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Evapotranspiration, vapour pressure and climatic water deficit in Ethiopia mapped using GMT and TerraClimate dataset

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Abstract: In the present research, a scripting cartographic technique for the environmental mapping of Ethiopia using climate and topographic datasets is developed. The strength of the Generic Mapping Tools (GMT) is employed for the effective visualisation of the seven maps using high-resolution data: GEBCO, TerraClimate, WorldClim, CRUTS 4.0 in 2018 by considering the solutions of map design. The role of topographic characteristics for climate variables (evapotranspiration, downward surface shortwave radiation, vapour pressure, vapour pressure deficit and climatic water deficit) is explained. Topographic variability of Ethiopia is illustrated for geographically dispersed and contrasting environmental setting in its various regions: Afar, Danakil Depression, Ethiopian Highlands, Great Rift Valley, lowlands and Ogaden Desert. The relationships between the environmental and topographic variables are investigated with aid of literature review and the outcomes are discussed. The maps are demonstrated graphically to highlight variables enabling to find correlations between the geographic phenomena, their distribution and intensity. The presented maps honor the environmental and topographic data sets within the resolution of the data. Integration of these results in the interpretation maps presented here brings new insights into both the variations of selected climate variables, and the topography of Ethiopia.

Keywords: cartography, climatic water deficit, environmental management, Ethiopia, evapotranspiration mapping, vapour pressure

INTRODUCTION

General demand for agricultural production results in associated pressure on natural landscapes in Ethiopia which triggers land cover changes. These processes reflect a complicated interplay of the anthropogenic activities, landscapes and natural factors, including topographic and climate parameters. Sustainable agricultural activities in Ethiopia strongly depend on estimating climate and environmental parameters indicating the favourable areas for plant growth. It can be well reflected in spatial-temporal fluctuations in the air temperature and humidity, soil moisture or terrain ruggedness. Climate parameters useful for assessment of regional suitability of landscapes for vegetation growth include water evaporation and transpiration, topography (terrain relief), air moisture related to the vapour pressure deficit. More complex parameters may be evaluated numerically, for instance, using climate water deficit which shows annual evaporative demand that exceeds available water.

A complex interplay of factors affects vegetation, canopy and crop health through climate fluctuation [Batáry *et al.* 2015; Benami *et al.* 2021]. As a result, agricultural studies require modelling, visualisation and detailed analysis of various soil, climate and meteorological parameters that affect regional environmental sustainability, such as evapotranspiration, downward shortwave radiation, vapour pressure and climatic water deficit. Technical cartographic tools, geospatial analytics and data visualisation by GIS support such studies by modelling climate datasets and mapping information on agricultural parameters.

The goal of this study is to visualise several environmental data related to the agricultural monitoring and local climate setting in the country. To achieve this goal, the objective was to produce a series of climate maps covering Ethiopia. The technical approach was based on the Generic Mapping Tools (GMT) and high-resolution raster datasets in NetCDF format. The visualised data and presented maps are based on modelling following parameters: downward surface shortwave radiation, vapour pressure, vapour pressure deficit, climatic water deficit and evapotranspiration.

The evapotranspiration is a direct function of water evaporation and transpiration from a surface area to the atmosphere showing the surface energy balance components [Ayenew 2003]. It strongly depends on surface elevation and topographic ruggedness that control vegetation types dominating on various types of landscape patches. Besides evapotranspiration, other types of variables provide accurate information for agricultural resource monitoring and management [Elbeltagi *et al.* 2020]. These include, for instance, vapour pressure, air temperature, land cover types with specific information on the vegetation types (coniferous or broad leafs). Moreover, as previously noted (El Maayar and Chen [2006]), evapotranspiration reflects heterogeneities in vegetation, topography and soil texture. Therefore, deep analysis of the evaporation variability requires integration of several datasets for comparative analysis and finding correlations between the climate and environmental data.

If the data pool is small, the derived information (maps or graphs) is insufficient for comparison of variables and assessment of the environmental parameters. Therefore, one solution is to aggregate various data from open sources: climate data (WorldClim), topographic data SRTM DEM [Dile *et al.* 2020; Worku *et al.* 2021], *in situ* data from weather stations [Rodriguez-Dominguez *et al.* 2019], sensor data from MERIS [Tadesse *et al.* 2015], biochemical fieldwork measurements of the plant leaves [Collings *et al.* 2019], to mention a few data sources. Although an alternative is to avoid areas on the map which have "no-data" status, it is always better to search for the open data. Data visualisation enables to perform comparative analysis on local- and regional scale environmental trends, and to find dependencies and patterns [Lemenkova 2021a]. One more alternative of effective data visualisation is to depict cartographic elements using upscaling or downscaling for the areas with small values that otherwise become visually insignificant. Finally, manipulating with colour palettes, making an accent on the smaller areas, highlighting and enlarging areas of interest are one of many cartographic techniques that aim at a more effective data visualisation.

This paper reports a case study of practical application of GMT for visualising climate, topographic and environmental data as a series of maps showing agricultural parameters in Ethiopia and their spatial correlations. The presented methods are grounded in a GMT scripting framework for cartographic representation [Lemenkova 2019c]. The research presents an effort designed to find cartographic solutions in visualisation of the agricultural maps for demonstrating spatial variability among the environmental parameters related to Ethiopia.

MATERIALS AND METHODS

GENERAL INFORMATION

Methods and approaches of the geospatial analysis, data processing, modelling and visualisation in Earth sciences are diverse [Beyene *et al.* 2018; Gebru, Tesfahunegn 2020; Klaučo *et al.* 2013; Lindh, Lemenkova 2021; Schenke, Lemenkova 2008; Suetova *et al.* 2005; Villarreal-Guerrero *et al.* 2020]. However, the principal difference of the GMT from the traditional GIS consists in script-based philosophy which enables smooth repeatability of the workflow. At the same time, mapping environmental high-resolution data from the open sources is an important task for ecological monitoring of Ethiopia, since it satisfies the need for regularly updated maps that reflect actual state of the parameters affecting vegetation and soil aimed to reflect the ongoing environmental and climate changes. This necessarily requires frequent revisions of maps that could be updated as often as necessary. This is possible using GMT automated scripting techniques that significantly facilitates mapping compared to the traditional GIS-based routine. In view of this, this study demonstrated the advantage of using GMT scripting tools in cartography for environmental mapping of Ethiopia.

Various papers have addressed the question of methods of mapping agricultural, climate and environmental parameters specifically in landscape, environmental and geologic studies [Adimassu *et al.* 2014; Ahmad *et al.* 2020; Andualem, Demeke 2019; Diodato *et al.* 2010; Klaučo *et al.* 2017; Lemenkov, Lemenkova 2021a, b, c; Tamene *et al.* 2017]. Although GIS are commonly used for data processing and mapping in geospatial studies, scripting methods by means of Generic Mapping Toolset (GMT) are more effective for plotting cartographic data, as providing more accurate and automated solutions for digital agriculture and environmental monitoring using diverse datasets. GMT is capable to process multi-format data, which is useful when visualising data from various sources, such as climate and geographic factors, topographic variability of the terrain [Collins *et al.* 2017], proximity of crop lands to the rivers, identification of land use or land cover types, possibility of droughts (analysis of annual temperature), or even social-economic data, for instance, local farmer population in Ethiopia. Key parameters may be originally present in diverse data formats which requires effective processing such datasets when quantifying regional climate settings for sustainable agroecosystems [Peter *et al.* 2020]. These can be used for agricultural assessment and environmental sustainability in Ethiopia.

DATA COLLECTION AND COMPILATION

In this study, data were merged from numerous sources that vary in scale, geographic extent, formats and resolution. The materials include qualitative and quantitative data retrieved from the TerraClimate [Abatzoglou *et al.* 2018], WorldClim [Fick, Hijmans 2017], CRUTS (Climatic Research Unit) version 4.0 [Harris *et al.* 2020]. Open source climate and meteorological data were compiled to support environmental mapping of Ethiopia. The GEBCO data [GEBCO Compilation Group 2020] were used for topographic mapping and clipped using the Digital Chart of the World (DCW) vector layer. The GEBCO is a 15 arc-second raster grid showing the most competent and detailed topography and bathymetry data of the Earth, widely used in geosciences [Gauger *et al.* 2007; Lemenkova 2020a, b]. The data were integrated to produce the compatibility across the map series.

MAPPING IN GMT

The cartographic visualisation and mapping were performed by methods of spatial data processing using GMT scripting toolset [Wessel *et al.* 2019]. GMT smoothly combines the advanced technical scripting methods and recognises the majority of spatial data formats that can be imported and processed. In this study, several modules of GMT were used by existing technique [Lemenkova 2019a, b; 2021b]: grdcut, makecpt, grdimage, psbasemap, pscoast, psclip, grdcontour, pstext, psconvert. Climatic water deficit estimation was visualised to assess irrigation demand and landscape stress in Ethiopia. This parameter shows the estimated amount of water plants that would be used if it were available [Flint *et al.* 2015]. Since the maps aim to demonstrate the variability of the environmental parameters, the projection was defined identical for all the maps for compatibility reasons.

Map annotations were added using the "pstext" module of GMT by manual editing of the coordinates and the annotated text. For example, it can be seen in following code snippet for the subtitle in Figure 7 (Climatic Water Deficit): "gmt pstext -R0/10/0/15 -JX10/10 -X0.1c -Y8.0c -N -O -F+f11p,13,black+jLB >> $ps << EOF 0.0 9.0 Dataset: TerraClimate. Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24\232) EOF". The colour palettes were selected for the most effective visualisation, to highlight the extremal values, and to make maps compatible with others in the series. Those were defined using the GMT command "gmt makecpt". To adjust existing colour palettes to the actual data range, stretching was used for the following colour palettes: "elevation", "panoply", "jet", "cyclic", "turbo", "inferno" and "wysiwyg". The contrast hues and colour palette solutions, the variations of the fonts and relationships in hierarchies of the annotations have been maintained persistently among the maps and among elements such as country boundaries, river network, colour scale, clipped country map and an insert global map. The maps present raster files plotted by GMT with regulated transparency.

RESULTS AND DISCUSSION

The results are presented as seven new maps of Ethiopia demonstrating changes of the selected climate and environmental variables in the topographic and geological context: Afar Triangle and Danakil Depression, Ethiopian Highlands, Great Rift Valley, lowlands and Ogaden Desert.

Gradual changes in values of the environmental variables show correspondence with local and regional relief and trends in climate parameters. The results include a set of new medium-scaled maps of Ethiopia produced using GMT for each of the environmental parameters. The maps are based on the high-resolution datasets derived and interpreted from the open sources: GEBCO, TerraClimate, WorldClim, CRUTS 4.0. The maps can be used in relevant similar studies on Ethiopia.

The cartographic visualisation of the data is presented through the GMT-based mapping to demonstrate variability and correlation of the given parameters in details over the contrasting geographic units annotated in the topographic map (Fig. 1): the Ethiopian Highlands, with dominated cool climate, and the lowlands (Afar, Danakil Depression) with dominated arid climate. The comparison of maps is necessary for the analysis of the heterogeneous patterns of climate variables in such drought-prone regions as Ethiopia. This can assist in agricultural monitoring which requires advanced mapping techniques and cartographic visualisation of high-resolution data. When comparing maps (Figs. 1–2), it can be seen that downward surface shortwave radiation in Ethiopia (Fig. 2) shown the highest values (over 271 W·m^{-2}) in the southern region of the country (bright red colours), while the lowest ones (<235 W·m^{-2}) are dominating in the Danakil Depression and Afar (blue colours areas in Fig. 2).

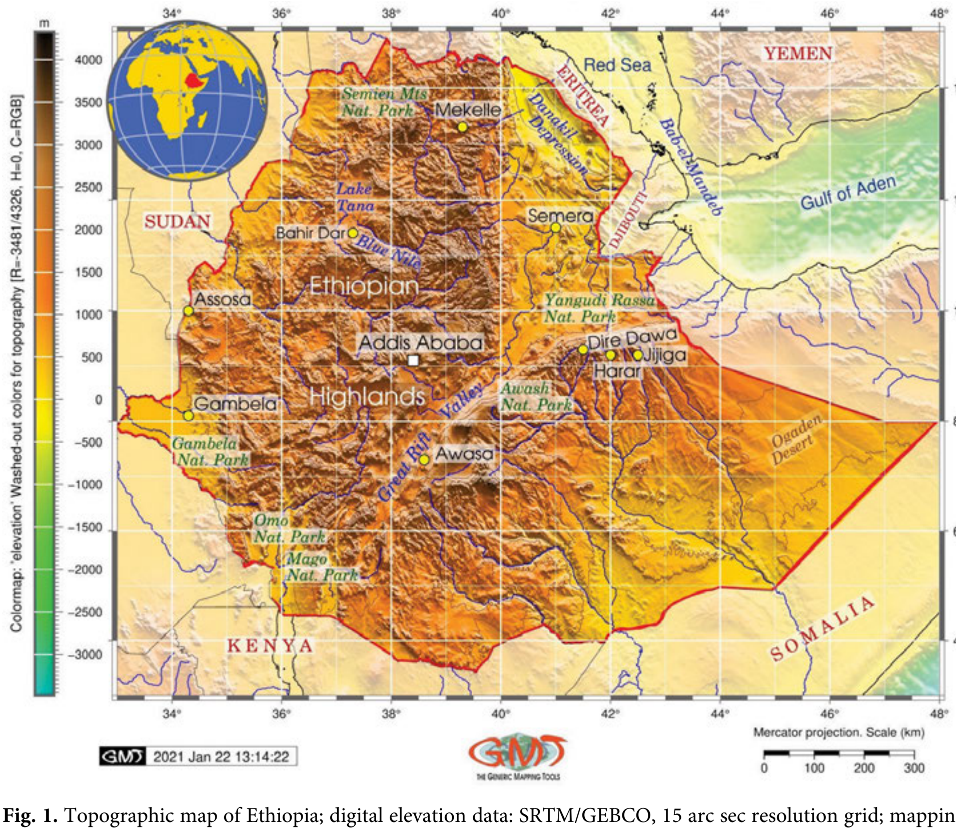

Fig. 1. Topographic map of Ethiopia; digital elevation data: SRTM/GEBCO, 15 arc sec resolution grid; mapping: GMT; source: own study

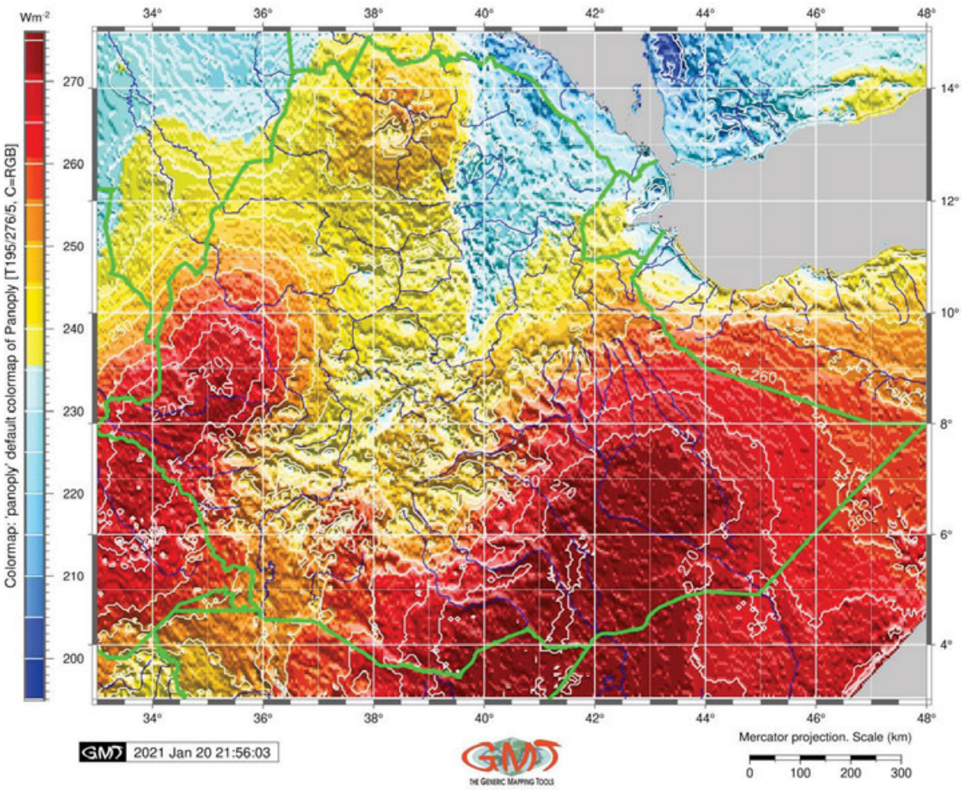

Fig. 2. Downward surface shortwave radiation in Ethiopia (2018) visualised using TerraClimate WorldClim, CRUTS v4.01 data variables; spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

Using GMT-based maps for detecting arid regions not suitable for agricultural activities together with other cartographic methods assists in advanced environmental analysis by comparative analysis. For instance, comparing water pressure (Fig. 3) with topographic map (Fig. 1) demonstrates the effects of the relief and topographic variations on water pressure. The vapour pressure deficit (*VPD*), shows negative difference, or deficit, between the actual air moisture and the theoretical amount of moisture that the air could hold once saturated. In the conditions of the saturated air, water condense out forming water over leaves, which is ultimately a limiting factor in plant growth rates across the ecosystems [Novick *et al.* 2016]. Therefore, a comparison between the vapour pressure deficit (Fig. 4) and the topography (Fig. 1) shows their potential interactions reflected as a correspondence between the isolines and contours of the Great Rift Valley clearly depicted on the both maps. The lowest values (from –1 to 1, blue colours in Fig. 4) are typical for the Ethiopian Highlands while higher values are clearly visible in the Danakil Depression and Afar reaching values 3.5 (yellow colour) up to 6 (bright red). Climatic water deficit is higher in the coastal areas and the Afar Triangle (110–145), while higher (60–100) in the Ethiopian Highlands. Vapour pressure (*VAP*) is the highest in the coastal areas (*VAP* values from 3 to 6) while low values in the Ethiopian Highlands (*VAP* from 0 to 2). The correlation of the vapour pressure with relief is illustrated by the isolines and colour schemes remarkably corresponding to the contours of the Afar and the Great Rift Valley.

As demonstrated on these maps, the GMT develops a data-driven technique that can visualise spatial data accurately and rapidly. Such a principle differs significantly from the existing traditional GUI-based GIS. For instance, GMT employs data capture and processes various formats including raster and vector files. Due to the accurate data visualisation, GMT assists in information retrieval and more complex interpreting.

However, the GMT-based maps can be coupled with cartographic visualisation made using GIS. Such an integrated approach combining different maps can assists in decision-making for agricultural monitoring of Ethiopia, spatial environmental analysis and data modelling. The advantages of the integrated studies consist in processing multiple variables (e.g. vapour deficit, evapotranspiration, climate water deficit and many more) that may be used for indicating suitability of the selected regions for arable lands or as a basis parameters in more complex environmental estimations and modelling.

Climate and environmental changes create challenges for landscapes and vegetation coverage. These are well reflected in landscape dynamics that results in new land cover types and affected biodiversity. Landscape variability and dynamics is largely affected by regional climate setting and variations in local parameters that in turn are controlled by the atmosphere-soil interactions. For instance, water from the soil is being transported upward to the atmosphere, which is caused by the evaporation from the soil surface and transpiration from plants. As a consequence, the evapotranspiration can indicate on more or less favourable regions for vegetation growth and intensity of the vegetation coverage (sparse or dense). Such an analysis can assist in decision making regarding the sustainable agriculture and environmental land management.

The evapotranspiration reflects biophysical processes of the evaporation and transpiration of plants that are useful for environmental and ecological assessment. This can indirectly show how local and regional landscapes are controlled by climate and topography reflected in vegetation health and canopy

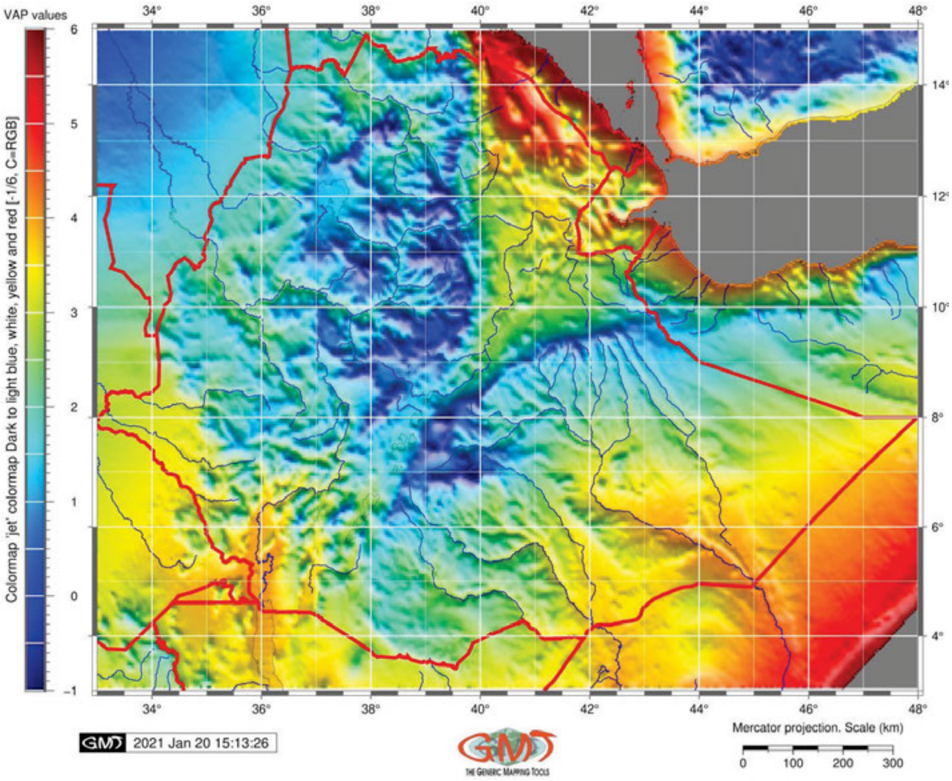

Fig. 3. Vapour pressure (*VAP*) in Ethiopia (2018); Dataset: TerraClimate, WorldClim, CRUTS v4.01; spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

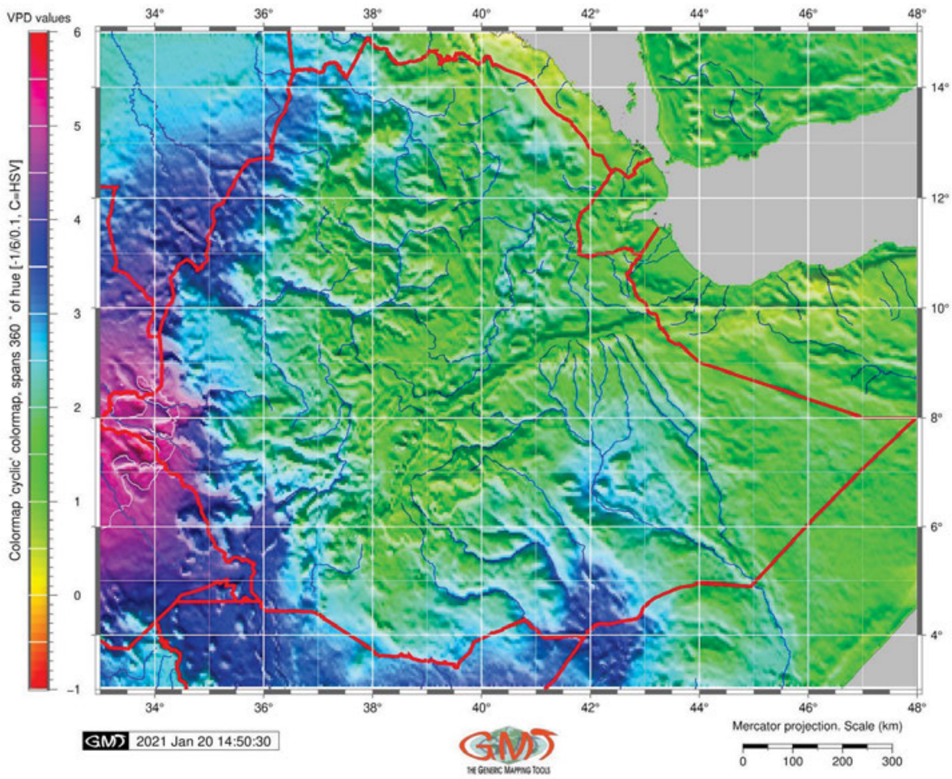

Fig. 4. Vapour pressure deficit (*VPD*) in Ethiopia (2018); dataset: TerraClimate, WorldClim, CRUTS v4.01; spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

coverage. For example, the potential evapotranspiration (Fig. 5) well correlates with the topographic patterns and shows the lowest values (<120 mm) in the Ethiopian Highlands and the highest values (>220 mm) in the south, which demonstrates general zoning of the area with respect to the relief of the country. The actual evapotranspiration (Fig. 6) reaches its highest values (over 120 mm) in the north-eastern region of the country (39.5°E, 14.3° N) following by the areal in the west (over 120 mm, 35°E, 8°N).

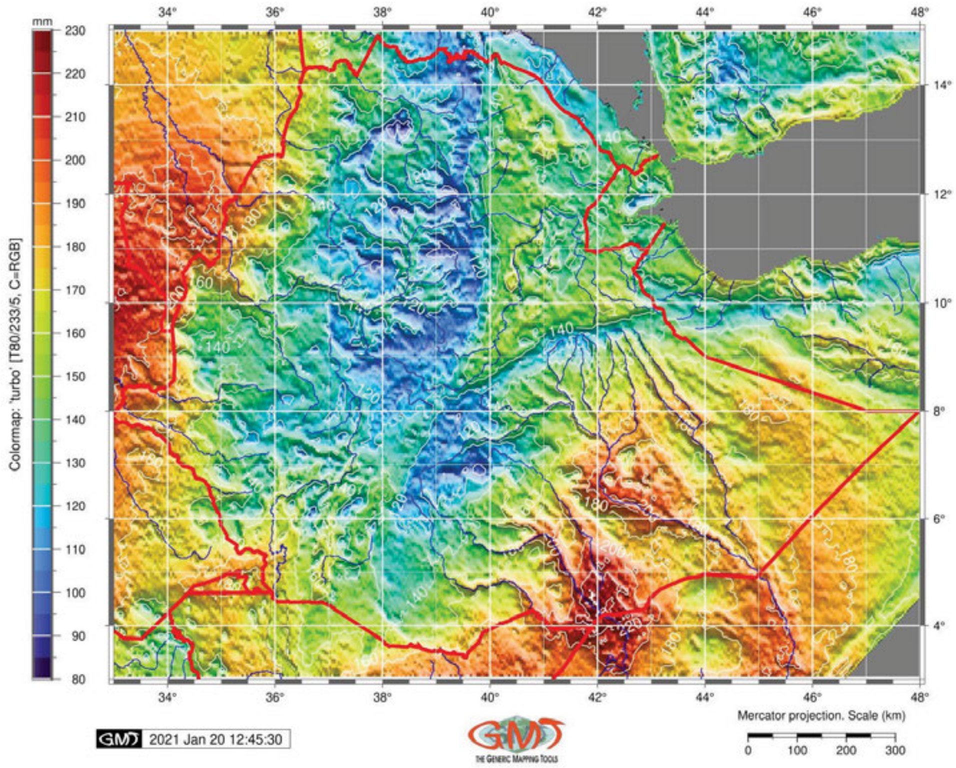

Fig. 5. Potential evapotranspiration (*PET*) in Ethiopia (2018); dataset: TerraClimate, WorldClim, CRUTS v4.01; spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

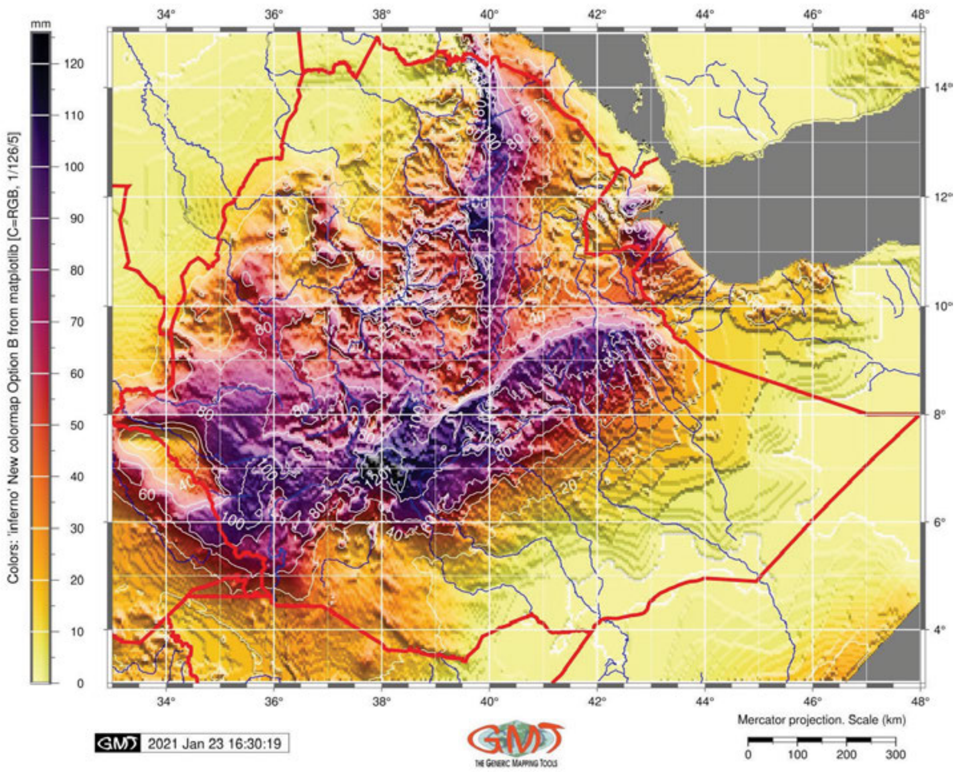

Fig. 6. Actual evapotranspiration (*AET*) in Ethiopia (2018); Dataset: TerraClimate, WorldClim, CRUTS v4.01; Spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

Random selection of the enlarged patches, grouping and hierarchical comparison of the selected fragments for landscape analysis may assist in the multi-scale evaluation of the potentially suitable areas for the crop fields with different patch sizes in Ethiopia. For instance, regional location of the Danakil Depression well correlates with the lowest values of the climatic water deficit (<10 mm) which accentuated topographic locations of various landscapes type sites in Ethiopia through pairwise comparative analysis of the two geographic datasets. On the contrary, the highest values (>220 mm, pink rose colour in Fig. 7) are notable for the mountainous areas in the south of the country.

Mapping environmental and climate parameters benefits from the automated scripting methods, since it increases accuracy and speed of mapping workflow. As a response to these needs, GMT presents excellent solutions for environmental mapping of Ethiopia by ensuring cartographic quality for environmental data analysis.

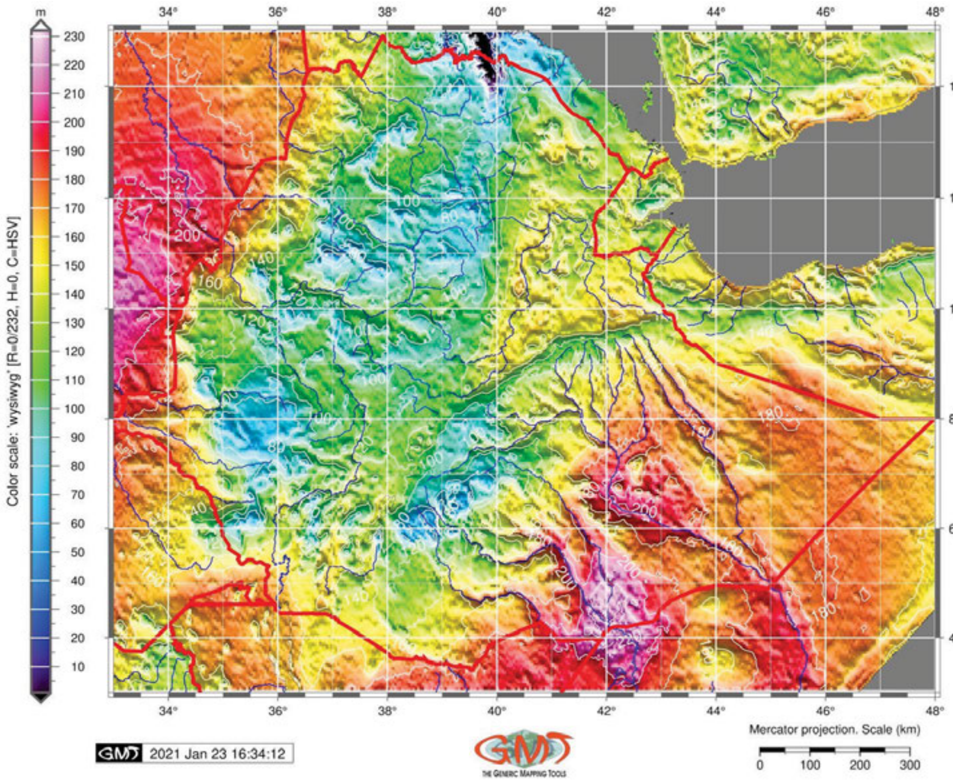

Fig. 7. Climatic water deficit (*DEF*) in Ethiopia in 2018; dataset: TerraClimate, WorldClim, CRUTS v4.01; spatial resolution: 4 km (1/24°); mapping: GMT; source: own study

Besides the demonstrated methodological application of GMT, this study proposed an environmental framework of mapping Ethiopia that may assist in agricultural policy makers and optimise crop monitoring based on the advanced geospatial data processing. The scripting techniques of GMT have been recognised as an effective tools for automatic processing of the spatial data which can also be applied in crop data analysis, landscape studies and land cover use monitoring. The advantage of the GMT application in geospatial studies of Africa is that it enables to produce accurate and robust print-quality maps by providing a time-efficient workflow of data processing through the automated workflow which is achieved by scripts. For instance, GMT scripts enable to plot maps based on the automated mapping which significantly accelerates the workflow of mapping. This is applicable for the environmental and climate studies of Ethiopia enabling to improve mapping and assist in estimation of environmental and climate setting.

The presented series of maps aims to examine local climate variations over Ethiopia that affect vegetation health and conditions of growth. The methodology included using scripting methods of GMT by analysing TerraClimate datasets covering Ethiopia. The environmental and climate mapping has an ultimate goal of assisting agricultural needs. Therefore, it requires operative monitoring of climate datasets using open sources, such as TerraClimate. Such data can also be used for comparative analysis by years that enables time series analysis or retrospective mapping.

CONCLUSIONS

Based on the identified research limitations in the existing literature on Ethiopia, this study applied algorithms of GMT scripting techniques for advanced geospatial data processing for mapping climatic and environmental variables. The geospatial data have been used from the open sources for mapping selected climate variables of Ethiopia. For example, this include variations of vapour pressure (*VAP*) and vapour pressure deficit (*VPD*), actual and potential evapotranspiration (*AET* and *PET*) and climate water deficit (*DEF*) compared to the topography of the country.

In this way, the paper presents a challenging task of supportive environmental mapping of Ethiopia. In turn, water resource management and land monitoring opens up opportunities for agricultural development and vegetation monitoring in the country. The design of the map series regulated hierarchical composition and relationship between the elements on maps showing different data (climate and topographic). The visualisation of these data has been performed using a variety of GMT colour palettes and innovative application of the continuous hue colour schemes (see Figs. 1–7). Effective cartographic visualisation of the climate and environmental parameters by GMT contributes to the ecological monitoring of Ethiopia to ensure that its unique and topographically diverse landscapes are accurately monitored using advanced methods.

Interpolated colouring and contouring of the continuous fields of the meteorological variables visualised on the maps (evapotranspiration in actual and potential computations, vapour pressure deficit, climatic water deficit) highlighted correlations between the environmental categories and the topography of Ethiopia which includes such complex landforms and geological units as Afar Triple Junction, Danakil Depression, Ethiopian Highlands, Great Rift Valley, lowlands and Ogaden Desert. Thus, the maps emphasised logical, physical and hierarchical relations between the climate, topographic and meteorological parameters that strongly affect soil setting and, as a consequence, control vegetation growth. The topographic relief around the selected regions of the country in extremal values (depressions and highlands) can be visible at the cross-correlation analysis and pairwise comparison of the maps.

The GIS-based visualisation for georeferenced data is a topic that has received increasing attention in publications over the last decades. These include, for instance, quality visualisation of the geospatial data, cartographic algorithms of data modelling, open sources for public geographic repositories, to mention a few. To contribute to the existing environmental studies on Ethiopia and to increase the existing information of the climate and environment variability of the country, this paper presented a thematic series of the seven new maps covering Ethiopia. The maps demonstrated spatial variations of the selected climate and ecological parameters that correlate with topographic setting of the country. In this way, the study aimed to contribute to the environmental analysis of Ethiopia.

As a recommendation for future studies extended use of the programming languages and application of machine learning algorithms can improve techniques of mapping along with other datasets used for more detailed environmental analysis. The present study intended to provide a framework for thematic environmental mapping of Ethiopia using GMT for mapping climate variables related to droughts. Such an analysis may be used for assessment of crop health in agricultural monitoring of the country, as well as a background for hydrological and environmental mapping of Ethiopia.

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REFERENCES

ABATZOGLOU J., DOBROWSKI S., PARKS S., HEGEWISCH K.C. 2018. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Scientific Data. Vol. 5, 170191. DOI 10.1038/sdata.2017.191.

ADIMASSU Z., MEKONNEN K., YIRGA C., KESSLER A. 2014. Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. Land Degradation & Development. Vol. 25 p. 554–564. DOI 10.1002/ldr.2182.

AHMAD I., DAR M.A., ANDUALEM T.G., TEKA A.H. 2020. GIS-based multi-criteria evaluation of groundwater potential of the Beshilo River basin, Ethiopia. Journal of African Earth Sciences. Vol. 164, 103747 p. 1–10. DOI 10.1016/j.jafrearsci.2019.103747.

ANDUALEM T.G., DEMEKE G.G. 2019. Groundwater potential assessment using GIS and remote sensing: A case study of Guna tana landscape, upper blue Nile Basin, Ethiopia. Journal of Hydrology: Regional Studies. Vol. 24, 100610 p. 1–13. DOI 10.1016/j.ejrh.2019.100610.

AYENEW T. 2003. Evapotranspiration estimation using thematic mapper spectral satellite data in the Ethiopian rift and adjacent highlands. Journal of Hydrology. Vol. 279(1–4) p. 83–93. DOI 10.1016/S0022-1694(03)00173-2.

BATÁRY P., DICKS L.V., KLEIJN D., SUTHERLAND W.J. 2015. The role of agri-environment schemes in conservation and environmental management. Conservation Biology. Vol. 29(4) p. 1006–1016. DOI 10.1111/cobi.12536.

BENAMI E., JIN Z., CARTER M.R., GHOSH A., HIJMANS R.J., HOBBS A., KENDUIYWO B., LOBELL D.B. 2021. Uniting remote sensing, crop modelling and economics for agricultural risk management. Nature Reviews Earth & Environment. Vol. 2 p. 140–159. DOI 10.1038/s43017-020-00122-y.

BEYENE A., CORNELIS W., VERHOEST N.E.C., TILAHUN S., ALAMIREW T., ADGO E., DE PUE J., NYSSEN J. 2018. Estimating the actual evapotranspiration and deep percolation in irrigated soils of a tropical floodplain, northwest Ethiopia. Agricultural Water Management. Vol. 202 p. 42–56. DOI 10.1016/j.agwat.2018.01.022.

COLLINGS E.R., ALAMAR M.C., REDFERN S., COOLS K., TERRY L.A. 2019. Spatial changes in leaf biochemical profile of two tea cultivars following cold storage under two different vapour pressure deficit (VPD) conditions. Food Chemistry. Vol. 277 p. 179–185. DOI 10.1016/j.foodchem.2018.10.095.

COLLINS C.D., BANKS-LEITE C., BRUDVIG L.A., FOSTER B.L., COOK W.M., DAMSCHEN E.I., ..., ORROCK J.L. 2017. Fragmentation affects plant community composition over time. Ecography. Vol. 40 p. 119–130. DOI 10.1111/ecog.02607.

DILE Y.T., AYANA E.K., WORQLUL A.W., XIE H., SRINIVASAN R., LEFORE N., YOU L., CLARKE N. 2020. Evaluating satellite-based evapotranspiration estimates for hydrological applications in data-scarce regions: A case in Ethiopia. Science of The Total Environment. Vol. 743, 140702. DOI 10.1016/j.scitotenv.2020.140702.

DIODATO N., CECCARELLI M., BELLOCCHI G. 2010. GIS-aided evaluation of evapotranspiration at multiple spatial and temporal climate patterns using geoindicators. Ecological Indicators. Vol. 10(5) p. 1009–1016. DOI 10.1016/j.ecolind.2010.02.009.

EL MAAYAR M., CHEN J.M. 2006. Spatial scaling of evapotranspiration as affected by heterogeneities in vegetation, topography, and soil texture. Remote Sensing of Environment. Vol. 102(1–2) p. 33–51. DOI 10.1016/j.rse.2006.01.017.

ELBELTAGI A., ASLAM M.R., MOKHTAR A., DEB P., ABUBAKAR G.A., KUSHWAHA N.L., VENANCIO L.P., MALIK A., KUMAR N., DENG J. 2020. Spatial and temporal variability analysis of green and blue evapotranspiration of wheat in the Egyptian Nile Delta from 1997 to 2017. Journal of Hydrology. Vol. 594, 125662. DOI 10.1016/j.jhydrol.2020.125662.

FICK S.E., HIJMANS R.J. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology. Vol. 37 p. 4302–4315. DOI 10.1002/joc.5086.

FLINT L.E., FLINT A.L., THORNE J.H. 2015. Climate change: Evaluating your local and regional water resources. U.S. Geological Survey, Reston, VA. Fact Sheet. Vol. 2014(3098). DOI 10.3133/fs 20143098.

Gauger S., Kuhn G., Gohl K., Feigl T., Lemenkova P., Hillenbrand C. 2007. Swath-bathymetric mapping. Reports on Polar and Marine Research. Vol. 557 p. 38–45. DOI 10.6084/m9.figshare.7439231.

GEBCO Compilation Group 2020. GEBCO 2020 Grid – A continuous terrain model of the global oceans and land. British Oceanographic Data Centre, National Oceanography Centre, NERC, UK. DOI 10.5285/a29c5465-b138-234d-e053-6c86abc040b9.

Gebru T.A., Tesfahunegn G.B. 2020. GIS based water balance components estimation in northern Ethiopia catchment. Soil and Tillage Research. Vol. 197, 104514. DOI 10.1016/j.still .2019.104514.

Harris I., Osborn T.J., Jones P., Lister D. 2020. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data. Vol. 7, 109. DOI 10.1038/s41597-020-0453-3.

Klaučo M., Gregorová B., Koleda P., Stankov U., Marković V., Lemenkova P. 2017. Land planning as a support for sustainable development based on tourism: A case study of Slovak rural region. Environmental Engineering and Management Journal. Vol. 2(16) p. 449–458. DOI 10.30638/eemj.2017.045.

Klaučo M., Gregorová B., Stankov U., Marković V., Lemenkova P. 2013. Determination of ecological significance based on geostatistical assessment: A case study from the Slovak Natura 2000 protected area. Open Geosciences. Vol. 5(1) p. 28–42. DOI 10.2478/s13533-012-0120-0.

Lemenkov V., Lemenkova P. 2021a. Using TeX Markup Language for 3D and 2D Geological Plotting. Foundations of Computing and Decision Sciences. Vol. 46(1) p. 43–69. DOI 10.2478/fcds-2021-0004.

Lemenkov V., Lemenkova P. 2021b. Measuring equivalent cohesion Ceq of the frozen soils by compression strength using Kriolab Equipment. Civil and Environmental Engineering Reports. Vol. 31(2) p. 63–84. DOI 10.2478/ceer-2021-0020.

Lemenkov V., Lemenkova P. 2021c. Testing deformation and compressive strength of the frozen fine-grained soils with changed porosity and density. Journal of Applied Engineering Sciences. Vol. 11(2) p. 113–120. DOI 10.2478/jaes-2021-0015.

Lemenkova P. 2019a. GMT based comparative analysis and geomorphological mapping of the Kermadec and Tonga Trenches, Southwest Pacific Ocean. Geographia Technica. Vol. 14(2) p. 39–48. DOI 10.21163/GT_2019.142.04.

Lemenkova P. 2019b. Geomorphological modelling and mapping of the Peru-Chile Trench by GMT. Polish Cartographical Review. Vol. 51(4) p. 181–194. DOI 10.2478/pcr-2019-0015.

Lemenkova P. 2019c. Topographic surface modelling using raster grid datasets by GMT: Example of the Kuril-Kamchatka Trench, Pacific Ocean. Reports on Geodesy and Geoinformatics. Vol. 108 p. 9–22. DOI 10.2478/rgg-2019-0008.

Lemenkova P. 2020a. GEBCO Gridded Bathymetric Datasets for mapping Japan Trench geomorphology by means of GMT Scripting Toolset. Geodesy and Cartography. Vol. 46(3) p. 98–112. DOI 10.3846/gac.2020.11524.

Lemenkova P. 2020b. Variations in the bathymetry and bottom morphology of the Izu-Bonin Trench modelled by GMT. Bulletin of Geography. Physical Geography Series. Vol. 18(1) p. 41–60. DOI 10.2478/bgeo-2020-0004.

Lemenkova P. 2021a. The visualization of geophysical and geomorphologic data from the area of Weddell Sea by the Generic Mapping Tools. Studia Quaternaria. Vol. 38(1) p. 19–32. DOI 10.24425/sq.2020.133759.

Lemenkova P. 2021b. Geodynamic setting of Scotia Sea and its effects on geomorphology of South Sandwich Trench, Southern Ocean. Polish Polar Research. Vol. 42(1) p. 1–23. DOI 10.24425/ppr .2021.136510.

Lindh P., Lemenkova P. 2021. Evaluation of different binder combinations of cement, slag and CKD for S/S treatment of TBT contaminated sediments. Acta Mechanica et Automatica. Vol. 15 (4) p. 236–248. DOI 10.2478/ama-2021-0030.

Novick K.A., Ficklin D.L., Stoy P.C., Williams C.A., Bohrer G., Oishi A.C., ..., Scott R.L. 2016. The increasing importance of atmospheric demand for ecosystem water and carbon fluxes. Nature Climate Change. Vol. 6(11) p. 1023–1027. DOI 10.1038/ nclimate3114.

Peter B.G., Messina J.P., Lin Z., Snapp S.S. 2020. Crop climate suitability mapping on the cloud: A geovisualization application for sustainable agriculture. Scientific Reports. Vol. 10(15487). DOI 10.1038/s41598-020-72384-x.

Rodriguez-Dominguez C.M., Hernandez-Santana V., Buckley T.N., Fernández J.E., Diaz-Espejo A. 2019. Sensitivity of olive leaf turgor to air vapour pressure deficit correlates with diurnal maximum stomatal conductance. Agricultural and Forest Meteorology. Vol. 272–273 p. 156–165. DOI 10.1016/j.agrformet .2019.04.006.

Schenke H.W., Lemenkova P. 2008. Zur Frage der Meeresboden-Kartographie: Die Nutzung von AutoTrace Digitizer für die Vektorisierung der Bathymetrischen Daten in der Petschora-See [To the question of seafloor mapping: The use of AutoTrace Digitizer for the vectorization of the bathymetric data in the Pechora Sea]. Hydrographische Nachrichten. Vol. 81 p. 16–21. DOI 10.6084/m9.figshare.7435538.

Suetova I.A., Ushakova L.A., Lemenkova P. 2005. Geoinformation mapping of the Barents and Pechora Seas. Geography and Natural Resources. Vol. 4 p. 138–142. DOI 10.6084/m9.figshare .7435535.

Tadesse T., Senay G.B., Berhan G., Regassa T., Beyene S. 2015. Evaluating a satellite-based seasonal evapotranspiration product and identifying its relationship with other satellite-derived products and crop yield: A case study for Ethiopia. International Journal of Applied Earth Observation and Geoinformation. Vol. 40 p. 39–54. DOI 10.1016/j.jag.2015.03.006.

Tamene L., Adimassu Z., Aynekulu E., Yaekob T. 2017. Estimating landscape susceptibility to soil erosion using a GIS-based approach in Northern Ethiopia. International Soil and Water Conservation Research. Vol. 5(3) p. 221–230. DOI 10.1016/j. iswcr.2017.05.002.

Villarreal-Guerrero F., Pinedo-Alvarez A., Flores-Velázquez J. 2020. Control of greenhouse-air energy and vapor pressure deficit with heating, variable fogging rates and variable vent configurations: Simulated effectiveness under varied outside climates. Computers and Electronics in Agriculture. Vol. 174, 105515. DOI 10.1016/j. compag.2020.105515.

Wessel P., Luis J.F., Uieda L., Scharroo R., Wobbe F., Smith W.H.F., Tian D. 2019. The Generic Mapping Tools version 6. Geochemistry, Geophysics, Geosystems. Vol. 20 p. 5556–5564. DOI 10.1029/2019GC008515.

Worku G., Teferi E., Bantider A., Dile Y.T. 2021. Modelling hydrological processes under climate change scenarios in the Jemma sub-basin of upper Blue Nile Basin, Ethiopia. Climate Risk Management. Vol. 31(100272). DOI 10.1016/j.crm .2021.100272.