenomena and updating of the results. To avoid incorrect interpretations and analyses of the results geometrical attributes of the data should be considered taking into account physical nature of the modelled phenomena.

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ГИС ПРОСТОРНЕ АНАЛИЗЕ ДИСТРИБУЦИЈЕ ВИСИНЕ СНЕГА: ИСТРАЖИВАЊЕ НА ЗАПАДНИМ РОДОПИМА, БУГАРСКА

Резиме: Циљ рада је да покаже предности коришћења информационих технологија у истраживању снежног покривача. Подаци о снежном покривачу су углавном добијени након посматрања и мерења на метеоролошким станицама, али су они често оскудни и недовољни. Проблем у анализи снежног покривача је како просторно представити податке и који је најбољи модел. Област коју обухвата истраживање јесте западни део Родопских планина (Јужна Бугарска). Просторна анализа дистрибуције висине снега урађена је у програму ArcGIS апликацијом Spatial Statistics Tools и Geostatistical Analyst. Истраживање је показало да би приликом просторног представљања података о висини снега, требало узети у обзир надморску висину и пад терена. Мање важним се показала експозиција терена. У овом случају је регресиони модел показао бољи резултат у односу на онај остварен Кригингом.

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