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SCRIPTING LANGUAGES FOR GEOMORPHOLOGICAL MODELLING AND TOPOGRAPHIC VISUALIZATION OF SERBIA

ABSTRACT: Scripting cartographic technique is a new method of geospatial data visualization – especially with thematic mapping such as geomorphological models. The purpose of this study was to explore the use of Generic Mapping Tools (GMT) and R for geomorphological and topographic mapping of Serbia using free open datasets (DEM, SRTM/GEBCO, OpenStreetMap). Current trend in education and research of distance-based and online-based education suggests that application of free high-resolution data for modelling and mapping by open source cartographic toolsets are more likely to result in deep geospatial analysis of the geomorphology of Balkans with associated geographic phenomena: hydrology, soils, vegetation, geology. Presented fragments of scripts aim to demonstrate the technical usage of R and GMT coding in cartographic workflow with a case study on Serbia. Using qualitative descriptive cartographic approach to visualize the slope, aspect and terrain elevations over the country and the ‘raster’ package provided by R, it was found that the geomorphology of Serbia spatially differs in southern and northern parts of the country resulting in regional geologic evolution and tectonic dynamics of the Balkan formation. The presented maps portrayed general distribution of the landforms in Serbian region of Balkans. The research contributes to the methodological development and testing of the cartographic techniques as well as geomorphological and environmental studies of Serbia.

KEYWORDS: R, programming language, GMT, script, geomorphology, Serbia, mapping, cartography

INTRODUCTION

Qualitative cartographic data visualization and spatial analysis are the essential steps in geographic research. Plotting maps, graphs, and models representing

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Topographic map of Serbia

SRTM/GEBCO 15 arc sec resolution global terrain model grid



OpenStreetMap tile of Serbia. Plotting: R package 'OpenStreetmap'

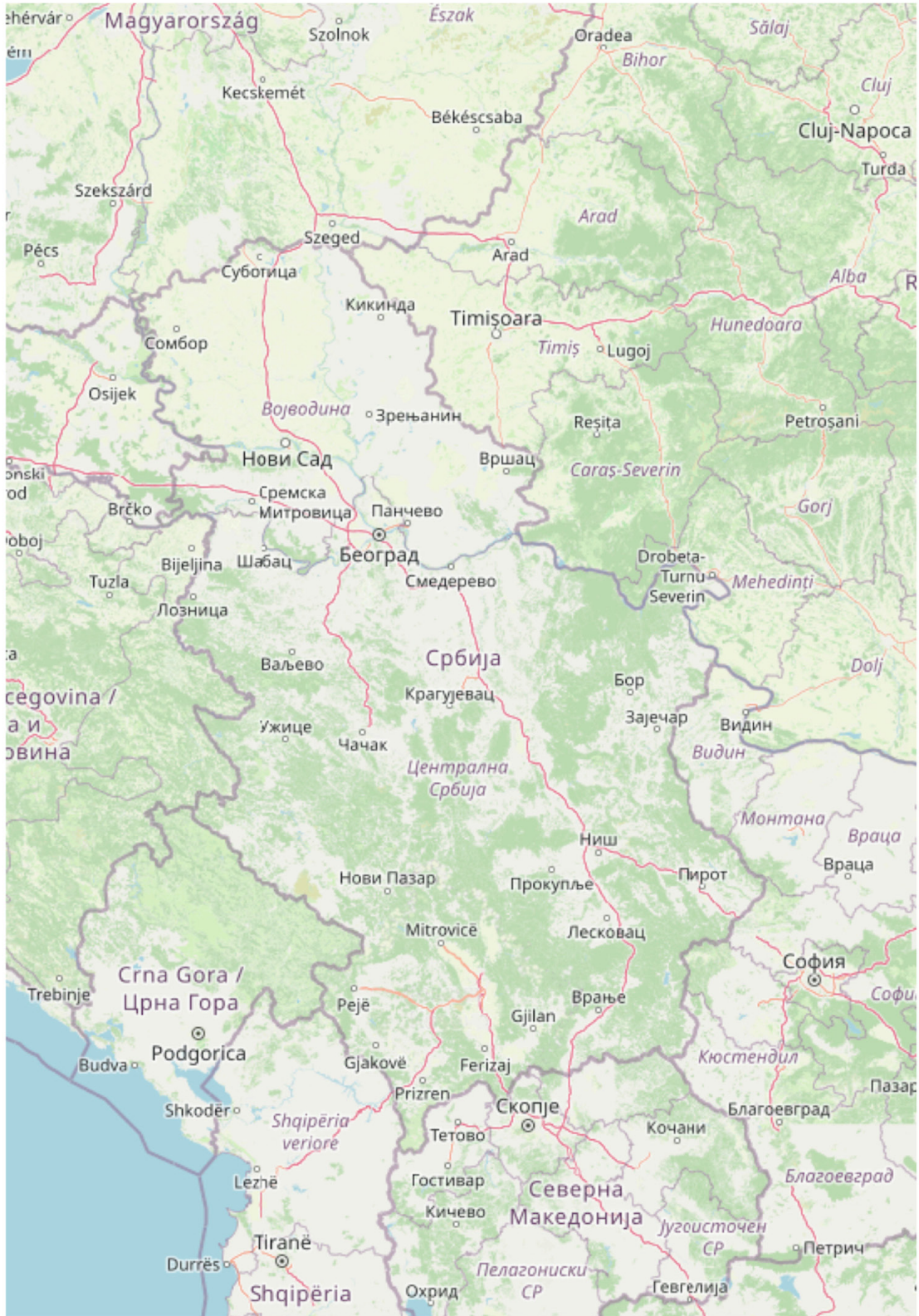


Figure 1. Map of Serbia. Left: GMT mapping. Right: OpenStreetMap, R. Source: author.

the phenomena of the Earth's objects present cartographic findings which in turn can significantly help in further research related to the Earth sciences (geological, environmental, geomorphological and landscape studies). However, it can be challenging, since there is not one accepted and universal cartographic method for data visualization and GIS mapping due to the wide variety of GIS. Analysis of territory is an essential part in environmental studies which involves such processes as data search and capture, data processing and visualization, data interpreting and modelling. At the same time, the process of cartographic data analysis is required to be selective and systematic while applying criteria for data quality with arising questions (Raster or vector? General or thematic? Topographic or environmental? Large-scaled or small-scaled? Fine-resolution or medium (or even coarse) resolution?) and GIS tools for data processing and mapping. Despite these challenges in the cartographic workflow, environmental mapping is always well worth the effort, since the results contribute to the increase of the general pool on research focused on the sustainable development and environmental modelling of the Earth.

There is no shortage of publications on the Balkan and Central European environment and ecology, land cover types and geology (see e.g. Marković et al., 2020; Cvetković et al., 2004; Gerzina & Djerić, 2017; Klaučo et al., 2013a, 2013b; Joó et al., 1981). There are also related papers on using GIS, spatial analysis and data modelling in environmental studies (Marović et al., 2002; Suetova, 2005; Lemenkova, 2020a, 2020b; Klaučo et al., 2014, 2017; Lemenkova et al., 2012; Lindh, 2004; Schenke & Lemenkova, 2008). However, there is not much of specific reference to using programming languages and scripting toolsets in cartographic data processing. There are various publications on using commercial GIS in geographic studies and environmental monitoring but none of them fulfill the requirements of the open source programming libraries and scripting tools which correspond to modern cartography.

In contrast with existing research on environmental studies of Serbia and Balkans (Bokhorst et al., 2009; Aufgebauer et al., 2012; Alex et al., 2019; Vidojević et al., 2020) this article first discusses cartographic issues of using the Generic Mapping Tools (GMT) relevant to high-quality data mapping. In addition, the code snippets used for visualization of the data are presented for repeatability with a detailed technical explanation on data processing. Furthermore, the reference is made to the GMT styles that were applied for topographic mapping of Serbia (specific codes of the most important GMT modules 'grdcut', 'psbasemap', 'grdcontour', 'pscoast' and 'pstext' are presented and explained in brief).

The R libraries for visualization of the free geodatasets and their geomorphological modelling are presented using R programming language (R Core Team 2020). These include such packages as 'tmap' (Tennekes, 2018), 'OpenStreetMap' and 'raster' as well as the dependent libraries ('ggplot2', 'maps', 'sp', 'sf'). Furthermore, some examples of functions presented in R flags were described and explained and cartographic results were compared. This is then followed by the discussion of results on geomorphological modelling of the slope, aspect and topographic elevation depicting the geomorphology of Serbia

by using scripting cartographic approach to qualitative spatial geographic research. Finally, there is a recommendation on further studies and consideration of the open source datasets applicability (such as OpenStreetMaps) in geomorphic studies and ways of cartographic visualizing and modelling of such data for spatial analysis.

DATA AND METHODS

A large number of approaches can be applied to cartographic data visualization and geomorphological modelling where the research focus and preferred choice of GIS will influence geospatial analysis. The geomorphological modelling depends on whether the data are used as a set of the raster grids that relate to a particular territory or vector files (e.g. ArcGIS ESRI .shp format). Another issue concerns a process of data collection, interpretation and geospatial analysis that may include additional set of data organized in layers for mapping layouts used for 3D and 2D terrain modelling. This paper presents a combination of quantitative and qualitative geomorphological research, where the input geodata are analyzed following data capture using scripting approaches of the GMT and R. There are following strategies using in this paper for geomorphological analysis.

The data capture has been performed from the two sources: 1) GEBCO/SRTM dataset (GEBCO Compilation Group, 2020) used for plotting Figure 1 (topographic map of Serbia); 2) Embedded datasets in R using packages ‘OpenStreetMap’ and ‘raster’. Besides GEBCO grid, the ETOPO1 can also be used as a replacement (Lemenkova, 2020e) which has a lower file size comparing to GEBCO, although lower resolution as well. After data collection is complete, the set of data is focused upon, where data modelling and cartographic visualization is a separate step following data capture.

The topographic map (Figure 1) has been plotted by GMT cartographic scripting toolset (Wessel & Smith, 1995) using methodological approach discussed in details in existing relevant technical papers (Lemenkova, 2019a, 2019b). The mapping has been based on the sequence of codes by modules for plotting cartographic elements (Lemenkova, 2019c):

- Module ‘grdcut’ for selecting study area: `gmt grdcut GEBCO_2019.nc -R18/24/41/47 -Gserbia_relief.nc`
- Module ‘grdimage’ for visualizing the raster: `gmt grdimage serbia_relief.nc -Cmyocean.cpt -R18/24/41/47 -JM6i -P -I+a15+ne0.75 -Xc -K > $ps`
- Module ‘psbasemap’ for adding cartographic grid with ticks and title: `gmt psbasemap -R -J -Bpx1f0.5a1 -Bpy1f0.5a1 -Bsxg1 -Bsyg1 -B+t"Topographic map of Serbia" -O -K >> $ps`
- Module ‘grdcontour’ for modelling isolines (topographic contours with a span every 1,000 m): `gmt grdcontour serbia_relief.nc -R -J -C1000 -W0.1p -O -K >> $ps`
- Module ‘pscoast’ for adding borders and rivers: `gmt pscoast -R -J -P -Ia/thinner,blue -Na -N1/thickest,red -W0.1p -Df -O -K >> $ps`

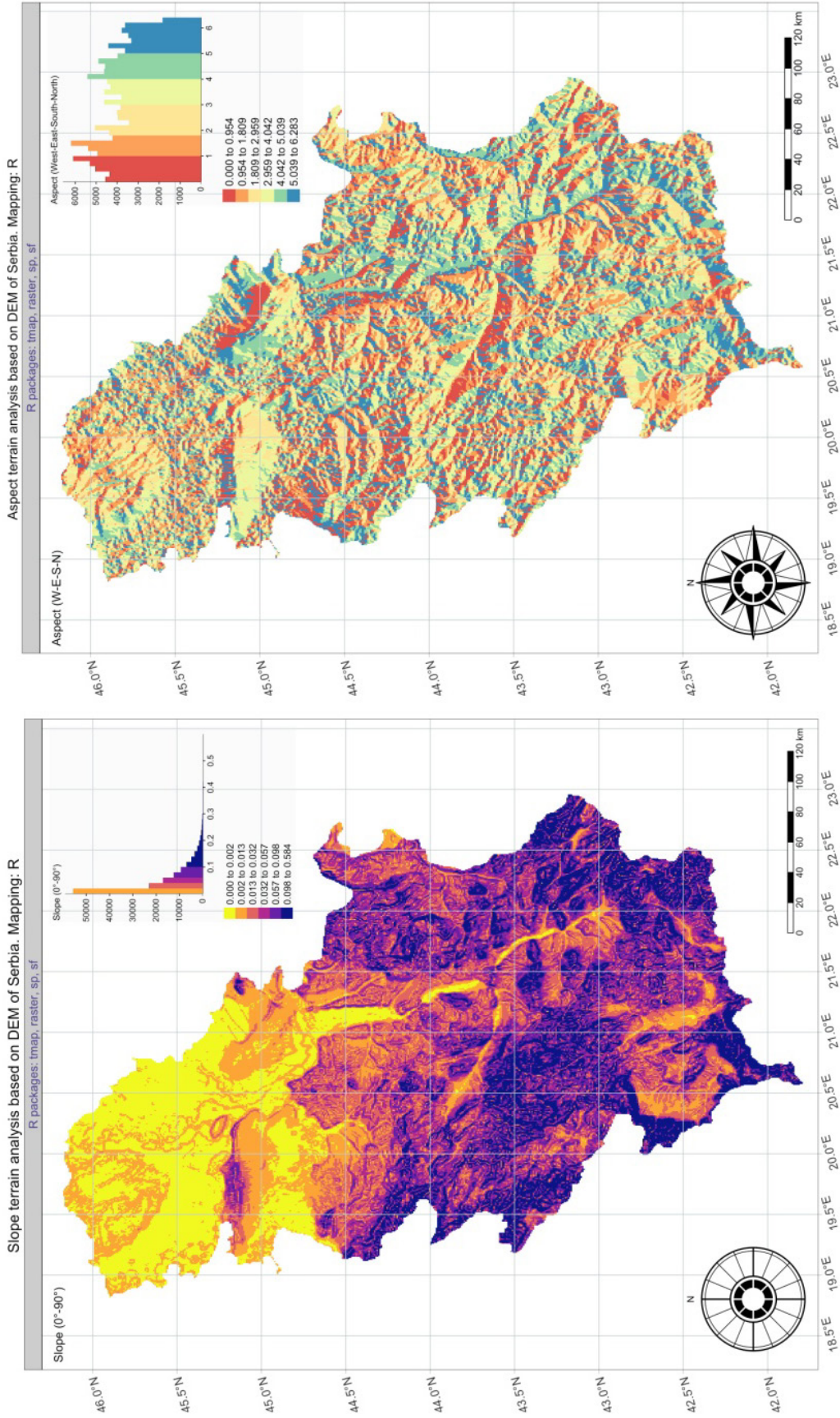


Figure 2. Left: slope modelling; Right: aspect modelling; Visualization: R; Source: author.

- Module ‘pstext’ for adding text annotations: `gmt pstext -R -J -N -O -K -F+jTL+f14p,Helvetica-Narrow-Oblique,black+jLB -Gwhite@30 -Wthin- nest >> $ps << EOF 20.0 44.1 Belgrade EOF`
- Module ‘psxy’ for adding points (circle for capital city of Belgrade with coordinates in LON/LAT convention): `gmt psxy -R -J -Sc -W0.5p -Gyellow -O -K << EOF >> $ps 20.0 44.0 0.3c EOF`

The examples given above illustrate the principle of GMT functionality which performs mapping in a stepwise programmable manner similar to the programming language and scripting approaches used in geosciences for data analysis and processing (e.g. Lemenkova, 2019d, 2019d, 2019f). The final map made in GMT is presented in Figure 1 (left).

The next step in data analysis included the use of R library ‘OpenStreet-Map’ for data visualization in Figure 1 (right). This has been plotted using libraries ‘maps’, ‘ggplot2’, ‘OpenStreetMap’ and dependent ‘sp’ of R. First, the data coordinates have been given using LAT/LON convention by the following two codes: ‘upper_left <- c(48, 18.0)’ and ‘lower_right <- c(40.0, 24)’ where the coordinates for the corners of the map were defined. Then the map in Figure 1 (right) was modeled on a screen using the following code: ‘map_osm <- openmap(upper_left, lower_right, type = c('esri-topo'))’. Afterwards the map has been visualized using command ‘plot(map_osm)’.

The third step in research methodology included geomorphological analysis using the two major libraries of R; ‘raster’ (used for modelling slope, aspect, hillshade and visualizing DEM based elevation), and ‘tmap’ used for cartographic mapping. The most important functions of the ‘tmap’ included the following ones. The general style of the layout was defined using the ‘tmap_style’ function. Then the raster was visualized using the ‘tm_shape’ function: ‘tm_shape(slope, name = "Slope", title = "Slope")’. The scale bar on all the maps has been added by the function ‘tm_scale_bar()’ with set up parameters (position, color, text).

The ‘tm_compass()’ function has been used for presenting compass oriented star in the lower left corner of the maps (Figure 2 and 3). The main cartographic visualization has been set up using the ‘tm_layout()’ function where a variety of parameters was adjusted (legend, position and text, title, histograms on data distribution, margins, among others). The ticks on the grid have been defined using the function ‘tm_graticules()’ with a set up text size, color, frequency of step. All the maps have been plotted in RStudio (RStudio Team 2017).

The geospatial datasets are usually visualized into a digital form for closer study and analysis (Gohl et al., 2006; Josimović & Pucar, 2010; Keller et al., 2020; Kuhn et al., 2006). This concerns the cartographic workflow techniques as well. Datasets such as raster grids, OpenStreetMap tiles, vector layers, contour lines of rivers and country boundaries may not be geoprojected and therefore additional geodata processing may be directly interpreted and reprojected using GDAL (Geospatial Data Abstraction Library). An example would be a the projecting of the OpenStreetMap tile of Serbia by ‘openproj’ function which projects the open street map to an alternate coordinate system. For instance, selecting a Lambert Conic Conformal projection requires the following code:

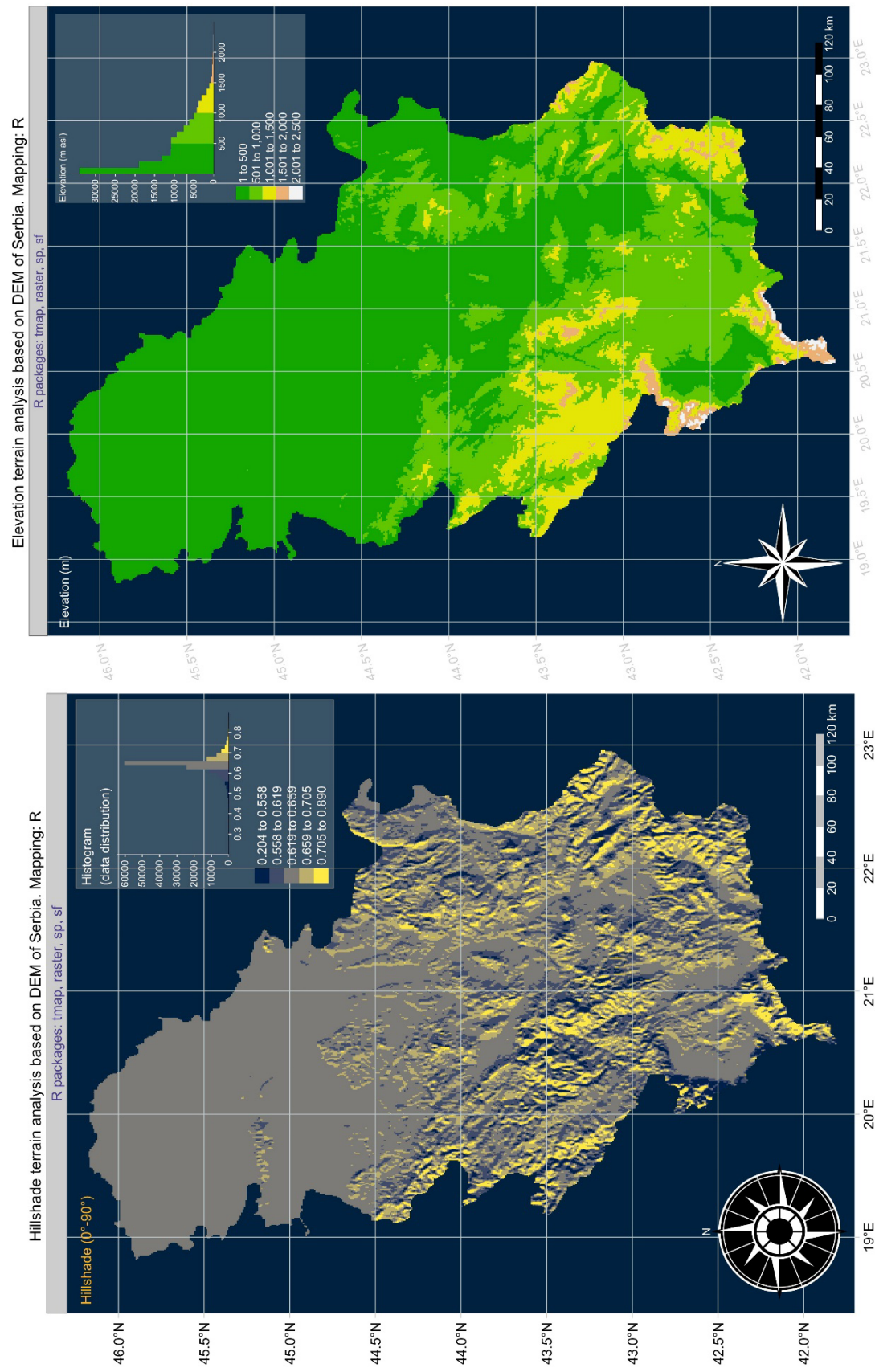


Figure 3. Left: Hillshade modelling; Right: Elevation DEM, R; Source: author.

map_serbia <- openproj(map_osm, projection="+proj=lcc +lat_1=41 +lat_2=47 +lat_0=44 +lon_0=21"). Then visualization of the map has been performed by the following code: plot(map_serbia, removeMargin=TRUE).

RESULTS AND DISCUSSION

The results shown in this manuscript demonstrated topographic data covering the territory of Serbia (SRTM, GEBCO, embedded datasets) processed in various ways by the scripting techniques of GMT toolset and R libraries. The results include visual geospatial data: cartographic layouts, plotted additional insert maps showing global location of the country, geomorphological models of slope, aspect and hillshade of the relief, visualized OpenStreetMap tiles. Six maps have been visualized using scripting cartographic techniques of R and GMT which shows a machine learning approach in contemporary cartography combining programming techniques of script writing with visualization of geospatial data.

Four of the maps were mapped for the geomorphological research (Figure 2 and 3), and two maps as topographic visualization (Figure 1). The map in Figure 1 (left) was plotted in GMT using presented techniques which can be repeated by the GMT learners and the datasets from GEBCO/SRTM grids using additionally available examples of GMT mapping (e.g. Lemenkova, 2020c, 2020d). The other maps (Figure 2 and 3) were plotted in RStudio and demonstrated the relief particularities in Serbia: slope steepness, aspect orientation by compass (West-North-East-South), hillshade relief which shows the relief with artificial illumination of the modeled light source which gives a visually effective way of the terrain representation and is widely used in the geographic studies or research. The maps are accompanied by the plotted histograms showing general statistical data distribution.

The paper is illustrated by the six cartographic images made by the author using free open source data and tools: the GMT scripting toolset and R (RStudio environment). The results are presented in form of topographic maps, geomorphological models histograms, which provide visualization of the topographic distribution of relief over the Republic of Serbia. The novelty of the research consists in the innovative cartographic methods that use GMT and R scripting for mapping the territory of Serbia which has not been published before. The study utilizes open source tools and data and presents automatization of the cartographic workflow through scripting which implies the repeatability of codes for similar geographic research in Serbia due to the free datasets and free instruments (R and GMT).

In this study, the data were captured freely from the open sources, which is a valuable point nowadays, since many researchers and scholars have a tendency for the online-based, home-based or distance-based studies and self learning. At the resulting research step, the data were visualized using a variety of modules and functions. These maps were digitally visualized on a screen and then saved. Plotting two maps side-by-side has been done: Twomaps <- tmap_arrange(map1,

map2). `tmap_save` (Twomaps, "Serbia_SlopeAspect.jpg", dpi = 300, height = 10, width = 15), where height and width determine map dimensions.

CONCLUSION

Existing studies on Serbian environment (Savic et al., 2021; Francke et al., 2016; Gachev et al., 2016; Kadović et al., 2012) identified that processing data reflected variability of the ecological and geographic processes that mirror its geomorphology which takes an important part of the land cover studies as a part of the complex ecosystems in Serbia. Hence, effective cartographic visualization of the terrain is a way of increasing our understanding of the landforms, visualizing possible correlations between the hydrological, botanical and soil factors in geomorphological context and increasing cartographic flexibility by using free data (SRTM, GEBCO, OpenStreetMap), supported by the open tools such as GMT and RStudio.

This research demonstrated that scripting methods are a means of more effective and flexible cartographic routine, since coding enables geographic data processing more quickly and transparent comparing to GIS. This research also pointed out factors associated with the use of R and GMT: the need of mastering scripting syntax as such and the access to the internet for data capture, installations and eventual look-up at technical tutorials. Geographic literature is also linked to the research on the geomorphology of the Balkans (Temovski et al., 2019; Toljić et al., 2013; Zagorchev, 2021) reflecting variability of Serbian geomorphology in regional context: mountains, valleys, highs, hills, and a variety of minor landforms.

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СКРИПТНИ ЈЕЗИЦИ ЗА ГЕОМОРФОЛОШКО МОДЕЛОВАЊЕ И ТОПОГРАФСКУ ВИЗУЕЛИЗАЦИЈУ СРБИЈЕ

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РЕЗИМЕ: Скриптна картографска техника је нов метод визуелизације геоспацијалних података – посебно са тематским мапирањем као што су геоморфолошки модели. Циљ овог проучавања је истраживање употребе Генеричког алата за мапирање (енгл. GMT) и R за геоморфолошко и топографско мапирање Србије користећи слободне отворене скупове података (DEM, SRTM/GEBCO, OpenStreetMap). Актуелан тренд у образовању и истраживање наставе на даљину и онлајн наставе указује на то да примена слободних података високе резолуције за моделовање и мапирање путем картографског алата из отворених извора, највероватније резултира дубоком геоспацијалном анализом геоморфологије Балкана са повезаним географским феноменима: хидрологија, земљишта, вегетација, геологија. Приказани фрагменти скрипта имају за циљ да демонстрирају техничку употребу R и GMT кодирања у картографском процесу рада где је Србија у фокусу истраживања случаја. Користећи квалитативни описни картографски приступ

да би се визуелизовали нагиб, положај и издизање земљишта широм земље и „растер” пакет обезбеђен путем R, откривено је да се геоморфологија Србије просторно разликује у јужним и северним деловима земље што резултира регионалном геолошком еволуцијом и тектонском динамиком балканске формације. Приказане мапе показале су генералну дистрибуцију рељефа у делу Балкана у којем је Србија. Истраживање доприноси методолошком развоју и тестирању картографских техника као и геоморфолошким изучавањима и изучавањима животне средине у Србији.

КЉУЧНЕ РЕЧИ: R, програмски језик, GMT, скрипт, геоморфологија, Србија, мапирање, картографија