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GEOCOMPUTATION OF DEM BASED TERRAIN RELIEF IN BULGARIA USING GMT AND R SCRIPTING APPROACHES

P. Lemenkova¹

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ABSTRACT

This paper analyzes two scripting approaches for topographic and geodetic visualization and geomorphological modeling of Bulgaria: R language and Generic Mapping Tools (GMT). The data include high-resolution raster grids: topographic datasets (GEBCO, SRTM), geoid model based on Earth Gravitational Model 2008 (EGM-2008) and DEM for geomorphological modeling of terrain: slope, aspect, hillshade and elevation. Scripting mapping was used as a replacement of the standard GIS methods of data visualization by a programming approach which is beneficial for the mapping workflow in terms of effectiveness of data processing. The paper presents 7 new maps and concludes that mapping by R and GMT that incorporate shell scripting and finely adjusted controlling on cartographic plotting, along with expanded functionality of data visualization in GMT and geospatial modeling in R, have the greatest potential for contemporary cartographic and geodetic techniques.

1. Introduction

In the early 1990s, scripting cartographic program Generic Mapping Toolset (GMT) emerged as new mapping approach to generate publication-quality maps and automate workflows [41]. Along with programming languages, such as R [33], the scripting techniques present new ways of automatization in mapping and increase the precision and accuracy of data processing in Earth sciences [16].

¹ Polina Lemenkova, Researcher, Université Libre de Bruxelles, École polytechnique de Bruxelles (Brussels Faculty of Engineering), Laboratory of Image Synthesis and Analysis (LISA). Building L, Campus de Solbosch, Avenue Franklin Roosevelt 50, Brussels 1000, Belgium. E-mail: polina.lemenkova@ulb.be or pauline.lemenkova@gmail.com

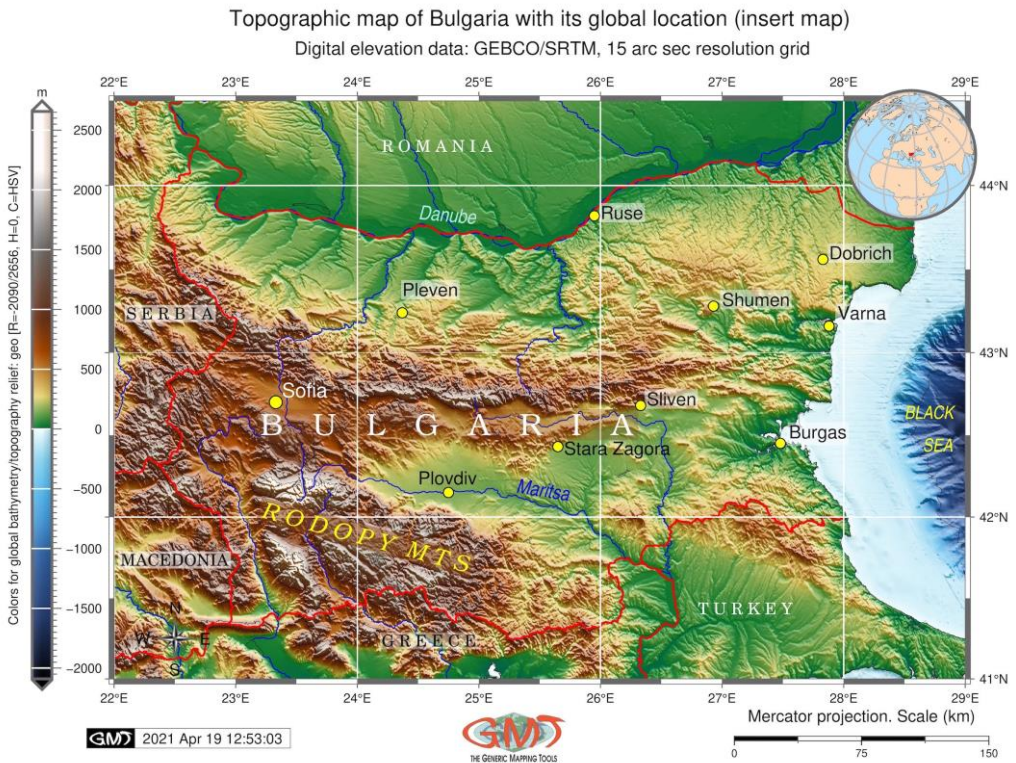


Figure 1. Topographic map of Bulgaria. Mapping: GMT. Source: author

In preparing geographic research supported by mapping, cartographers frequently ask themselves ‘Which GIS software do I need?’, or ‘What kind of geodata do I need to use?’ The answers depend on the purpose and scale of the proposed maps and the topic being investigated (e.g., hydrological, topographic, geomorphological, biogeographic or land cover mapping). The general rule in selecting GIS is that GIS with an open-source availability (especially for students) is preferable, unless a commercial GIS software is available in the university GIS centers.

In view of the increasing mode of the distance-based research, e-learning or online-based studies, the availability of GIS becomes a crucial factor for cartographic mapping and geospatial analysis in universities. Compared to the numerous existing applications of GIS in geospatial research [4 – 6, 12 – 15, 36, 39], the GMT has gained momentum as a cartographic tool in geophysical and geological mapping, with examples of various existing applications [17 – 19, 22 – 24], which is caused among other factors by its free open-source availability. The same can be applied to the R programming language which has also been widely used in various applications of data modeling and statistical analysis [20, 27].

Based on the analysis of functionality of GMT and R and their key differences with GIS, this paper presents the distinctive approaches of these two scripting tools, and how these have led to the unique possibilities in contemporary mapping. If the geomorphological data modeling is a main task of the research, the GIS would be expected to demonstrate that it has a broad functionality in the topographic data processing both for 2D and 3D data visualization, as it is possible by GMT [25, 26].

2. Materials and Methods

2.1. Data

When choosing cartographic datasets, the aim is to address the study area in a comprehensive manner using possibly high-resolution datasets available online for topographic and environmental data: ETOPO1, GEBCO, SRTM, GLOBE, CORINE, to mention a few of them. Another point of concern consists in the acceptable data formats: GRID (.grid), GeoTIFF, vector layers in ArcGIS .shp format), NetCDF (.nc), readable or importable by a specific GIS.

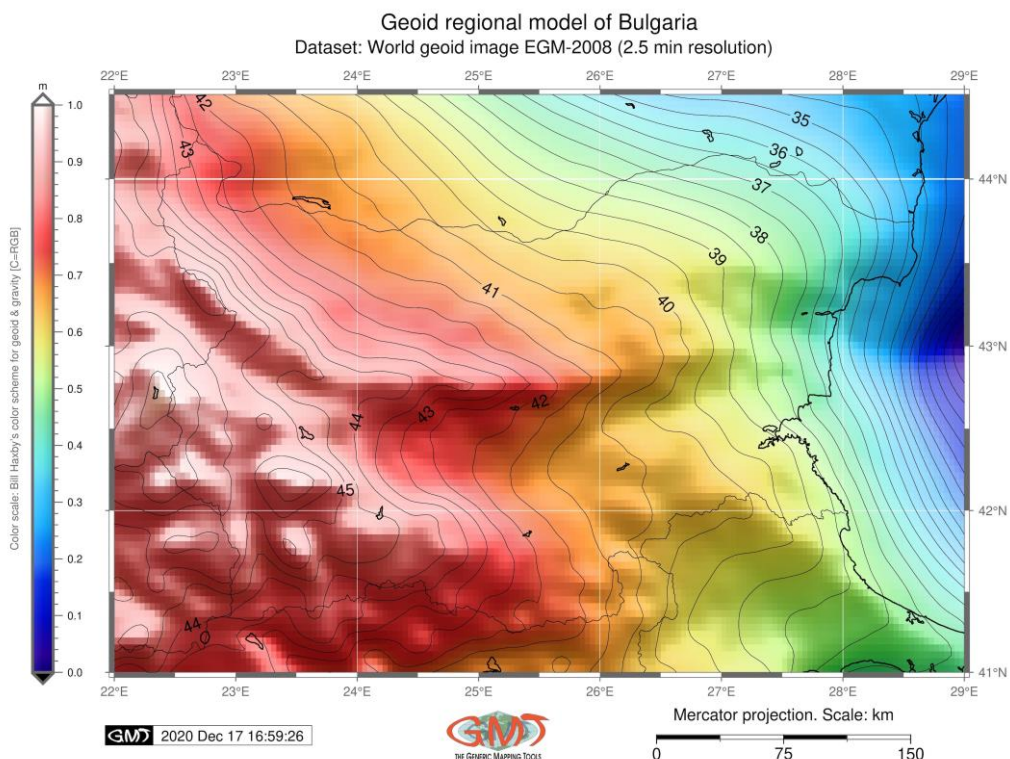


Figure 2. Geoid model of Bulgaria. Mapping: GMT. Source: author

A data analysis of land cover change or spatio-temporal context of changes may seek recent geodata (less than 5 years old) and then include earlier rasters for comparative analysis. This is a commonly acceptable scheme for the land cover changes and analysis of correlation with geomorphology of the study area — especially as used in landscape studies and environmental applications, i.e. based on Landsat TM or Sentinel-2A imagery [29, 30]. However, in general, the origin of data should be as recent as possible. Based on these general rules, this research uses high-resolution, the most recent available datasets: GEBCO/SRTM grid used for mapping (Fig. 1), the geoid model determined by Earth Gravitational Model 2008 (EGM-2008) [32] for mapping (Fig. 2), gravity grid for mapping (Fig. 3) using available geophysical datasets and raster grid from the Scripps Institution of Oceanology [34, 35] and embedded datasets by ‘raster’ of R used for mapping (Fig. 4 – 7).

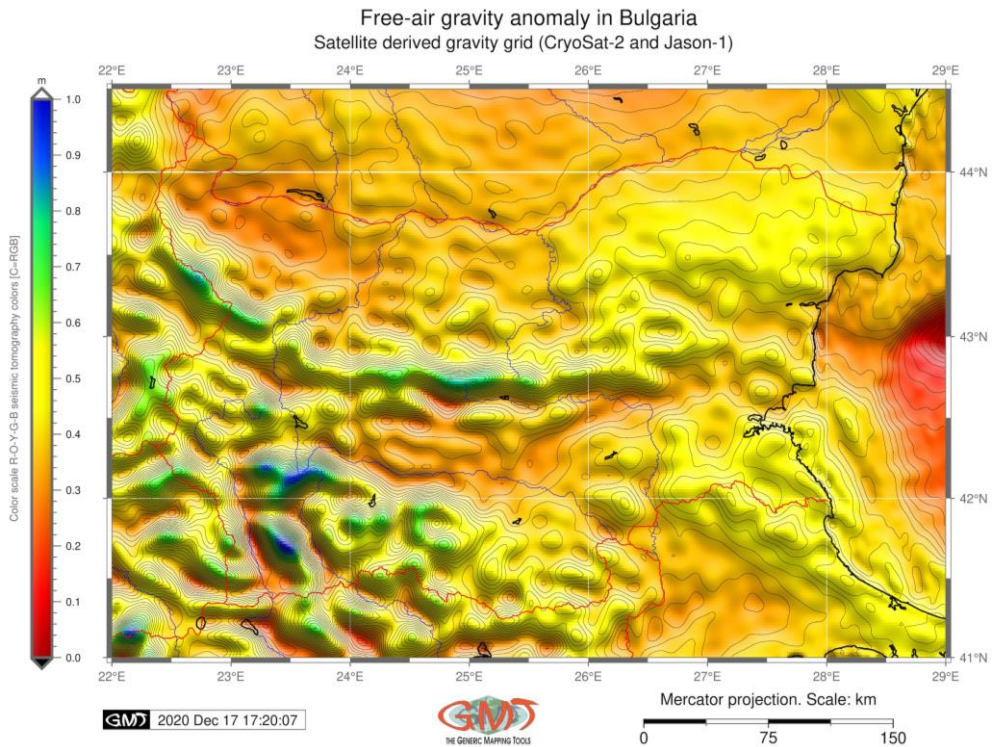


Figure 3. Geophysical gravity approximations in Bulgaria. Mapping: GMT. Source: author

2.2. GMT scripting

The thematic maps (Fig. 1, 2 and 3) have been plotted by GMT cartographic scripting toolset [41] using methods discussed in relevant previously published papers [21]. The mapping was based on the sequence of codes by modules for plotting cartographic elements [28]. The GMT scripting and coding process for each map relies on the use of GMT modules assigning ‘flags’ (or commands, using specific syntax) for specific cartographic elements (grid ticks, bar scale, annotations, color palette, title and subtitle, etc.) to the map’s layout. This process (for example, for annotating texts by ‘pstext’ or plotting elements by ‘psxy’) may have iterations and be repeated as many times as necessary and then be integrated in a script. The issue of GMT syntax needs to be strictly considered, as well as the general file organization (working directory, path to files, etc). Each GMT module has a specific guide that provides functional information on its use (flags, options, etc) of the commands and the nuances. For example, the usage of the selected commands of the GMT for Figures 1, 2 and 3 is illustrated below:

1. The ‘grdimage’ module was used for raster image, Fig. 1: ‘gmt grdimage bg_relief.nc -Cpauline.cpt -R22.0/29.0/41.0/44.5 -JM6.5i -I+a15+ne0.75 -Xc -K > \$ps’.
2. Adding the capital was done using the code for a circle point of the city location: ‘gmt psxy -R -J -Sc -W0.5p -Gyellow -O -K << EOF >> \$ps 23.0 42.0 0.2c EOF’.
3. Annotating the text was done by the following code: gmt pstext -R -J -N -O -K -F+f10p,Helvetica,black+jLB -Gwhite@30 >> \$ps << EOF 23.0 42.1 Sofia EOF.

4. The 'grdconvert' module was used for converting the geoid model calculated from the Earth Gravitational Model 2008 (EGM-2008) into the grid file, Fig. 2: 'gmt grdconvert n00e00/w001001.adf EGM2008bgl.grd'.
5. The 'img2grd' module was used for converting the image in Fig. 3 to grid by the code: 'gmt img2grd grav_27.1.img -R2.0/29.0/41.0/44.5 -GgravBG.grd -T1 -I1 -E -S0.1 -V'.
6. Adding the scale bar, time stamp, and annotations was done by the following code: 'gmt psbasemap -R -J -FONT=9p,Helvetica,black -Lx13.0c/-1.3c+c50+w150k+l"Mercator projection. Scale: km"+f -UBL/-5p/-40p -O -K >> \$ps'.
7. The 'pscoast' module was used for plotting general coastal lines on the map: 'gmt pscoast -R -J -P -Na -W0.6p -Df -O -K >> \$ps'.
8. The logo was plotted by the code: 'gmt logo -Dx6.2/-2.0+o0.1i/0.1i+w2c -O -K >> \$ps'.
9. The file conversion from to image file using GhostScript was done using the following code: 'gmt psconvert Geoid_BG.ps -A0.5c -E720 -Tj -Z'.
10. The GDAL was used for retrieval of information: 'gdalinfo gravBG.grd -stats'.

The examples of these codes demonstrate the principle of GMT approach which uses fine adjusting of each of the cartographic elements on the map by the commands in each line of the code. Taken together and run as a script, these codes produce the maps shown in Figures 1, 2 and 3 for topographic mapping (Fig. 1), geoid model (Fig. 2) and geophysical mapping (Fig. 3).

2.3. R scripting

The mapping in R has been done using specific libraries: 'raster' [8] and 'tmap' [40] using RStudio. The visualized maps in Figures 4, 5, 6 and 7 show the geomorphometric analysis which considered the variety of published literature on geomorphologic issues [31, 7, 10, 11, 37]. The presented geomorphometric analysis includes the general geomorphological modelling of Bulgaria: slope, aspect, hillshade and elevation over the whole country, based on DEM, embedded in the 'raster' packages of R and using cartographic embellishments available in the 'tmap' package of R.

In addition to the general syntax of R and commands of 'raster' package, the important steps include data capture using country names which narrows the focus of a research and maps: 'alt = getData("alt", country = "Bulgaria", path = tempdir())'. Afterwards the terrain characteristics have been plotted using the following codes: 'slope = terrain(alt, opt = "slope")', which returns the computed slope of the relief, plotted by 'plot(slope)' code. The same procedure was repeated for the aspect and hillshade as follows: 'aspect = terrain(alt, opt = "aspect")', 'plot(aspect)'; 'hill = hillShade(slope, aspect, angle = 40, direction = 270)'; 'plot(hill)'; 'plot(alt)'. After the terrain characteristics were calculated, the next stage of mapping was done by the 'tmap' library of R which has a better functionality (aesthetics, visualization, cartographic elements) comparing to the default 'raster' visualization due to the wide functionality of such commands as tm_scale_bar, tm_compass, tm_layout, tm_graticules, tm_raster where the respective (self-explaining elements were defined: their color, positions, font, size and rotation for texts, background color, color palette for the raster grid, etc).

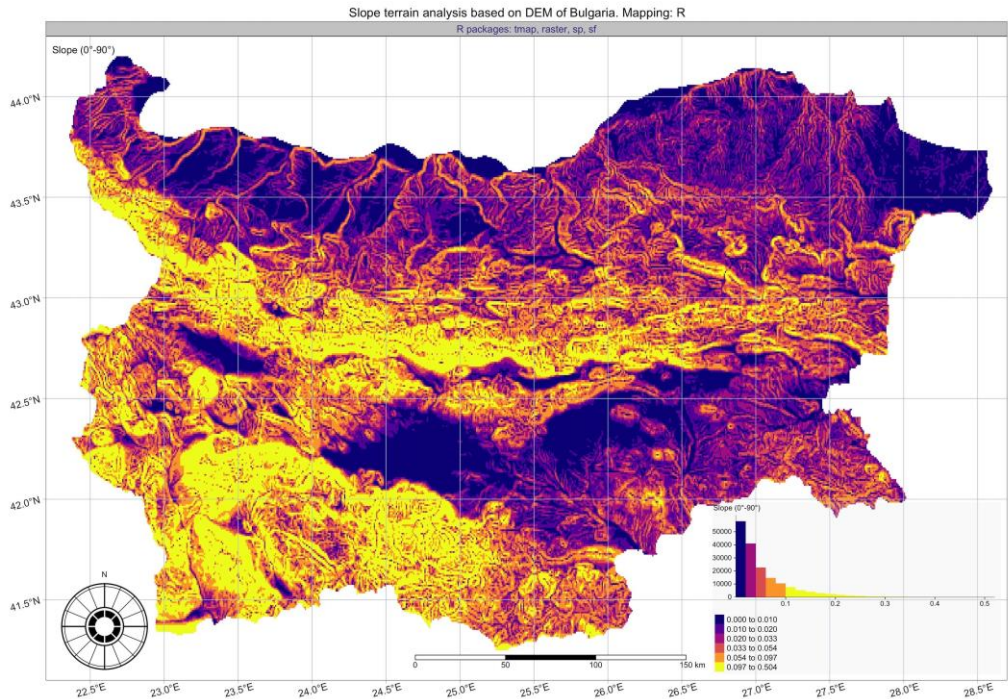


Figure 4. Slope geomorphometric analysis of Bulgaria. Mapping: R. Source: author

Numerous options of the ‘tmap’ package are available as ‘flags’ to include only necessary cartographic elements and adjust their visual appearance most relevant to the map extent of Bulgaria. The methods include the following codes explained as the sequence below:

1. Example of the parameters used by ‘tm_layout’ function for plotting slope (Fig. 4) is as follows: `tm_layout(scale = .8, main.title = "Slope terrain analysis based on DEM of Bulgaria. Mapping: R", main.title.position = "center", main.title.color = "black", main.title.size = 1.0, title = "Slope (0°-90°)", title.color = "black", title.size = 1.0, title.position = c("left", "top"), panel.labels = c("R packages: tmap, raster, sp, sf"), panel.label.color = "darkslateblue", panel.label.size = 1.0, legend.position = c("right", "bottom"), legend.bg.color = "grey90", legend.bg.alpha = .2, legend.outside = F, legend.width = .3, legend.height = .5, legend.hist.height = .15, legend.title.size = 0.9, legend.text.size = 0.8, inner.margins = 0).`
2. Example of the code used by function ‘tm_scale_bar’ for adding bar scale in Fig. 5: `for tm_scale_bar(width = 0.25, text.size = 0.9, text.color = "black", color.dark = "black", color.light = "white", position=c("left", "bottom"), lwd = 1).`
3. Example of the code used for mapping Fig. 5 (hillshade) is as follows: `tm_shape(hill, name = "Hillshade", title = "Hillshade", auto.palette.mapping = F) + tm_raster(title = "Histogram \n(data distribution)", palette = "cividis", style = "kmeans", legend.show = T, legend.hist = T, legend.hist.z=0).`
4. Example of combination overlaying hillshade with DEM elevation as shown in Fig. 7 is presented in following code: `tm_shape(hill) + tm_raster(palette = gray(0:10 / 10), legend.show = F) + tm_shape(alt, name = "Elevation", title =`

```
"Elevation") + tm_raster(title = "Elevation (m asl)", alpha = 0.5, palette = terrain.colors(256), legend.show = T, legend.hist = T, legend.hist.z=0).
```

The examples given above present snippets of codes used for mapping Figures 4, 5, 6 and 7 showing terrain analysis of Bulgaria based on DEM embedded in R package ‘raster’.

3. Results

This paper provides the information to enable effective use of scripting techniques in cartography and the geomorphometric analysis based on integrated use of R and GMT, analysis and synthesis of published works [1, 3, 9, 38] on Bulgaria, its environment and geography.

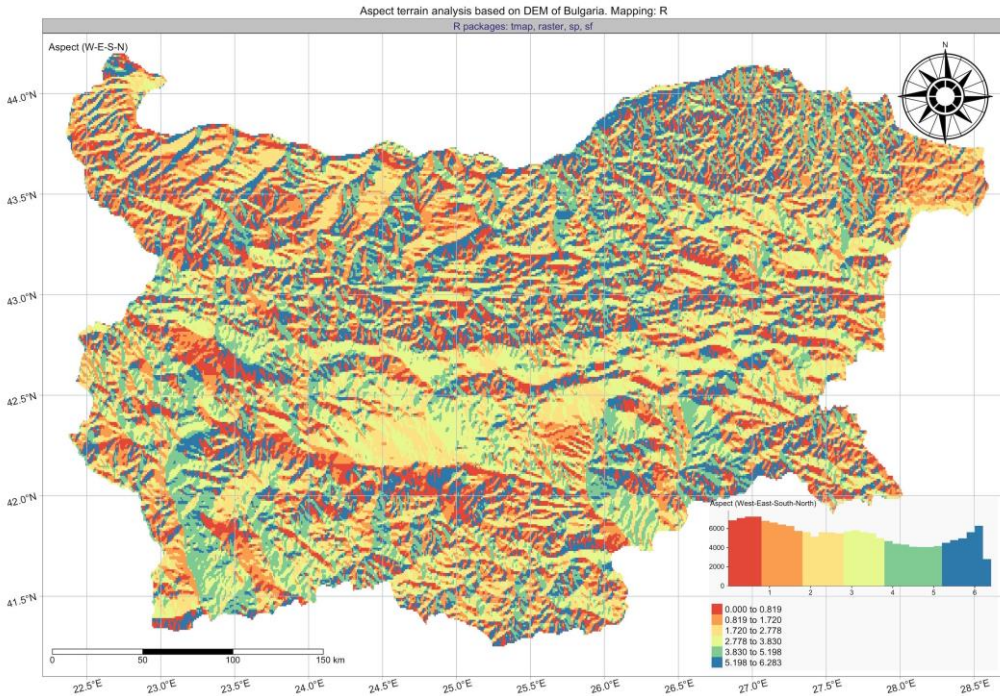


Figure 5. Aspect geomorphometric analysis of Bulgaria. Mapping: R. Source: author

A new dataset integrating topographic, geoid and geomorphological raster grids for Bulgaria was created for this project and performed in R and GMT. Both the GMT and RStudio environments were set up to import, visualize and process data from the raw data on topography and geodesy. This cartographic process was created in both R and GMT and uses a scripting approach demonstrated in the Methods section. The presented scripting approach has many perspectives nowadays in the written in view of the popularization of the distance-based research and online education, which required free datasets and open-source instruments for cartographers. The scripts of GMT and R have been designed and implemented for each of the 7 thematic maps to facilitate raster grids entry by means of GMT modules and R libraries. The functionality of RStudio represents one of the novel values of scripting cartography.

To facilitate data analysis and data assessment, some statistic general functionalities, such as calculation and visualization of the histograms of data distribution are included in Figures 4 – 7 using R 'tmap' package.

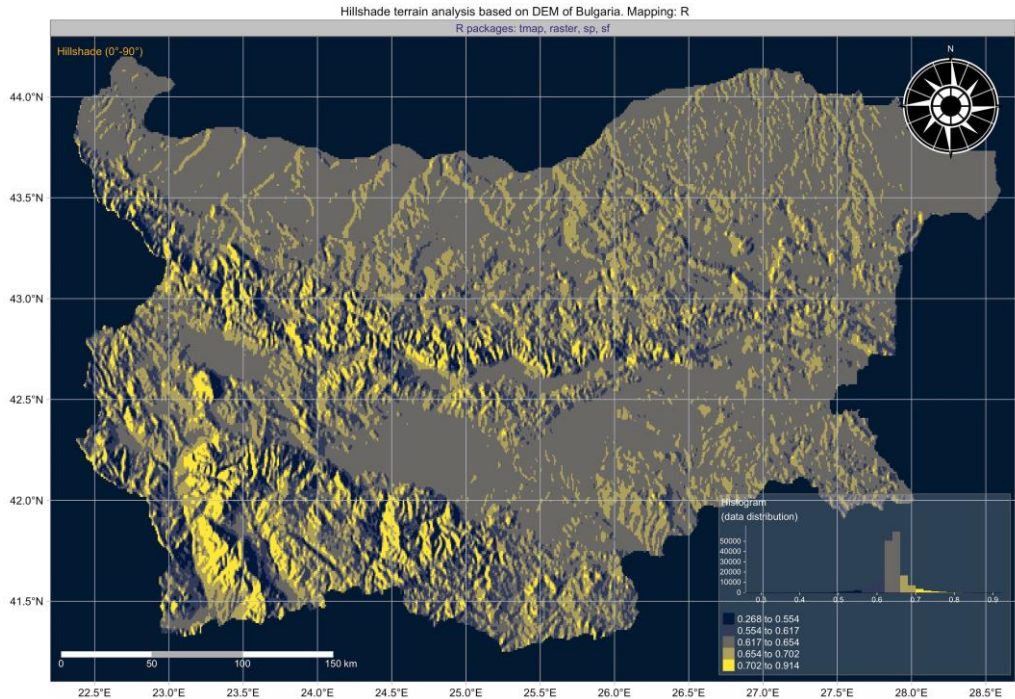


Figure 6. Hillshade geomorphometric analysis of Bulgaria. Mapping: R. Source: author

All the main functions are contained in a single script which integrates the lines of code 'responsible' for plotting cartographic elements. The maps were used to analyze the visualized landforms of the terrain based on DEM, their aspect orientation and hillshade used for visualization of the relief and the applied thematic geophysical studies, such as analysis of the geoid undulations or gravity fields.

The GMT is integrated with GDAL functionality for re-projecting and warping the raster grids and information retrieval (e.g. data extent for color palette adjustments). GDAL can transform and re-project raster data, based on their format specifications (NetCDF, GeoTIFF, GRD), and re-project customized by geographic projections (e.g. standard parallels, central meridian, etc) with special parameters and geodetic filters on all fields. It is possible to provide the coordinates of an exact geographic point using the graticule on the maps, and easily identify and extract information from topographic and geomorphological maps in the project to re-use them in thematic research on Bulgaria. The export of data from GMT and R produces outputs in various formats, but the selected were JPG for graphical plotting.

A set of various GMT modules has been implemented to automatically plot cartographic elements, project and visualize raster data, add text annotations and insert global map, as shown in Figure 1. The R library 'raster' required to enable the geomorphometric calculations of the DEM was used for terrain modeling (Fig. 4 – 7). The database of country codes embedded by GMT (parameters of the 'pscoast' module) was used to obtain the ISO 3166-1 alpha-2 country codes for plotting the insert map in Figure 1. The geographic data on

Bulgaria (topography, elevation from DEM, slope, aspect, hillshade, geoid and gravity) were visualized in this paper the first time using RStudio and GMT integrated approach.

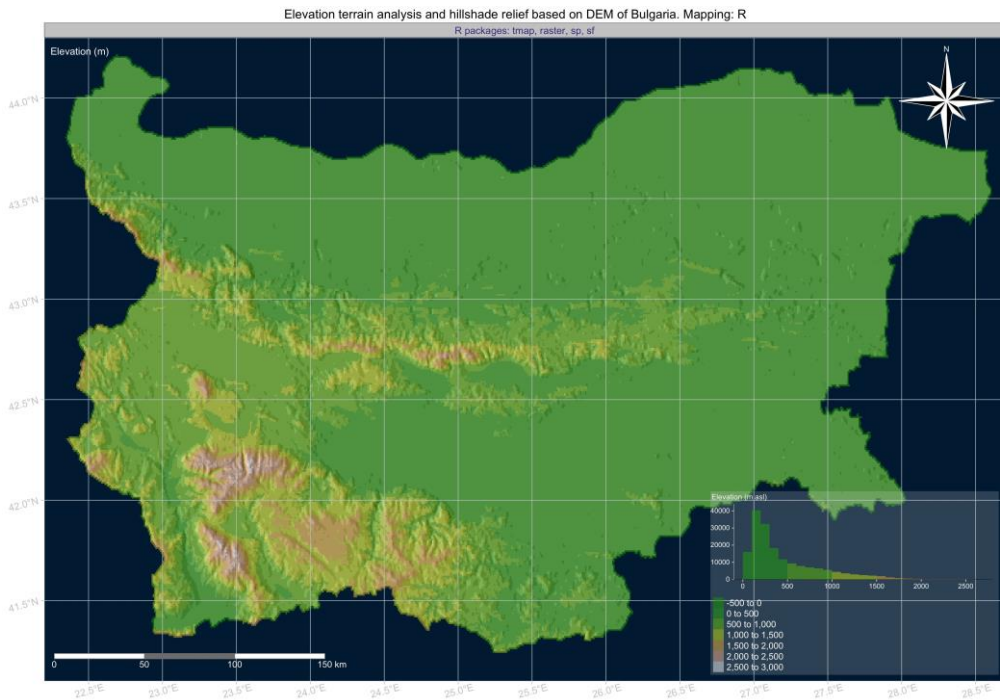


Figure 7. DEM elevation map of Bulgaria. Mapping: R. Source: author

4. Discussion

Being able to both use cartographic scripting tools and perform geodata processing which includes all technical steps of mapping workflow is a necessary skill of a cartographer. The main objectives for scripting approaches in geoinformatics in relation to the cartographic automatization are: conduct data processing using the GMT modules; efficiently use R libraries (install, activate and use) and their functionality by R syntax and general principles of R graphics [2]; find possible data sources and select only the necessary geodata (both raster and vector); read a sufficient amount of literature for geographic review of the study area; critically evaluate the selected data (in terms of quality, resolution, relevance, actuality and coverage) using accepted criteria on data capture; format and re-project data by necessity; use R libraries 'raster' for geomorphological modelling and 'tmap' for cartographic visualization; use GMT modules for geophysical, geological and topographic mapping.

The generalized knowledge regarding the correlation between the geophysics and topography and their effects on geomorphic landforms and orientation were considered while analyzing data. Various color palettes of R (RColorBrewer library) were used to highlight the spatial distribution of natural geomorphological phenomena, such as slope, aspect, hillshade and elevation: 'spectral', 'gray(0:10/10)', 'terrain.colors(256)', 'plasma'. The diverse versus homogeneous areas in terms of topography, geoid undulations, gravimetric anomalies were

visualized by GMT using 'haxby' and 'seis' color palettes, while the topographic map was plotted using 'geo' color palette.

5. Conclusion

The present research demonstrates for the first time in Bulgaria, a modern cartographic mapping approach of a country fully based on the shell scripting techniques by GMT and R. The machine learning approach demonstrated in this paper was used to support automatization in cartographic procedures which is still a relatively novel method compared to the traditional existing GIS (such as ArcGIS, QGIS, SAGA GIS, Idrisi GIS, ENVI GIS, etc). The presented mapping is based on using a free open-source GMT cartographic toolset and R language, as well as available high-resolution geographic datasets on Bulgaria. The available raster grids data were imported to the GMT and RStudio environment using libraries of R ('raster') and modules of GMT ('img2grd', 'grdconvert', 'grdimage'), formatted, projected, and processed using syntax of both R language and GMT scripting toolset.

Therefore, the methodology presented in this study provides an automated way to allow the wide use of coding in mapping workflow. The presented 7 new thematic maps of topographic and geomorphic characteristics of Bulgaria (slope, aspect, elevation and hillshade, geoid, gravimetry and topography) were produced to demonstrate the machine learning approaches in modern cartography as a case study of scripting approaches in mapping Bulgaria. The high-resolution raster datasets were visualized using GMT techniques and RStudio environment, exploiting its potential to produce maps by a sequential use of codes for each module and adjusting flags for fine printing-quality maps using scripting techniques.

In addition to the methodology which combines the GMT and RStudio, this paper presented a new thematic set of 7 maps based on the open datasets on geophysics, geoid, topography to use these maps for further thematic studies and an introduced scripting cartographic methodology for topographic data visualization and modeling of the existing geomorphological data, which can be used for various thematic geographic studies of Bulgaria. The R 'raster' package containing data on country (borders) and DEM elevation and was initially used for modeling derivatives (slope, aspect and hillshade). The total study area covers the whole country of Bulgaria and the shallow waters in coastal areas of the Black Sea. These maps have been processed on the basis of the geographic distribution of Bulgaria and the availability of the existing datasets (GEOBC/SRTM, geoid model derived from Earth Gravitational Model 2008 (EGM-2008), gravity grids, data embedded in R). The final mapping demonstrated both high level of automatization and a printing-quality of cartographic layouts covering Bulgaria, which proved the high effectiveness of the scripting techniques in mapping.

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ГЕОИЗЧИСЛЯВАНЕ НА ЦИФРОВ МОДЕЛ НА РЕЛЕФА В БЪЛГАРИЯ С ПОМОЩТА НА GMT И R СКРИПТОВЕ

П. Леменкова¹

Ключови думи: GMT, R, картография, релеф, геодезия

РЕЗЮМЕ

Статията анализира два скриптовни подхода за топографско-геодезическа визуализация и геоморфологично моделиране на релефа на България: език R и Generic Mapping Tools (GMT). Данните включват растерни мрежи с висока разделителна способност: топографски набори от данни (GEBCO, SRTM), геoidен модел, базиран на земния гравитационен модел 2008 (EGM-2008) и DEM за геоморфологично моделиране на терена: наклон, аспект, хълм и надморска височина. Скриптовото картографиране е използвано като замяна на стандартните ГИС методи за визуализация на данни чрез програмен подход, който е от полза за работния процес на картографирането по отношение на ефективността на обработката на данни. Статията представя 7 нови тематични карти и прави заключението, че картографирането с помощта на R и GMT, което включва шел скриптове и управление на картографския продукт, заедно с разширената функционалност на визуализация на данни в GMT и геопространствено моделиране в R, имат най-голям потенциал като съвременни картографски и геодезически техники.

¹ Полина Леменкова, изследовател, Свободен университет в Брюксел, Технически факултет в Брюксел, Лаборатория за синтез и анализ на изображения (LISA). Сграда L, Кампус Солбош, Авеню Франклин Рузвелт 50, Брюксел 1000, Белгия. E-mail: polina.lemenkova@ulb.be