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Scripting methods in topographic data processing on the example of Ethiopia

Polina Lemenkova

Schmidt Institute of Physics of the Earth, Russian Academy of Sciences.
Department of Natural Disasters, Anthropogenic Hazards and Seismicity of the Earth.
Laboratory of Regional Geophysics and Natural Disasters (Nr. 303).
Bolshaya Gruzinskaya St, 10, Bld. 1, Moscow, 123995, Russian Federation. ORCID ID: https://orcid.org/0000-0002-5759-1089 Tel.: +007-916-298-37-19. Email: pauline.lemenkova@gmail.com

ABSTRACT: This study evaluates the geomorphometric parameters of the topography in Ethiopia using scripting cartographic methods by applying R languages (packages 'tmap' and 'raster') and Generic Mapping Tools (GMT) for 2D and 3D topographic modelling. Data were collected from the open source repositories on geospatial data with high resolution: GEBCO with 15 arc-second and ETOPO1 with 1 arc-minute resolution and embedded dataset of SRTM 90 m in 'raster' library of R. The study demonstrated application of the programming approaches in cartographic data visualization and mapping for geomorphometric analysis. This included modelling of slope steepness, aspect and hillshade visualized using DEM SRTM90 to derive geomorphometric parameters of slope, aspect and hillshade of Ethiopia and demonstrate contrasting topography and variability climate setting of Ethiopia. The topography of the country is mapped, including Great Rift Valley, Afar Depression, Ogaden Desert and the most distinctive features of the Ethiopian Highlands. A variety of topographical zones is demonstrated on the presented maps. The results include 6 new maps made using programming console-based approach which is a novel method of cartographic visualization compared to traditional GIS software. The most important fragments of the codes are presented and technical explanations are provided. The presented series of 6 new maps contributes to the cartographic data on Ethiopia and presents the methodology of scripting mapping techniques.

Keywords/phrases: Cartography, Ethiopia, Geomorphology, Geomorphometry, R-software

INTRODUCTION

Geomorphometry Context

This study presents the geomorphometric modelling and 2D and 3D topographic mapping of Ethiopia by scripting technologies of GMT and R. The unique feature of geomorphometry consists in its multidisciplinarity that includes a set of the intersecting disciplines and branches of knowledge: i) mathematical algorithms of numerical data modelling, ii) local geomorphology and geometry of the terrain (slope steepness and curvature); iii) geographic setting including land cover/land use types (e.g. Birhanu *et al.*, 2019; Shiferaw *et al.*, 2019); iv) surface geology (Purcell *et al.*, 2011); v) soil properties (Teshome *et al.*, 2013; Abbate *et al.*, 2015; Subhatu *et al.*, 2017; Mekuriaw *et al.*, 2018); vi) cartographic data visualization; and vii) computer science including methods of the advanced data processing by the machine learning approaches.

Geomorphometry has been an object of recent activity in publications on the terrain mapping, applications of the advanced methods of quantitative DEM modelling, high-resolution spatial data processing and land-surface analysis (Bishop *et al.*, 2003; Gessler *et al.*, 2009; Guth, 2009; Wang *et al.*, 2010; Drăguț *et al.*, 2011; Alvioli *et al.*, 2016). The analytical approach to cartographic visualizing of land topography by the data processing of the terrain height results in detailed regional geomorphological mapping of the shape of the Earth (Giles, 1998; Billi, 2015; Kabite and Gessesse, 2018).

Cartographic visualization of the Earth's surface presents three aspects of data visualization: 1) terrain modelling (e.g. Lemenkova *et al.*, 2012; Bishop *et al.*, 2018;

Alvioli *et al.*, 2020a, 2020b), 2) Digital Elevation Model (DEM) based data analysis (e.g. Lemenkova, 2020a, 2020b; Hu *et al.*, 2021), 3) topographic/bathymetric mapping (Suetova *et al.*, 2005a; Gauger *et al.*, 2007; Schenke and Lemenkova, 2008; Lemenkova, 2020e;). The DEM can be mapped effectively to derive the geomorphometric parameters (slope and aspect of the local topography) and to calculate hill shade visualizations with perspective view, especially for DEM and raster data with high resolution (Chang and Tsai 1991; Deng *et al.*, 2007; Lemenkova, 2020f, 2020g).

Research Problem

One of the problems and challenges of geomorphometry consists in technical development of cartographic solutions to extracting parameters and variables from DEM. This involves considering the importance of the selected software (for instance, this study adopts R, while others may use ArcGIS Spatial Analyst of GRASS GIS), but also the capture, organizing, and processing of geospatial data, that is, DEM. DEM is the main input dataset to geomorphometric analysis. Various parameters can be extracted from DEM and used for quantitative assessment of the land-surface form. These include, among others, topographic heights and absolute and relative elevation, geomorphologic and morphometric variables, terrain datasets and attributes.

Among other morphometric variables, Digital Elevation Model (DEM) refers to a gridded set of points in Cartesian space attributed with elevation values that approximate Earth's ground surface (Pike *et al.*, 2009). A key issue is that DEM processing provides an opportunity for deriving various information from the data array, such as sampling land surface (height measurements), modelling a surface from the elevation data, deriving land-surface parameters: slope steepness gradient (in degrees), aspect and curvature.

To meet the demand for updated topographic mapping and geomorphometric analysis in Ethiopia, it is necessary to apply an advanced cartographic approach for the reliable high-resolution datasets which involves the mapping workflow using scripting techniques. Hence, selecting high-resolution open source data and effective algorithms of data processing nowadays present the problem in geomorphometric studies. In view of this problem, this paper regards the geomorphological modeling of Ethiopia as an example of how scripting cartographic methods using high-resolution DEMs can be applied for geomorphometric modelling as well as 2D and 3D topographic surface mapping for analysis of the terrain relief.

Research Goal

The study goal is to investigate the topographic variations of the relief in Ethiopia affecting its geomorphometric parameters. The study uses different scripting approaches of cartographic data modelling with the view to plotting a series of new maps. The actuality of this study consists in contribution to current knowledge on variability in topographic elevations and geomorphometric variables across Ethiopia using advanced cartographic solutions. Geomorphometric maps enable measuring the link between the topographic characteristics of terrain, the geometric shape of the Earth's surface, and the effects of this surface on other variables measured in respective disciplines of Earth science (geophysics, geology, landscapes).

The R programming language is free and has open source availability. It can be used not only for the statistical analysis but contains special geospatial libraries (packages) that can be used for mapping. Because syntax of R is logical and straightforward it is effective to apply it in cartographic modelling and mapping. GMT is a powerful cartographic scripting toolset and has great potential in mapping due to the wide variety of modules specially designed for cartographic plotting.

On the other hand, combination of the two approaches has an effective solution for geomorphometric analysis, because GMT lacks the special modules for geomorphometry but demonstrates advanced cartographic adjustments, while R on the contrary, is effective for geomorphometric data modelling yet has lesser possibilities in cartographic. Combination of both tools improves geomorphological and topographic analysis by selecting the advantages and eliminating the disadvantages of each method. Scripting has been recognized as an effective cartographic instrument for topographic mapping and 2D and 3D modelling (Lemenkova, 2020h, 2021a, 2021b; Lemenkov and Lemenkova, 2021). Most available GIS software required significant handmade cartographic routine and lacks automatization, and there is a need to have a way of solving such problem. This can only be achieved by applying the machine learning methods in cartography and topographic data visualization through accurate and rapid handling of the geospatial datasets. Thus, utilizing programming approaches in geographic studies at the geomorphometric analysis required the use of the appropriate scripting tools, such as GMT and R.

MATERIALS AND METHODS

Data collection

The data for Figure 1 and 2 were based on the raster grid GEBCO with 15 arc-second resolution (Schenke, 2016; GEBCO Compilation Group 2020) and ETOPO1 with 1 arc-minute resolution (Amante and Eakins, 2009), respectively. The data for Figures 3 to 6 were based on the SRTM DEM with 90 m spatial resolution embedded in R package 'raster'. These data have been then processed in GMT and R, respectively.

Topographic mapping using GMT

The Generic Mapping Tools (GMT) part of this research was based on using the GMT scripting toolset (Wessel *et al.*, 2019) and included the 2D and 3D visualization of the topography of Ethiopia. The GMT based mapping was performed using a console-based approach of scripting (4 shell scripts have been written in Xcode and executed in the GMT console). Since GMT is a toolset with specific syntax, the explanation of its code requires some comments on its style, as follows (the implication being that general knowledge of the GMT scripting approach is familiar to the reader, so the explanation concerns some of the most important lines of the code)

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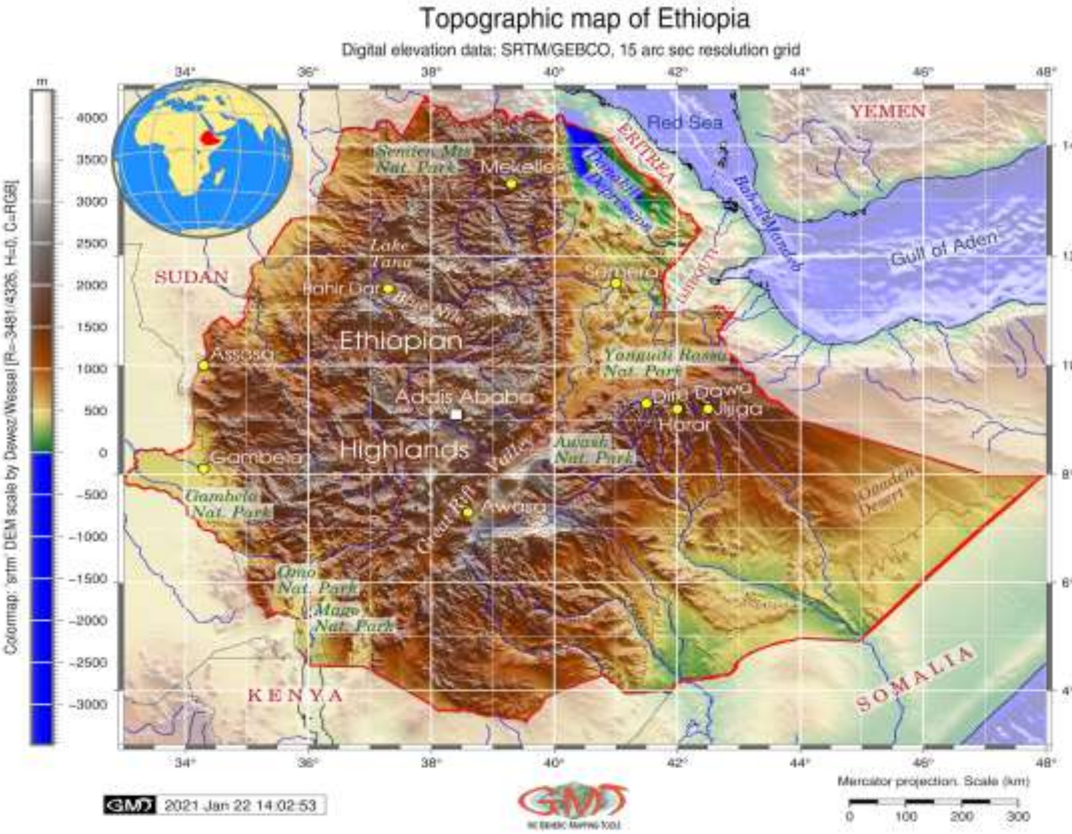

FIgure 1. Map of the study area. Mapping: GMT. Data: GEBCO. Source: author.

In general, method of GMT plotting involved several operations with modules, each of which added certain cartographic elements on a map, e.g. either a graticule or a color visualization of the raster image (grdimage), color scale legend (psscale), isolines (grdcontour), clipping the region of Ethiopia (psclip) by the Digital Chart of the World (DCW) vector contour (grdcontour), adding annotations (pstext). More specifically, the visualization of the raster image (Fig. 1) has been performed using the following code: 'GMT grdimage et_relief.nc -Cmyocean.cpt -R33/48/3/15 -JM6.5i -I+a15+ne0.75 -t60 -Xc -P -K > $ps'.

Clipping the study area was done using the clipping mask: 'GMT psclip -R33/48/3/15 -JM6.5i Ethiopia.txt -O -K >> $ps'. Adding a subtitle was done using the code: 'GMT pstext -R0/10/0/15 -JX10/10 -X0.1c -Y8.0c -N -O -F+f10p,21,black+jLB >> $ps << EOF 4.0 9.0 Digital elevation data: SRTM/GEBCO, 15 arc sec resolution grid EOF'. Adding coastlines, borders and rivers was done as follows: 'GMT pscoast -R -J -P -Ia/thinner,blue -Na -Wthinner -Df -O -K >> $ps'. Making color palette was done using the data on the actual topographic extent of the square of the selected area as follows: 'GMT makecpt -Csrtm.cpt -V -T-3481/4326 > pauline.cpt'. In turn, the data range was checked up by Geospatial Data Abstraction Library (GDAL) utility 'gdalinfo' using the code: 'gdalinfo -stats et_relief.nc'.

The 3D model (Fig. 2) has been plotted using the 'grdview' module as follows: 'GMT grdview et_relief1.nc -JM10c -R33/48/3/15 -JZ3.2c -Cpauline.cpt -p125/30 -Qsm -N-3500+glightgray -Wm0.07p -Wf0.1p,red -B1/1/2000:"Bathymetry and topography (m)":wESZ -S5 -UBL/200p/-17p -K > $ps'.

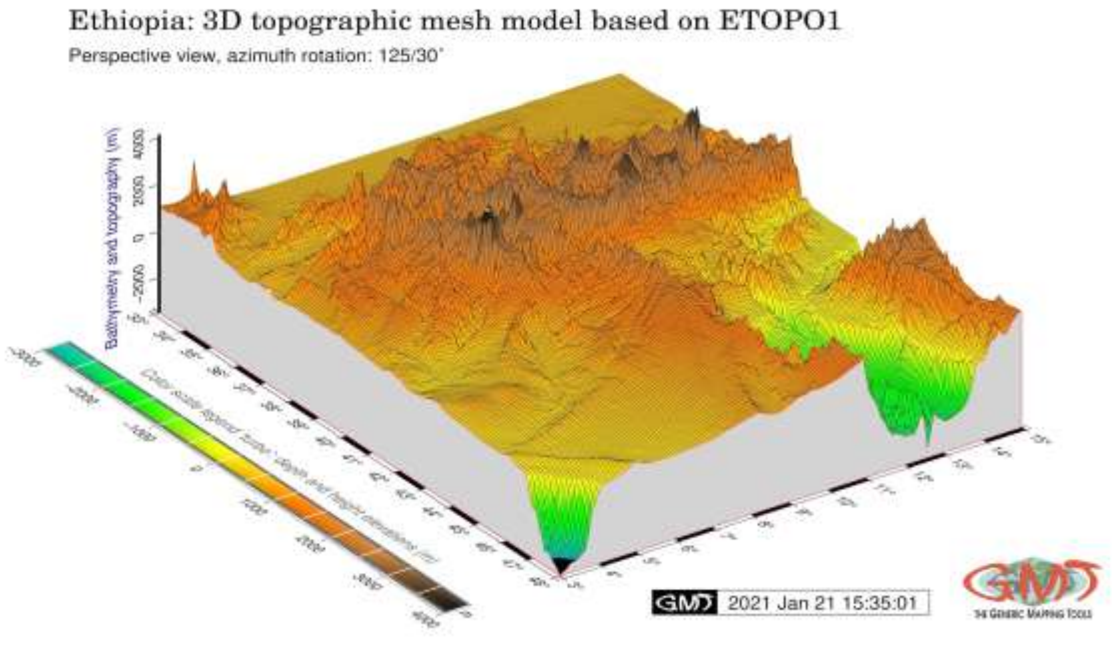

Figure 2. 3D perspective sidewise visualization of the relief in the Afar Depression and surrounding Ethiopian Highlands. Mapping: GMT. Source: author

In such a way, the script has been constructed using a combination of the lines of code. Thus, the executed script consisted of the lines of code with specific GMT modules resulted in process of mapping that produced the output images (Fig. 1 for the 2D view and Fig. 2 for the 3D view of the Ethiopian topography).

Geomorphometric analysis using R

Geomorphometric modelling of Ethiopia by R language (R Core Team 2020) has been implemented in the RStudio environment using two major packages: 'tmap' (Tennekes, 2018) and 'raster' (Hijmans and van Etten, 2012). All processes have ben automated using a single R script written in Xcode and run from the RStudio, making the method amenable and applicable to a sequence of maps in a series (Fig. 3–6). All of the processes described here use R syntax available in R 'raster' and 'tmap' libraries. The data have been collected using the code 'alt = getData("alt", country = "Ethiopia", path = tempdir())'.

Then the models for the slope (Fig. 5) and aspect (Fig. 6) have been generated using the codes 'slope = terrain(alt, opt = "slope")' and 'aspect = terrain(alt, opt = "aspect")'. The preliminary plotting of the both have been performed using the plot() function. The hillshade map (Fig. 4) was then derived by the raster computation using the data for previously calculated slope (Fig. 5) and aspect (Fig. 6) of the original DEM (Fig. 3). More precisely, the hill shade (Fig. 4) was modeled as a derivative of the both rasters as follows: 'hill = hillShade(slope, aspect, angle = 40, direction = 270)'.

The 'tmap' package has been used for more sophisticated mapping in R which enables to select effective color palettes using the code 'tmaptools::palette_explorer()' and performing plotting in a map mode: 'tmap_mode("plot")'. The maps were designed using various layout styles (tmap_style("beaver")) for the slope map, 'watercolor' for aspect, 'cobalt' for hillshade, and 'natural' for DEM visualizing elevation of Ethiopia.

RESULTS

Research outputs

This study, therefore, presented the analysis of the variability of topography in Ethiopia to support geomorphological monitoring. The output from this study can be compared to the results of previous studies on the topography of Ethiopia and its correlation with various aspects of the Earth processes and dynamics (Dessalegn *et al.*, 2014; Kindu *et al.*, 2015; Molin and Corti, 2015; Emishaw *et al.*, 2017; Guzman *et al.*, 2017; Asefa *et al.*, 2020). The results present a series of the six maps of the topography of Ethiopia demonstrating cartographic modelling using 2D and 3D perspective views.

Two of these maps (Fig. 1 and 2) were plotted and visualized using GMT; the others (Fig. 3 to 6) involved R-based programming. Analysis of topographic data based on the GEBCO/SRTM in Ethiopia (Fig. 1) confirmed the general decline in the elevation in the Afar Depression and the Great Rift Valley which shows the distribution of the major tectonic fault lines controlling the topographic curvature demonstrated in topographic 2D map (Fig. 1) and 3D model (Fig. 2).

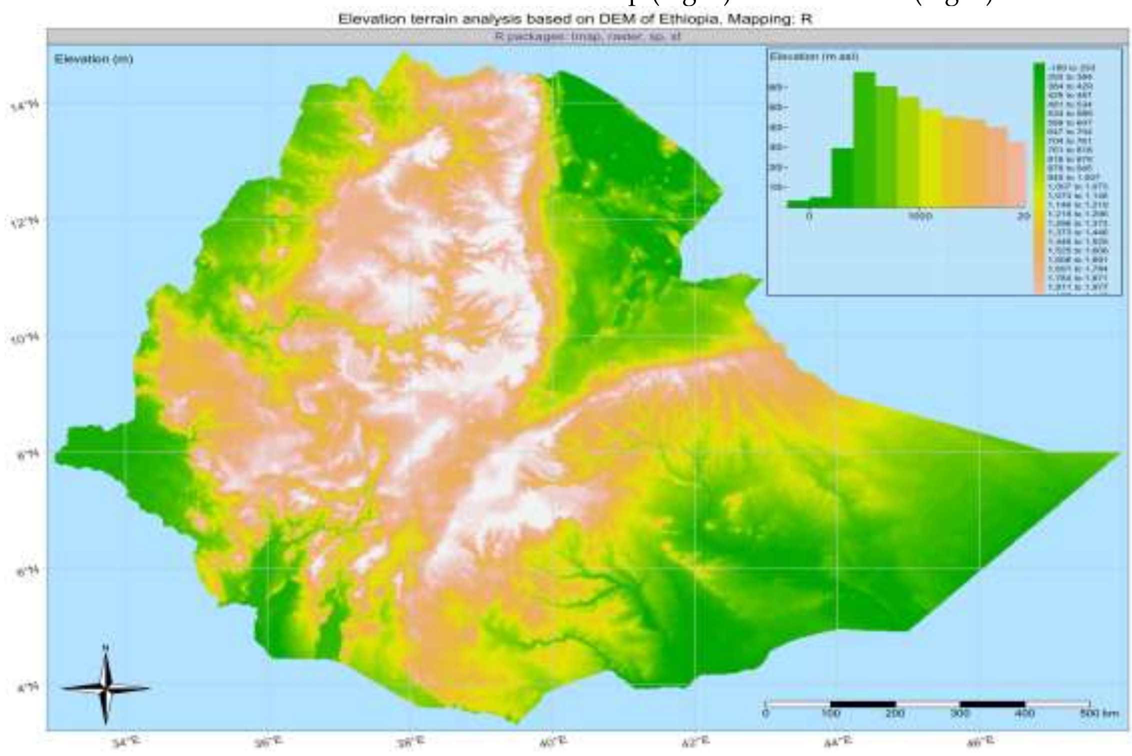

Figure 3. Elevation map. Data: SRTM 90 DEM. Mapping: R. Source: author.

Geomorphometric maps

As a result, the processing in R enables to create a series of the geomorphometric maps (aspect orientation, slope steepness, DEM visualized elevations and hillshade modelling), using syntax of 'tmap' and 'raster' packages and color symbolization of the R palettes to deliberately highlight and effectively visualize steepness classes in the slope map (Fig. 5), aspect WESN and its derivatives (NW, NE, SW, SE) divided by the frequency of data distribution (Fig. 6), elevation classes in DEM colored by the 'terrain. colors(256)' color palette (Fig. 3) and hillshade model (Fig. 4) illustrating the relief using the effect of the artificial light illumination, derived from the slope and aspect colored by 'cividis' color palette of R.

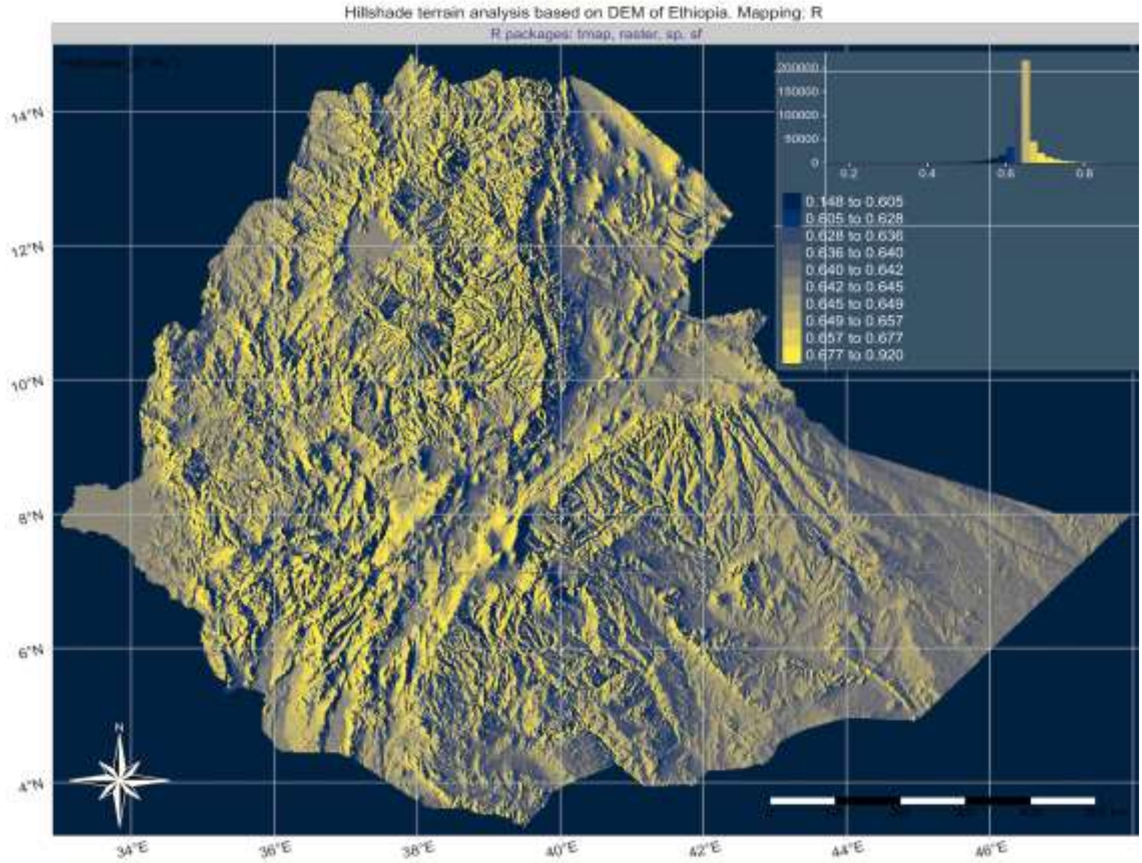

Figure 4. Hillshade relief map. Data: SRTM 90 DEM. Mapping: R. Source: author.

The resulting maps are produced at a resolution corresponding to the input data (SRTM DEM 90 m), and yield an effective color palette that represents the major topographic features of Ethiopia: the Ethiopian Highlands, the effectively visible triangle of the Afar Depression, the Somali Plateau and the lowlands colored by green (Fig. 3). As noted earlier by Vanmaercke *et al.*, (2010), the Ethiopian Highlands are characterized by steep gradient slopes, intense rainfalls and flash floods and sparse vegetation coverage.

Variability of relief in Ethiopia

The variability of the Ethiopian topography showed the increase in the mean values for the distinctive topographic features of the Ethiopian Highlands, such as Somali Plateau, mountainous region with Ras Dashen Mountain, as well as the clearly indicated depressions at Great Rift Valley, Afar Depression, Ogaden Desert (representing the southern and central regions of Ethiopia), Lake Tana (north-west) and Blue Nile River originating from Lake Tana (northern region) which demonstrated decline in the topographic heights based on SRTM grid (Fig. 3). Different elevation regions were highlighted by the color palettes for comparative analysis. The topographic data range varied from -3481 m to 4326 m, and a mean at 814.823 m according to the GEBCO grid inspected by GDAL utility 'gdalinfo'.

Fig. 3 presents a visualized DEM based on the SRTM-90 showing a raster map with height topographic elevations of the land surface above mean sea level. Topographic variations serve as good indicators of the near-surface geology, and geomorphology: e.g. steep mountains indicate rocks, while nearly flat relief indicate distribution of soils, and a mixture between the two types can be found on the intermediate steep slopes. Besides, existing studies pointed at correlations between the geomorphometric parameters (slope, aspect), geomorphology and topographic elevation of the area (e.g., Lemenkova, 2019c, 2019d). Fig. 4 illustrates the spatial distributions and variations of topographic heights in Ethiopia based on R modelling using SRTM grid with statistical histogram showing the distribution of pixels in the raster grid according to the slope position.

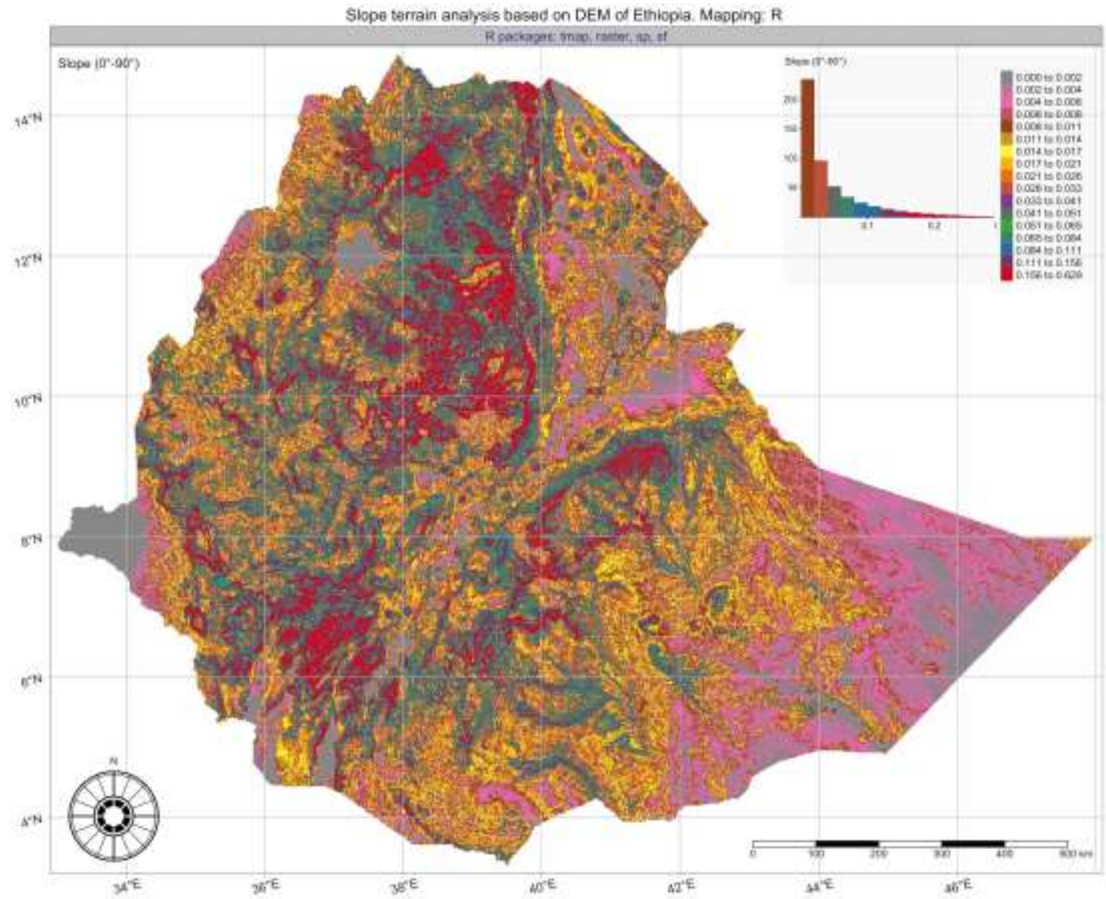

Figure 5. Slope steepness map. Data: SRTM 90 DEM. Mapping: R. Source: author.

Fig. 5 shows the frequency distribution (repeatability) of data according to the slope modelling. The highest statistical range of values (interval of 0.156 to 0.629, bright red color in Fig. 5 consistently demonstrated the moderate steepness of the slopes, whilst lowest interval (statistical values between 0.021 to 0.026, dark orange colors) show the steep slopes in the Ethiopian Highlands.

Respectively, the gentle slopes are colored pink and grey colors showing spatial distributions in the eastern corner of the country in the Somali Plateau. Other values of slope steepness are demonstrated in the histogram, respectively. Fig. 6 showed a general distribution of the aspect according to the orientation by compass with eight divisions (west-east-south-north and their derivatives southeast, southwest, northeast and northwest) generally ranging from western slope orientation (blue) to eastern (red) and their variables. The statistical analysis shows the distribution of pixels on the image.

DISCUSSION

Evaluation of geomorphometric parameters

The DEM based modeled land surface parameters can be used to describe the geomorphological elements of Ethiopia classified using geomorphological subdivision of the country. Besides the presented slope, aspect, hill shade and elevation derived from DEM, other landscape parameters can include more complex features derived from SRTM DEM, e.g. topographic curvature, sediment connectivity, flow direction, and more conceptual metrics based on spatial models. From a modelling perspective, the factor of scale is also crucial and fundamental in geomorphometry and feature extraction for calculating geomorphological parameters (Sofia *et al.*, 2014). The calculation of these parameters may be considered in future studies developing the topic of the present study.

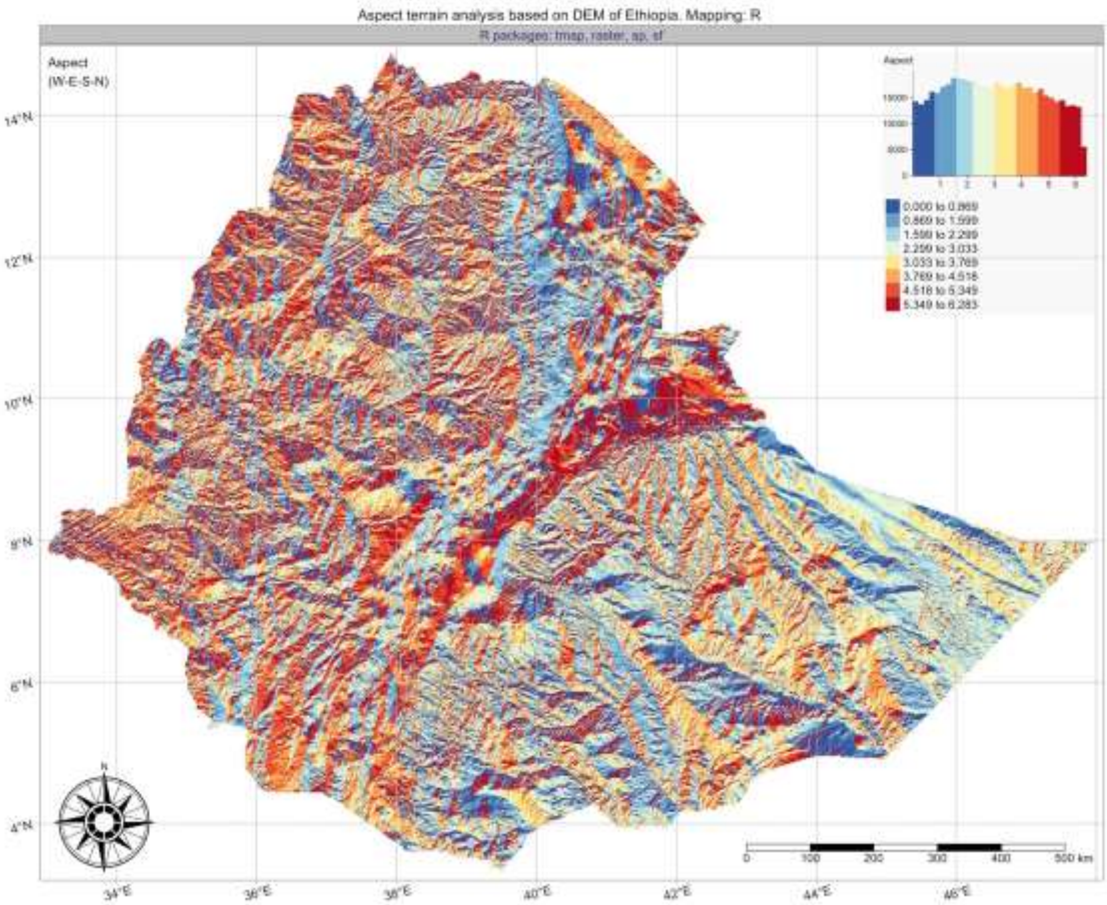

Figure 6. Aspect model. Data: SRTM 90 DEM. Mapping: R. Source: author.

The geomorphological landforms of Ethiopia evolved under the strong impact of the tectonic processes uplifting and rifting away the Arabian Plate from African Plate. As a result of the geologic evolution, Great Rift Valley now clearly divides the country into morphologically distinct regions: the uplifted dome of Ethiopia, western region with Ethiopian Plateau and southeastern region with Somali Plateau, forming landscapes sculptured by unique tectonic history of the region.

Western Ethiopian Plateau is high and dissected whilst the southeastern Somali Plateau has gentler relief landforms. Lower regions of the southeastern plateau is occupied by the Ogaden Desert (as can be visible in Fig. 1) which has vast red soil plains, canyons of the Wabe Shebele and its tributary rivers. Other landforms include the Audo Range and a variety of minor landforms that reflect the varying topographic elevations of the plateau (Mège *et al.*, 2015).

The geomorphological regions of Ethiopia are spatially distinct and can be separated into three major areas: 1) northern highlands; 2) the Rift Valley and the two depressions: Afar and Danakil; 3) southern plateau, which includes the Ogaden Desert with gently decreasing heights eastwards, to Somalia and the Indian Ocean (Billi, 2015). Of these, the geomorphology of the Afar Depression is unique, since it is strongly affected by the tectonic rifting processes (Corti *et al.*, 2015).

The Afar Depression is located in a triple junction between the three tectonic plates (Nubian, Somalian and Arabian) where the continental break-up still continues in it final stages. As a result, Afar has a unique geomorphology of landscapes with presented dike intrusions, faults and active volcanoes created during tectonic, volcano-tectonic and volcanic events.

The geomorphological features of the Great Rift Valley (Lakes Region), situated on active continental rift, is formed under the strong impact of Late Quaternary climatic and hydrological fluctuations, as well as active volcanism and tectonics. The Main Ethiopian Rift is occupied by seven major lakes: Chamo, Abaya, Awasa, Shala, Abijata, Langano, and Ziway, bordered by topographically elevated highlands where the tributary river sources originate (Ayenew and GebreEgziabher, 2015). Lake Haik, located in the Amhara Region proved climate variability that indirectly affected its current topographic shape by the accumulation of sediment layers, reflected in lake margins and coasts (Ghinassi *et al.*, 2015). The geomorphology and dimensions of these lakes gradually varied following the effects from different factors such as volcanism, active tectonics and climate fluctuations.

Geomorphic and stratigraphic studies revealed that the evolution of Late Pleistocene–Holocene fluvio-lacustrine system the Great Rift Valley was largely regulated by hydro-climatic processes, as well as other processes, such as volcanism, faulting, erosion, aeolian processes and accumulation of sedimentation. Important element of the landscapes in Ethiopia is presented by fluvial and lacustrine systems that present different drainage network and channel morphology, which is caused by the exceptional variety in geomorphological forms of Ethiopian landscapes as well as active tectonics and seismicity (Billi *et al.*, 2015).

Northern part of the Great Rift Valley experienced changes in the drainage pattern during latest Pleistocene and early Holocene. This was largely induced by tectonic deformation, volcanic activity, and arid climate during Last Glacial Maximum (Sagri *et al.*, 2008). As a result, the dynamics and strength of these processes finally sculptured the geometry of the basin and fluvial network in Great Rift Valley (Woldegabriel *et al.*, 1990; Benvenuti and Carnicelli 2015).

Application of geomorphometric characteristics

Geomorphometric characteristic of the landscapes includes data that define the landforms that express the terrain through their arrangement in the landscape as topographic shape of the Earth's surface. The presented geomorphometric maps of Ethiopia includes visualized morphometric derivatives such as slope steepness, defined through curvature by R algorithms, aspect of compass orientation and highlighted hill shade and elevation derived base on DEM. The geomorphometric and topographic study is based on using data from DEM for geospatial analysis of the information regarding the quantitative geomorphological and topographic models expressed in maps.

The continuity of the geomorphometric features in the variability of landscapes in Ethiopia is expressed through connectivity between depressions (Great Rift Valley) and highlands (Ethiopian Plateau). The variability of the geomorphological landforms visible in Ethiopia is categorized by variables, e.g. elevation heights, slope steepness, aspect orientation, geological rock stratification and exposure, and upper soil type. These are largely controlled by the combination of factors. Major factors of landform sculpturing include geological and tectonic factors, whilst minor factors include climate, soil and vegetation.

The importance of the topographic analysis in environmental studies can further be illustrated by the significant effect that altitude has on species biodiversity, distribution and richness in mountain ecosystems (Woldu *et al.,* 2020). Similarly, aspect, slope and altitudinal variation in Ethiopian landscapes controls distribution of vegetation types and floristic diversity (Kebede *et al.,* 2013). Besides ecological application, topographic modeling is applicable in hydrological research. At a larger scale, geomorphological data enable to better understand direction and density of fluvial networks with regards to the drainage basin and mountain chains. Finally, topographic variables serve as contributing elements in climate studies of Ethiopia (Fazzini *et al.,* 2015).

Perspective of machine learning in cartography

Scripting techniques undermined the existing GIS practices and changed the approaches in visualization and mapping (Lemenkova, 2020c, 2020d). Using scripts for preparing maps led to increased speed, aesthetic quality, effectiveness and precision of cartographic techniques providing an effect of the machine-based visualization in response to rapid development of the programming languages intended to increase automatization in scientific plotting and cartographic data processing (Lemenkova, 2018, 2019a, 2019b).

Machine learning applied for cartography and based on the open source repositories enables rapid data processing. Programming algorithms and scripting techniques show effective substitution of the GUI-based mapping used in traditional GIS and spatial data processing (e.g. Suetova *et al.,* 2005b; Klaučo *et al.,* 2013, 2017; Araya *et al.,* 2021). As a consequence, the ways of mapping and performing data processing are impacted by the new paradigm of scripting cartography. New approaches to mapping emerge with the development of the new packages fo R and Python, new updated versions of the GMT with improved functionality, as well as new plugins that can be used as add-ons to the traditional GIS for data integration (e.g. uploading Open Street Maps to QGIS as a background for the on-the-fly mapping).

This paper demonstrates the use of 'tmap' and 'raster' libraries and several modules of GMT, but there are many other useful tools, e.g. R packages, GMT modules, QGIS plugins and Python libraries that can be effectively used for mapping and other research tasks. Along with rapid automatization, cartographic workflow has to be altered in terms of the ways in which the process of mapping facilitates cartographic outcomes.

Despite the possible technical challenges in scripting routine caused by syntax and semantics forming structure of the programming languages (e.g. Python, AWK, R) and scripting toolset (e.g. GRASS GIS, GMT), this is an exciting opportunity to alter existing cartographic practices and maps production. Rapid conversion from the traditional GUI-based GIS to the scripting-based mapping can raise difficulties in learning special syntax of scripting which is similar to the programming language. Therefore, the optimal solution might be a combination of both GIS and scripting methods. The design of an effective integrated mapping is therefore methodologically flexible and based on the geospatial resources from the existing open source repositories (e.g. GEBCO, ETOPO1, EGM-2009, USGS datasets).

Rapid adoption of scripting into the existing way of cartographic visualization cannot be completely based on programming languages but requires flexible and adaptable improvisation in context of mapping object (geology, topography, geophysics, geomorphology land use/cover, climate or environmental data). This paper demonstrated the experience of using two approaches in scripting mapping based on R language and GMT scripting toolset as they presented two solutions to mapping: i) classic geospatial data visualization with a case study of topography of Ethiopia in 2D and 3D views; and ii) geomorphometric spatial analysis with a case study of Ethiopian Highlands and the Afar Depression. Thus, this paper comes from the experiences of application of the two scripting approaches in cartography: GMT and R.

Much of the diversity of the cartographic methods of visualization developed recently in various GIS software applies various approaches of spatial data processing. In contrast to these traditional GIS GUI-based methods, the novelty of the presented application of GMT and R methods (using RStudio environment) consists in the applied programing and scripting used for cartographic data visualization. This techniques featured shell scripting applied for map generation which enables repeated workflow for multiple maps of various areas of the Earth. The presented research demonstrates gained repeatability of the scripts and increased optimization of the cartographic data processing. Single-tool (one GIS) cartographic method typically presents a one-sided approach, while the demonstrated use of the simultaneous scripting approach by R and GMT presents a variability of modeling methods using machine-learning techniques applied to the high-resolution raster files.

Cartographic automatization is achieved through the repetitive scheme within a single script of GMT, or taking advantage of standardized syntax of R. Such methods may also apply to generate other maps of the same spatial extent of the series, in order to obtain a set from which to analyze a correlation between the parameters (environmental, climate, geological, geophysical and topographic data) using high-resolution raster files. Analysis of the high-resolution datasets, especially in the context of correlation between the environmental parameters (geomorphology of the slopes and aspect, surface geology and distribution of habitats) is applicable to the complex studies at the country level which is useful for the countries with such a contrasting topography and climatic extremes as Ethiopia.

CONCLUSION

Summary outline

This research presented an analysis of the topography of Ethiopia by a series of six new maps. Methodologically, the study demonstrated cartographic solution of applied programming aimed for increased speed and automatization of mapping through scripting. The study demonstrated topographic variability in Ethiopia which is carried out using R and GMT applied for handling high-resolution raster data. The presented series of maps shows for the first time how logical and straightforward scripting syntax of R and GMT can be used to plot topographic maps, build 3D models and perform geomorphological modelling that accurately reflects topographic-morphological relationships.

The application of R packages 'tmap' and 'raster' presented a geomorphometric analysis performed in RStudio that displays maps at which variables of DEM (SRTM90 of Ethiopia) were imposed: slope steepness, aspect orientation and hill shade model. In this case study of the Ethiopian Highlands, the presented research examined a series of the topographic and geomorphometric maps of Ethiopia using machine learning approaches and programming applications.

Advantages and benefits of scripting mapping

Advantages and benefits of scripting mapping include increased level of automatization of cartographic workflow which can significantly improve the quality, reliability and precision of cartographic outputs. Using the case study of mapping topography and geomorphometry of the Ethiopian Highlands in 2D and 3D views, the presented paper justifies the argument that application of scripting and programming approaches in cartography can satisfy the need for machine learning methods in geoinformatics aimed at automatization in mapping. Furthermore, it can extend the usable range of data from the open repositories due to the compatibility of formats in GMT by means of combination of GDAL and GMT for data format converting and preprocessing. Since the traditional GIS based methods of cartographic engineering do have certain advantages in their data processing and cartographic production, the presented methodology of scripting based mapping supports and contributes to the existing GIS approaches rather than replace them.

As for the design and cartographic aesthetics, various cartographic layouts behave differently in diverse GIS software and other technical tools (GRASS GIS, ArcGIS, QGIS, GMT, R, IDRISI GIS, ENVI GIS, Erdas Imagine, SAGA GIS, to mention a few) due to the variability of the default layout styles and general design functionality in each program. Therefore, as a recommendation in similar future studies, it is advised to experiment with a variety of available GIS for a comparison between possible mapping outputs. This study reports results demonstrating how mapping approaches change by using R and GMT scripting tools, and how selection of high-resolution data (raster and vector files on topography of Ethiopia) can be used for producing maps through much of the functionality of R packages and modules of GMT.

Recommendations for future studies

The methodological process of mapping demonstrated in this study can be utilized in similar research for map design based on a range of datasets available from the open repositories, intended for various purposes. These include environmental monitoring, geomorphological mapping, engineering assessment of the slope stability and probability of landslides, ecological habitat mapping, visual representation of topography in 2D and 3D view for analysis of the hydrological network and relief, to mention a few from possible applications. The GMT scripting toolset that was introduced for the 2D and 3D mapping demonstrated a method of plotting cartographic layouts through a set of console-based commands with flags defining the elements of maps in each respective module of GMT.

It is recommended that future works should examine correlations between the topographic and geologic setting of Ethiopia that strongly affected its landforms and geomorphology of the Great Rift Valley, Ethiopian Highlands and the Afar Depression. The produced maps contribute to the regional studies of Ethiopia and can be reused for different purposes: environmental and topographic analysis, engineering and thematic mapping of Ethiopia.

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