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GIS-BASED DELINEATION AND REGIONALIZATION OF GEOMORPHOGRAPHIC UNITS IN THE FLOODPLAIN OF OGOSTA RIVER BETWEEN THE SETTLEMENT GAVRIL GENOVO AND THE "OGOSTA" RESERVOIR (NW-BULGARIA)[1]

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This paper presents the results of computer-based landform classification of the area between the settlement Gavril Genovo and the "Ogosta" reservoir (NW-Bulgaria). Data obtained from Airborne Laser Scanning using *RIEGL LMS-Q680i* long-range and *RIEGL VQ-820-G* hydrographic airborne laser scanner with online waveform processing were used for generation of a precise Digital Terrain Model (DTM) 1x1 m. A methodological approach was proposed und tested for delineation of landform patterns in the floodplain. It includes delineation and cross-classification of Topographic Classification Index for lowlands and Vertical Distance to Channel Network in 56 classes using SAGA GIS. In order to achieve more real landform units the result was reclassified in 26 classes and verified through field investigation after a flood event in April 2014. Other compound geomorphometric variables, e.g. SAGA Wetness Index, Multiresolution Index of Valley Bottom Flatness were calculated. The obtained result can be used for detailed geomorphologic field mapping and can be applied in areas with similar geomorphographic and geomorphologic conditions.

Keywords: Digital Terrain Model (DTM), Airborne Laser Scanning Data (ALS), geomorphology, geomorphometric variables, landforms, geomorphographic units, Ogosta floodplain.

ГИС-БАЗИРАНО ЕКСТРАХИРАНЕ И РЕГИОНАЛИЗИРАНЕ НА ГЕОМОРФОГРАФСКИ ЕДИНИЦИ В ЗАЛИВНАТА ТЕРАСА НА РЕКА ОГОСТА МЕЖДУ С. ГАВРИЛ ГЕНОВО И ЯЗ. „ОГОСТА– (СЗ-БЪЛГАРИЯ)

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Резюме: Статията представя първоначални резултати от ГИС-базиран анализ за екстрахиране и регионализиране на морфложки единици в заливната

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тераса на р. Огоста между с. Гаврил Геново и яз. „Огоста“. Компютърно-базираният морфометричен анализ е извършен на базата на прецизен цифров модел на релефа с размер на отделен пискел 1×1 m, генериран от данни от въздушно лазерно сканиране. На базата на разработен за целта на изследването методически подход са екстрахирани, анализирани и рекласифицирани различни локални (базисни) и комплексни морфометрични променливи чрез използването на функции за ГИС-анализ. Разработеният методически подход позволява от една страна създаване на релевантни за геоморфоложки изследвания тематични карти, напр. наклон на склоновете, карта на теоретичен индекс за овлажнение на почвата, карта на индекс на заравненост на заливната тераса, а от друга идентифициране и регионализиране на реални геоморфоложки форми на изследваната заливна тераса или запазени остатъци от тях, напр. речно легло, старици, локални понижения в релефа, пясъчни грядове, пясъчни барове, наносни конуси и др. Разнообразието от форми в заливната тераса на р. Огоста е резултат от действието на редица геоморфоложки и хидроложки процеси като линейна и площна ерозия, периодични наводнения и антропогенна дейност особено през холоцена и съвремието. Идентифицираните морфоложки форми в изследвания район са групирани в 24 геоморфографски единици на базата на ГИС-базиран геостатистически анализ на топографски класификационен индекс за ниски земи (TCI for lowlands) и относителна височина на релефа. Всяка геоморфографска единица включва репрезентативни форми на заливната тераса, разпространени в определен височинен интервал. Получените резултати показват, че степента на детайлност зависи от броя класове на идентифицираните и регионализирани геоморфографски единици. Автоматизираната геоморфографска класификация в 6 или 8 класа дава възможност за по-лесно определяне на границите на основните единици в района – ниска и висока заливна тераси и други по-едри форми на релефа, но екстрахирането и регионализирането на по-малки, но специфични форми като пясъчни острови, грядове, локални понижения, старици и др. е възможно на базата на по-голям брой класове. Прилагането на разработения методически подход в други изследвания изисква геоморфоложка експертиза. Получените резултати ще бъдат използвани за моделиране на пространственото разпределение за арсен в почвата и хидродинамични модели на изследвания район. Тези резултати могат да послужат и за детайлно геоморфоложко картиране в изследвания район, а методическия подход би могъл да намери приложение за геоморфоложко изследване на други райони със сходен релеф.

Ключови думи: цифров модел на релефа, въздушно лазерно сканиране, геоморфология, морфометрични параметри, форми на релефа и морфографски единици, заливна тераса на р. Огоста.

INTRODUCTION

Geomorphometry is one of the most rapidly developing scientific field in geomorphology in the last decades (Hengl, Reuter 2009; Evans 2012). Delineation and mapping of geomorphometric terrain variables from digital terrain models (DTM) allow more accurate description of landforms (Pike 1988; Kleefisch, Koethe 1991). This approach contributes to description and analysis of complexity of the landforms additionally to knowledge of geomorphological processes, landform origin and development. A landform classification can include geomorphologic features and geomorphometric variables which describe some characteristics of the landforms or of their elements (e. g. Drăgut, Eisank 2011; Drăgut, Eisank 2012; Wieszorek, Migon 2014). Different methodological approaches for landform classification, which are used worldwide, give us a reason to make conclusion that the scale, the concrete goal of a landform classification and the used software impact computer-based geomorphologic analysis.

This paper presents the results of computer-based landform classification of the area between the settlement Gavril Genovo and the "Ogosta" reservoir. The area of interest has been chosen according to soil and ground contamination with heavy metals, especially arsenic. The challenge of this work was to identify and to regionalize morphological features in more or less flat area of the Upper Ogosta floodplain through automatic and expert based classification. The specific aims were the following: (i) to extract and to analyse appropriate geomorphometric variables, which could be used in landform classification; (ii) to decide the level of classification, i. e. the number of geomorphographic units including the requirement to identify the elevation of recognized landform patterns to the main stream of Ogosta and iii) landform classification based on DTM with resolution 1x1 m including delineation of geomorphographic units and landform patterns relating to geomorphological and hydrological landscape features.

TEST SITE

The test site is located between the settlement Gavril Genovo and the "Ogosta" reservoir in the upper part of the floodplain of Ogosta river (NW Bulgaria) (Fig. 1). It has highly complex topography, which reflects diversified morphology with complex polygenetic origin and a strong anthropogenic impact. The test site has an elevation between 180 and 286,1 m. The valley of Ogosta almost coincides with the Salashka syncline (Stoilov 1970). Geologically, the upper horizon is represented by Holocene alluvial deposits. Plio-pleistocene deposits with colluvial and alluvial deposits cover a wide area in the Southern slopes of Ogosta river in an elevation between 65 and 77 m (Wapzarov, Stoilov 1969). In the area of the test site alluvial deposits with Plio-pleistocene age form Pleistocene river terraces at the same elevation. According to Stoilov (1970) the Holocene low and high floodplains were formed respectively between a height 1-2,5 m and 3,5 – 6 m. Together with other erosive and accumulative landforms like sand bars, levees, locale depressions they are center on computer-based geomorphologic analysis this work.

MATERIAL AND METHODS

The data from high resolution Airborne Laser Scanning Data (ALS, known also as LiDAR – Light Detection and Ranging) was used for construction of a precise digital terrain model (DTM) with pixel size for each tile 0,5 × 0,5 m and 1x1 m for the whole study area of the upper part of the Ogosta floodplain. The ALS was done in March and in June 2013 by Airborne Technologies GmbH, Austria using two laser scanners: *RIEGL LMS-Q680i* long-range and *RIEGL VQ-820-G* hydrographic airborne laser scanner with online waveform processing.

The following two main conditions were considered while developing the classification approach. First, a large number of local and compound geomorphometric variables give quantitative description and information of landforms. The floodplain boundaries and its main characteristics could be described through slope-aspect classification, topographic wetness index (TWI), topographic classification (TCI) index for lowland and other compound geomorphometric variables (Fig. 1). Figure 1 shows the workflow of LiDAR data processing and GIS-based geomorphographic analysis in this work.

The algorithm for TCI index for lowland was developed by Bock et al. (2007) in order to ensure identification and delineation of lowland landforms (e. g. floodplain, river terraces, etc.). Second, the method had to handle Vertical Distance to Channel network (VDCN). To meet those requirements, the following classification schema was chosen: each calculated geomorphometric variable was analyzed due to

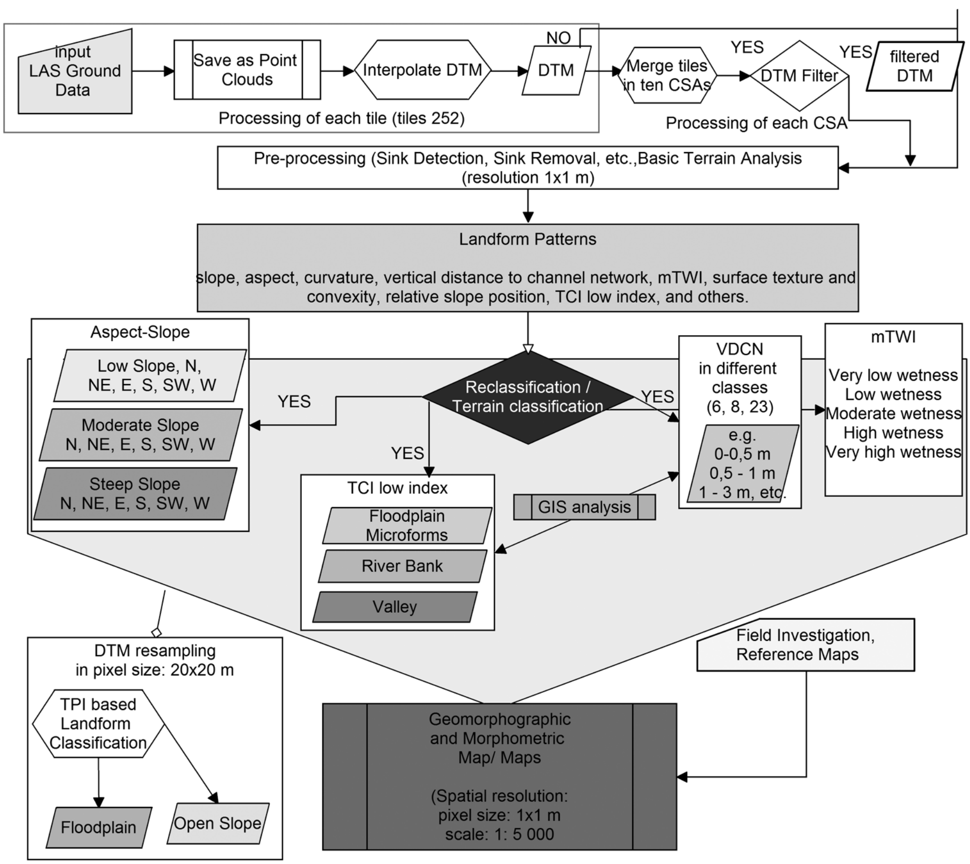

Fig. 1. Workflow of LiDAR-data processing and computer-based geomorphographic classification

its representativeness in the test site. The result shows that the TCI lowland index represents mostly realistic the geomorphographic situation in the study area. The TCI lowland index was reclassified in different classes (e.g. 6, 8, 18, 24 and 56) and the received results were compared with field mapping and the grid ‚Analytical Hillshading'. The sum of TCI index for lowland and VDCN raster layers has given a result that allowed the automatic and expert-based identification and extraction of 18 geomorphographic units (GMUs). One another approach was used to compare the result of this classification: it consists of cross-classification of TCI lowland index and VDCN in 56 classes. The result was analyzed due to its representativeness, the grid 'Analytical Hillshading' and field mapping, and then it was reclassified in 24 GMUs.

The computer-based geomorphographic landform classification was done using SAGA (System for Automated Geoscientific Analyses) open source software (http://www.saga-gis.org/en/index.html).

RESULTS

Automatic landform classification for the test site was performed. The classification of slope and aspect allowed us to define four groups of slope and aspect characteristics: near flat slope, low, moderate slope and steep slope with N, NE, E, S, SW, W aspect directions. This classification was used for delineation of floodplain boundaries in the test site.

Following the methodological approach developed and described above the obtained result represents geomorphographic landform patterns that were grouped in 24 geomorphographic units (GMUs) considering the cross-classification analysis of VDCN and TCI index for lowland. The areas up to 0,50 m and the areas between 0,5 and 1 m above Ogosta stream network represents the bankfull channel zone 1st stage. It includes the current stream bed and parafluvial zone according to the classification of Stanford (2006). Parafluvial zone is the area of the bank full channel in which flood channels, bars and levees, islands, spring brooks, ponds or scour holes are distributed (Stanford et al. 2005). Therefore, its identification and delineation in this work play a very important role from hydro-geological and hydrological point of view, in order to regionalize the area of annual sediment scour and deposition by floods and wind.

The active floodplain fragments - T0 (area that is often flooded) were recognized in the near flat areas in between 1 and 3 m above Ogosta stream. Fragmentary T0 fragments have a relative height up to 3,5 m (Fig. 2). The zone up to 1 m was defined by Ivanov (1964) as ‚Low floodplain up to 1 m" in the Eastern part of the map. In the relative height between 1 and 3 m above Ogosta stream were identified and delineated also the following landforms: convex micro-forms in T0, abandoned channels, river banks of recent and abandoned channels, embankments (natural – sand bars, levee, and anthropogenic). In this work fragments of a higher floodplain were recognized between 3,5 m and 6/6,5 m relative height (GMUs 200, 201,202, 203, 204, 205, and 206) (Fig. 2).

The obtained results were verified through field investigation in May 2014. The area was flooded (high flood was on 19 April 2014) and this event allowed us to compare the flood tracks with the obtained results in this work and old topographic maps

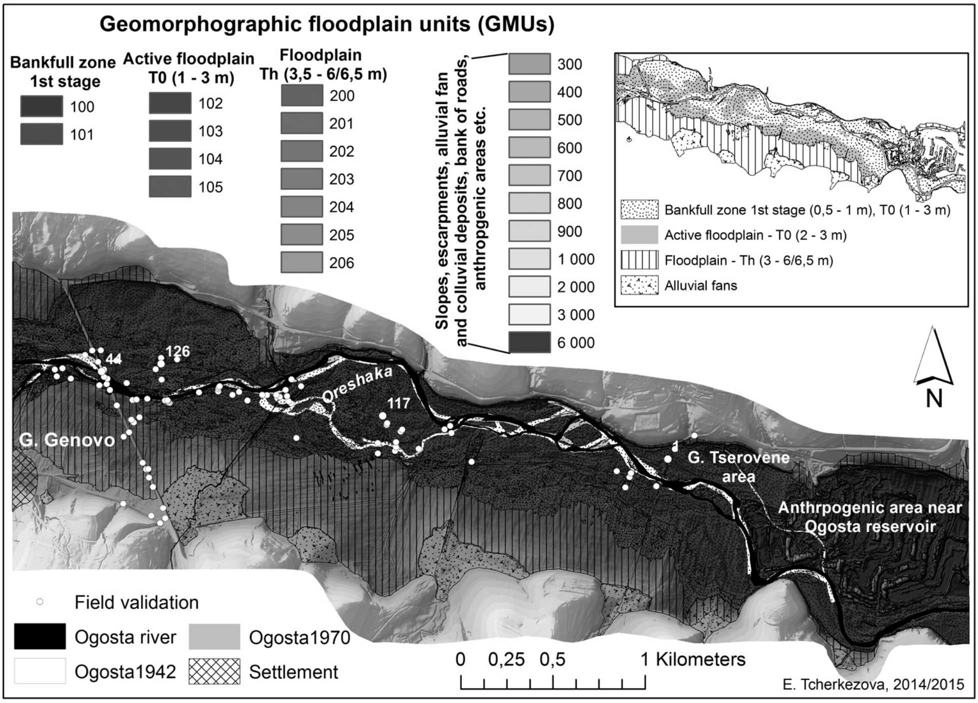

Fig. 2 Geomorphographic map

Legend: Geomorphographic units (GMU) – 100 – Bankfull channel zone 1st stage: stream bed, parafluvial zone with small locale depressions, backwater areas, abandoned channels and valleys, 0 - 0,5 m; 101 – Bankfull channel zone 1st stage: parafluvial zone, active floodplain T0 (fragments) with small locale depressions, backwater areas, abandoned channels, abandoned valleys, anthropogenic areas near Ogosta reservoir, 0,5 – 1 m; 102 – Active floodplain T0 (fragments) with small locale depressions, abandoned channels, river banks of recent and abandoned channels, embankments (natural and anthropogenic), sand bars, levees, anthropogenic areas near Ogosta reservoir, 1–1,5 m; 103 – Active floodplain T0 (fragments) with small locale depressions, more or less coarse structure with convex micro-forms, sand bars, levees, low escarpments, embankments (natural and anthropogenic), anthropogenic areas near Ogosta reservoir, 1,5–2 m; 104 – Active floodplain T0 (fragments), more or less coarse structure with convex micro-forms, sand bars, leeves, low escarpments, embankments (natural and anthropogenic), bank of roads, anthropogenic areas near Ogosta reservoir, 2–2,5 m; 105 – Active floodplain (T0) –2,5–3 m with small convex micro-forms, low escarpments, river banks, embankments (natural and anthropogenic), anthropogenic areas near Ogosta reservoir, 2,5–3 m; 200 – Floodplain (T0) (fragments) with coarse structure, escarpments, bank of roads, embankments (natural and anthropogenic), 3 – 3,5 m; 201 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 3,5–4 m; 202 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 4–4,5 m; 203 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 4,5–5 m; 204 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 5–5,5 m; 205 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 5,5–6 m; 206 – Floodplain Th (fragments) with coarse structure, alluvial fan deposits, escarpments, bank of roads, embankments (natural and anthropogenic), 6–6,5 m; 300 – Escarpments, alluvial fan deposits, colluvial deposits, slopes, up to 6,5–7 m relative height; 400 – Slopes, escarpments, alluvial fan and colluvial deposits, T1 fragments, bank of roads, 12–14 m; 500 – Slopes, escarpments, alluvial fan and colluvial deposits, bank of roads, 14–18 m; 600 – Slopes, escarpments, alluvial fan and colluvial deposits, bank of roads, small T2 fragments, 18–20 m; 700 – Slopes, escarpments, alluvial fan and colluvial deposits, bank of roads, 20–26 m; 800 – Slopes, escarpments, alluvial fan and colluvial deposits, slopes, T3 small fragments, bank of roads, 26–35 m; 900 – Slopes, escarpments, alluvial fan and colluvial deposits, slopes, bank of roads, 35–45 m; 1000 – Slopes, escarpments, alluvial fan and colluvial deposits, T4 small fragments, bank of roads, 45–55 m; 2000 – Slopes, escarpments, alluvial fan and colluvial deposits, 55–70 m; 3000 – Slopes, escarpments, alluvial fan and colluvial deposits, 70–80 m; 4000 – Slope, colluvial deposits and summit areas, 80–95 m; 5000 – Slope, colluvial deposits and summit areas, 95–185 m relative height; 6000 – Anthropogenic areas near "Ogosta" reservoir

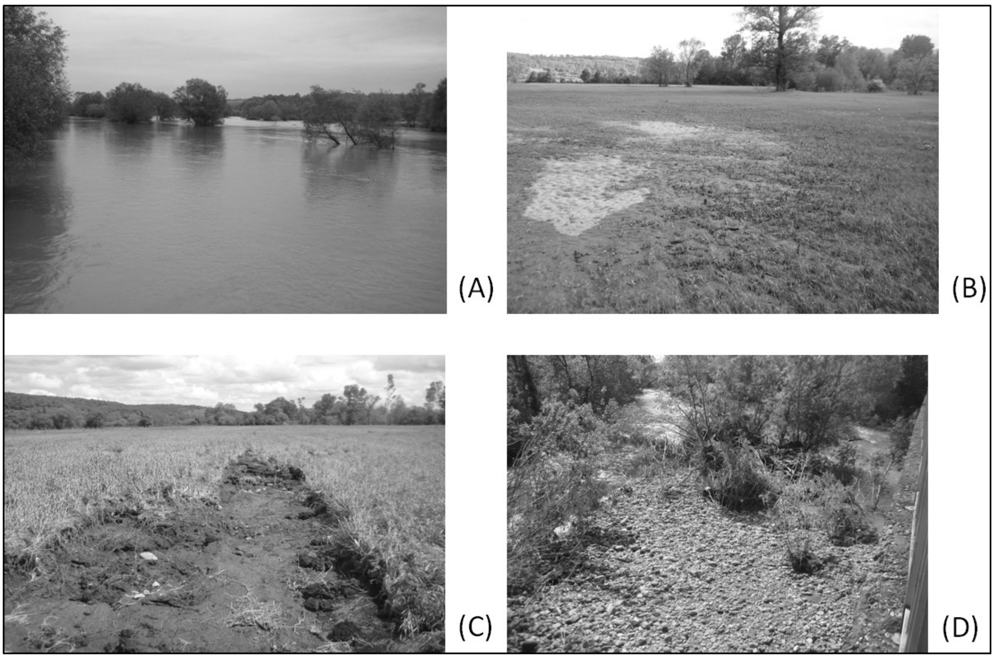

Fig. 3 Validation points of the geomorphic map

Legend: (A) Flooded area near validation points (VP) 1 and 2 in SE direction, GMU – 100 and 101; (B) Flooded area "Oreshaka, VP 117, GMU – 102; (C) Flooded area northern from the Hydrological station, VP 126, GMU – 200; (D) Stream bed deposits near VP 44, GMU 102. This area was the flood way to VP 126. Date: 8th May 2014

(Ogosta stream in 1942 and 1970) in scale 1:5000 (Fig. 2). The photos bellow show some of the validation points (VP) (Fig. 3).

The photo A (fig. 3) shows the flooded area near the ‚Ogosta' reservoir (Gorno Tserovene area) near the validation points 1 and 2. This situation confirms the accuracy of the regionalized GMUs 100 and 101. Photo B (Fig. 3) shows the flooded area in validation point 117 after the high flood in April 2014. In this area, the author has measured flood tracks in the trees with a height between 0,80 m and 1 m. Photo C (Fig. 3) shows tracks of the flooding in GMU 200 (until 2 m relative height) - validation point 126. In this area, a soil layer with very high concentration of arsenic and manganese was found during the field mapping. Photo D (Fig. 3) shows the area of the flood break on 19 April 2014 in validation point 44 (GMU 102).

CONCLUSION

Testing various combinations of local and compound geomorphometric variables and indexes allows us to conclude that the classification in pixel size of raster 1x1 m works satisfactorily with the landform classification of the test site in 24 groups using cross-classification of TCI lowland index and VDCN and geomorphologic interpretation of the received result. The role of the TCI lowland index and the extracted compound geomorphometric variables such as mTWI index and multi-resolution index of valley bottom flatness (MRVBF) by Gallant and Dowling (2003) will be also objects of further studies. The obtained results were verified during field investigation in May 2014 and show that the identified and delineated geomorphographic units correspond to real landforms and landform patterns in the study area.

The result will be used as basic data for flood modeling of the Upper Ogosta floodplain and predicting of spatial distribution of soil's contamination as well as for planning groundwater monitoring (e.g. construction of tube wells).

The expert geomorphological maps and papers (Stoilov 1970; Ivanov 1964) consist of homogenous geomorphologic units in terms of shape, lithology and age. Automatic and combined expert-automatic landform classification gives better results according to continuously spatial distribution of landforms and landform elements in the floodplain. The basic terrain ground data observed through the modern, innovative and precise ALS-technologies allows generation of very precise DTM. The received results allowed construction of geomorphographic maps in scale 1:5000. These results can be also used as basic data for detailed geomorphologic mapping in this area and can be applied in areas with similar geomorphographic and geomorphologic conditions.

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