

Degree of Areal Drainage Assessment Using Digital Elevation Models

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Abstract. The methodology of mapping and areal drainage evaluation was discussed. Generalized operations have been described, such as GIS technologies for topographic data. They resulted in maps for erosion network, density and depth of erosion network, as well as land surface sloping and further total evaluation as a drainage parameter.

1. Introduction

The widely-used term “drainage,” as applied by the majority of researchers, is a characteristic feature reflecting a set of conditions that determine the speed and volume of surface and ground water outflow from an area. This term is applied to describe and identify those factors concerning engineering protection design of flooding processes, determination of soil structure for the spacing and management of prevailing vegetation types, development of zoning schemes in determining melioration measures and so on. However, there are no clear guidelines or recommendations to determine and assess the drainage degree within this or that territory. It seems more advisable and appropriate to consider the quantitative characteristics so as to identify those set of factors stipulating the degree of drainage and defining their size and importance within the expert systems.

Accordingly, the main factors defining the degree of drainage could be classified into two groups, each of which includes natural and technogenic components.

The first group reflects properties of the massif in respect to ground water infiltration and is defined by the characteristic features of geological section and filtration properties of rocks, as well as the adverse impact due to technogenic factors (barrage, drainage systems etc.).

The second group depends on the pattern of natural or technogenic inverted relief determining the horizontal and vertical position of drainage baselines, and, respectively, the possible formation, structure and dynamic component of the unloaded filtration flow.

Significant and expensive full-scale studies are required to identify the specific features of the geological section and to determine the filtration parameters of geological components. Commonly-used approaches in analyzing the terrain structure are rather time-consuming, however, all necessary information about terrain parameters may be obtained on the basis of digital models (DEM).

The up-dated methodical basis and software in designing and applying digital terrain models (DEM) via modern geoinformation systems (GIS), allowing a totally new level in analyzing and solving these issues. The introduction of highly effective spatial resolution DEM and computerization promoted the development of sophisticated software and hardware systems in analyzing the hydrological and morphometric characteristics of different territories within the framework of



geoinformation systems.

To design regional DEM SRTM-3 data released by the United States National Aeronautics and Space Administration (NASA) [4-7] could be used as a dataset.

Previously, processing of such high-altitude data was completed by GIS i.e. Ilwis 3.5 to design the hydrographic network and its morphometric characteristics. To plot final cartographic data ArcGIS 9.3 was used. Designed regional DEM has been used to study the underground runoff characteristics of Kuznetsk Alatau.

The modeling of regional DEM is based on interpolating digital contours of large-scale topographic maps. Such a database was used to assess the drainage area of Tomsk.

2. Application technique of GIS in analyzing digital elevation models

The procedure in building terrain digital maps could be divided into three stages (table 1). The first two of which are supporting, while the third is the major one

The first stage involves the mapping of digitized contour map into point features, setting integrated height grids and assessing territorial coverage quality based on obtained data. The resultant sequence is transporting the obtained DTM data to GIS.

Table 1. Main assessment stages of territorial drainage based on DTM.

Stages	1	transport of DEM data to GIS
		↓
	2	designing DEM without local topographic lows mapping surface slope areas mapping drainage accumulation values
		↓
	3	mapping erosion network mapping erosion network density mapping daytime slope surface mapping river network incision depth mapping drainage coefficients

The second stage includes data processing created by DTM. To calculate the runoff areas throughout the territory the undrained relief depressions are eliminated by their alignment with the surrounding area (using the tool “fill sinks”). In this case, undrained relief depressions could be considered as accumulation object of surface- and transit of underground runoffs.

Based on the aligned DEM the flow direction within each unit cell is defined. Slope values are calculated for the central cell in block size 3 x 3. Flow direction is determined by determining the steepest slope (tool “flow direction”, method for determining the flow direction-“steepest slope”). In addition to the flow direction, it is possible to characterize DTM cell exposure. Further, cumulative drainage values are calculated for each elementary DEM cell. These values represent the number of cells introducing its drain into the estimating cell under the influence of gravitational forces, i.e. characterizing the catchment area. This procedure is implemented by the tool «flow accumulation».

The third and final stage involves the mapping of erosion network density and depth, as well as territorial day slope surface. The resultant map includes the integrated information.

Mapping erosion network is the subtraction of all runoff values from the matrix of cumulative values, which are less than the threshold value that is the minimum catchment area where surface-stream flow waters are formed with steady runoff throughout the year. In our case, the threshold is 300 elementary grids, corresponding to the catchment area of about 2.5 km². Then the identification of individual streams is performed on the database of merge points and their vectorization. To perform these operations “drainage network extraction tool ” was used. Accuracy of mapping (peak of junction, river network configuration) via GIS based on SRTM data is assessed in comparing

analogous by elements in traditional topographic map of corresponding scale.

Subsequent mapping and calculations were conducted in relation to one grid area.

The day surface slope map is build using the tool "Slope", which is similar to the tool "flow direction". Calculation assessment of slope is the slope between the estimated grid center and the adjacent centers. The highest value is regarded as the estimated slope grid value.

To estimate the erosion network density the investigated territory was divided into square grids where the side of the elementary grid is 100m. Within each grid the total length of drains was calculated and is divided by its area. The resulting value is assigned to a grid.

Cutting erosion depth network map is based on a statistical analysis of the terrain within the grid and plotted during the assessment phase of erosion density. Cutting erosion depth network is estimated as the difference between the maximum and minimum relief point, which value is assigned to the estimated grid.

These three terrain characteristic features- surface slope, cutting depth and density of erosion network could be used as an integral assessment of the relief role and be termed as drainage coefficient.

Density and depth of erosion network characterize the rate of erosion area irregularity. In this case, it indicates the relationship of surface and underground waters and determines the potential discharge of surface water and underground water through the erosion network. The surface slope value indirectly reflects the intensity of this discharge through hydraulic gradients.

The resultant map of drainage area, expressed as a system of scores, is compiled by using the "field calculator". The map elements correspond to the selected drainage groups: not drained, poorly drained, moderately drained and well drained.

3. Drainage network in Tomsk

We used the above-mentioned methods to examine the territory of Tomsk. This research has been conducted for a long time [7-8]. The drainage coefficient scheme of Tomsk in accordance with presented methodology techniques is presented in figure 1.

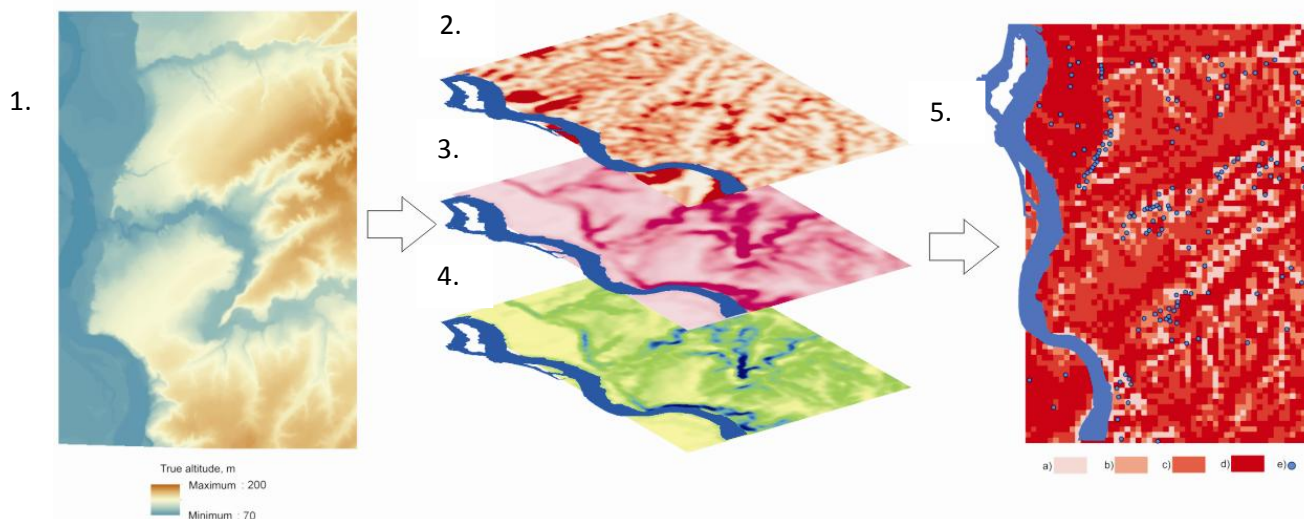


Figure 1. General drainage estimation scheme of Tomsk territory.

1. -digital elevation model; 2. -map of erosion network density; 3. -map of surface area slope; 4. -map of erosion network depth; 5. -map of drainage rate.

Tomsk is not only an old cultural and industrial city, but also a student town. It is located in overmoistened taiga zone of West Siberia on Tom River. The city has a complicated infrastructure. Modern multi-storied buildings are scattered throughout the city, however, the main concentration is in the center of Tomsk and its outskirts. The historical area includes historical and cultural monuments

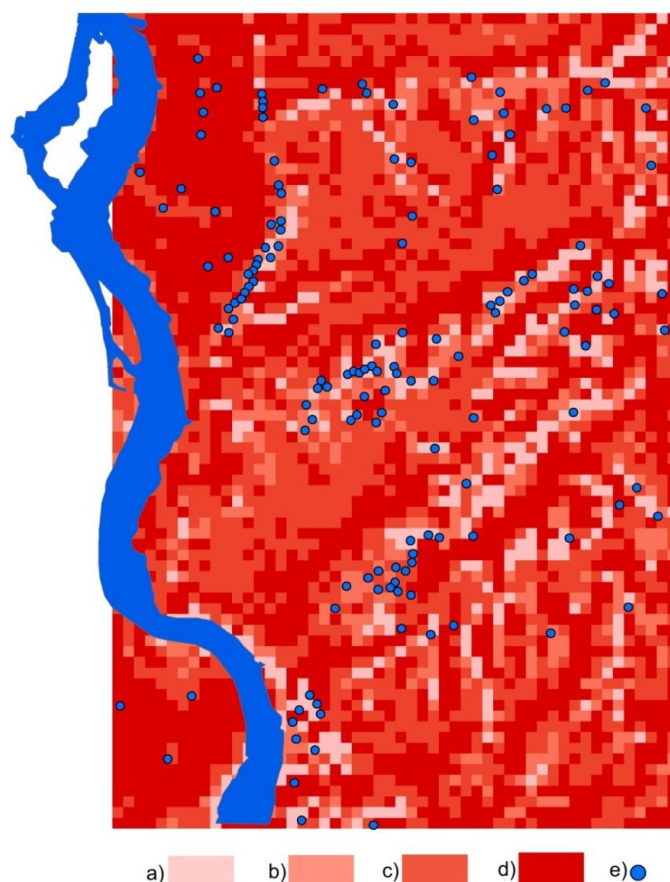
both wooden and stone. Such stone and wooden architecture monuments should be mentioned: temples, buildings of famous architects as K.K. Lygin, A.D. Kryachkov, P.F. Fedorovsky, A.K. Bruni and others; constructions with wood carvings of extraordinary beauty and complexity. Preservation of this cultural heritage is one of the most important targets of the town-planning policy.

Like many cities and towns in the world, Tomsk is confronted by one and the same geological problem – anthropogenic underflooding. Anthropogenic underflooding involves the rise of shallow groundwater levels stipulated by the town's activities and under the influence of natural and anthropogenic factors, including territorial geological structure and drainage system, underground water intensity and its poor water flow and evaporation.

Numerous municipal service facilities provoke possible technogenic changes of hydrogeological conditions leading to various emergency situations. For example, Lagerny Garden landslide slope and Solnechny district where multi-storied buildings are in critical condition due to the existing underflooding process.

The territorial drainage system, filtration section type and intensity flood sources predetermine the potential underflooding level. The importance of this question for Tomsk was firstly noted by D. S. Pokrovskiy. At that time only the qualitative drainage factors were considered. In this case, the assessment criterion was considered to be the underground water depth.

Figure 2 is a resultant map of the drainage coefficients within the city territory, showing only the quantitative aspect. The elements presented on the map correspond to the marked drainage groups: not drained, poorly drained, moderately drained and well drained. The characteristics of these elements shown on the resultant map and corresponding to the marked drainage groups is presented in table 2.



a) -well drained; b) -moderately drained; c) -poorly drained; d) -not drained; e) –spring.

Figure 2. Resultant map of drainage coefficient within the city territory.

To verify the suggested approaches in drainage estimation we used data based information on the mapping of springs. The configuration of drainage territorial field gradation correlates with the configuration of spring field distribution mapped by A.D. Nazarov. This fact testifies that the proposed approaches are appropriate.

Table 1. Indexes of drainage rate.

	Density of erosion network, min-max	Depth of erosion network, min-max	Surface area slope, min-max	Drainage coefficient, min-max
	km/km ² (number)	m (number)	degree (number)	(number)
Well drained	0.01-0.03 (0.33-1)	31-62 (0.5-1)	4.8-17.3 (0.28-1)	1.01-3
Moderately drained	0.005-0.01 (0.17-0.33)	9-31 (0.14-0.5)	2,4-4,8 (0.14-0.28)	0.45-1.01
Poorly drained	0.002-0.005 (0.07-0.17)	4-9 (0.06-0.14)	1.2-2.4 (0.07-0.14)	0.2-0.45
Not drained	0-0,002 (0-0.07)	0-4 (0-0.06)	0-1.2 (0-0.07)	0-0.2

4. Conclusion

The research conducted on the example of Tomsk territory shows that modern geoinformation systems used in the relief analysis, allow qualitative plotting of the erosion network and determine its basic morphometric characteristics. Based on the obtained data, a territorial drainage assessment was conducted.

The research results can be applied in engineering and geological exploration and can be useful for different departments and services ensuring the vital living activity of the city:

- to monitor and efficiently control the geological environment conditions;
- to assess probability, scale and intensity of the human impact aftergrowth;
- to justify administrative and engineering decisions aimed at sustainable environmental conditions;
- to estimate the city territory cost;
- to optimize funding planning in providing restoration works of historical Tomsk.

References

- [1] Tim Ormsby, Eileen Napoleon and Robert Burke 2004 Getting to know ArcGIS (Esri Press) p 572
- [2] Werner M 2001 Shuttle Radar Topography Mission (SRTM), Mission overview *J. Telecom* **55** 75-79
- [3] Rodriguez E, C S Morris, J E Belz, E C Chapin, J M Martin, W Daffer and S Hensley 2005 An assessment of the SRTM topographic products *Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California* p 143
- [4] Coltelli M, G Fornaro, G Franceschetti, R Lanari, M Migliaccio, J R Moreira, K P Papathanassiou, G Puglisi, D Riccio and M Schwabisch 1996 SIR-C/X-SAR multifrequency multipass interferometry: A new tool for geological interpretation *Journal Of Geophysical Research* **101** 23127-23148

- [5] Avseikov A S, Neifeld E A, Ryumkin A I and Tyabaev E S 1998 Geoinformation system at historical part of Tomsk city *Geoinformatics. Theory and practice* **1** 273-283
- [6] Dutova E M, Nalivaiko N G, Kuzevanov K I and Kopylova J G 1998 The chemical and microbiological composition of urban groundwater, Tomsk, Russia *Groundwater in the Urban Environment. Proceedings of the XXVIIth Congress IAH* **2** 125-130
- [7] Pokrovsky D S, Rogov G M and Kuzevanov K I 1998 The impact of urbanisation on the hydrogeological conditions of Tomsk, Russia *Groundwater in the Urban Environment. Proceedings of XXVIIth Congress IAH* **2** 217-223
- [8] Pokrovskiy D S, Dutova E M and Kuzevanov K I 2008 Application of geoinformation technologies for estimation of hydrogeoecology conditions of developed territories *News of higher educational institutions. Construction* **3** (591) 107-112