Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

SHORT COMMUNICATION

Development of a DEM in the GIS "PANORAMA" Based on a Topographic Map for the Southern Territory of the Fergana Valley

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ABSTRACT

The capabilities of GIS for constructing a digital elevation model of a mountainous area and visualizing a spatial image of the terrain are given in this paper. Graphic, digital data and topographic maps, which are the main sources for GIS, are described. The methods of vectorization of isolines and the requirements for technical means of processing graphic materials are presented in detail. The advantages and disadvantages of the DEM of a mountainous region are shown here. Segmentation methods using an interpolation polynomial are described in detail. A DEM of the mountainous area where the border between the republics runs was constructed in 2D and 3D formats using the GIS Panorama. Reducing the chord length when segmenting isolines on topographic maps leads to more accurate DEM construction. A vertical profile of a mountainous area with a visibility zone between two points was constructed. It is expected that the improved latitude, longitude and altitude parameters of the topographic map will be used to form a regional geodetic network and geospatial analysis of mountain ranges. It is proposed to use not only satellite data, but also classical geodetic networks and maps. It is recommended to use satellite and aerial photography to clarify the topographic and geodetic support of the studied area.

Keywords: Topographic Map; Coordinates; Segmentation; Vectorization; Isolines; Polynomial; DEM; GIS

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ARTICLE INFO

Received: 13 May 2025 | Revised: 24 June 2025 | Accepted: 27 June 2025 | Published Online: 5 August 2025

DOI: https://doi.org/10.30564/jees.v7i8.10001

CITATION

Abjaparova, D., Mirmakhmudov, E., Toshonpv B., et al., 2025. Development of a DEM in the GIS "PANORAMA" Based on a Topographic Map for the Southern Territory of the Fergana Valley. Journal of Environmental & Earth Sciences. 7(8): 16–21. DOI: https://doi.org/10.30564/jees.v7i8.10001

1. Introduction

The southern part of the Fergana Valley consists of mountain ranges, where the border between Uzbekistan and Kyrgyzstan is laid [1,2]. However, the exact data on the area of the mountain ranges is still unknown due to the approximate calculation method, insufficient field measurements and the lack of detailed aerial photography. If the relief is taken into account when determining the area, the numerical value will differ from the reference value obtained in the classical way. The size of the area must be improved using modern digital technologies and satellite navigation measurements. The use of satellite navigation receivers is an effective method for increasing the accuracy of point coordinates.

In recent years, the inter-republican commission [3] has carried out demarcation work not only in flat terrain, but also in mountainous areas where administrative-territorial boundaries, power lines, roads, protected areas and hydraulic structures pass. Geodetic measurements in these places differ significantly in density, picket configuration and time interval. These works should be based on the points of the state geodetic network (SGN), the coordinates of which were calculated on the basis of triangulation and levelling [4]. The use of high-precision tools is one of the main factors in creating a spatial digital elevation model (DEM) of a mountain area. It is recommended to reconnoitre the area and terrain using topographic maps before carrying out field work. If the area is located in the foothills, the role of such studies acquires a special status. Therefore, a digital elevation model (DEM) with complex relief is an integral part of the entire set of activities. This is especially true for hard-to-reach areas, where spatial information is poorly studied, and maps are compiled based on aerial photography and the results of optical geodetic measurements carried out in the 20th century [5]. This also applies to the heights of points and pickets obtained using trigonometric levelling and aerial photography. It should be noted that the lack of digital maps leads to certain problems in studying the ecology and physical and geographical characteristics of the area. For example, the DEM helps to accurately determine the boundaries of nature reserves, farms, and forestry lands located on hilltops. Difficulties arise during the design of hydrological facilities, power lines, railways and highways.

If the borders of several states are drawn along the hills, the task is complicated by the process of demarcation and delimitation. Therefore, to solve the described problems, it is necessary to prepare all graphic materials, aerial photography results and field measurements. The lack of digital maps in the WGS84 system makes it difficult to calculate the coordinates of particularly important objects [6]. This is especially true for the mountainous regions located between the republics and which should be created in a homogeneous coordinate system.

The digital relief model is a mathematical representation of a section of the Earth's surface obtained on the basis of field geodetic measurements, laser scanning, aerospace sounding data and topographic maps of various scales. The most correct information is field measurements and a geodetic network consisting of triangles, the vertices of which are topographic reference points. It is possible to calculate the elevation marks of points with known coordinates that display the terrain using horizontals. However, in the absence of reliable data on topographic maps, information about the area can be obtained from Google Earth, where the coordinates of objects are more accurately given. When using data from the global network, you should pay attention to geometric data containing information about the spatial position of the surface.

The advantage of using DEM is a significant reduction in time and labor costs compared to traditional technology [7]. This is especially true for engineering structures, for example, road routes, tunnel lengths, protected areas that depend on the terrain, geological and hydrological conditions of the area. When designing complex structures, the following is estimated in advance: the amount of work, labor costs, safety factor and comfort of movement, and infrastructure. It is necessary to have complete information about the area, which can be achieved using DEM. DEM is usually used to accurately model small areas. Since the selected sites represent mountain ranges and flat areas, the physical and geographical properties of the area were taken into account when creating the DEM. GIS Panorama is used to build a digital model that is adapted for topographic maps.

2. Materials and Methods

Classical topographic maps of 1 : 200 000 and 1 : 500 000 scale were used as the initial data. The scanned map (**Figure 1**), which is presented as a raster, must meet the requirements of the standard image format. The raster map must be scanned from the original with a resolution of at least 400 dpi, where the main condition is to be bound to the coordinate system of topographic maps. Therefore, the coordinate grid is the initial reference system for image transformation[8]. In the case of a significant deviation of the trapezoid frame from the original map, corrections appear to the coordinates of the edges of the frames, which affect the accuracy of the model through the coefficients of the differential equations.

Figure 1. Study area on a topographical map between two areas.

The horizontal error ranges from 0.1–0.8 mm at the map scale, but the acceptable average offset is 0.5 cross-sections. The accuracy of the model is determined by the scale of the source map and the complexity of the relief, which requires solving the problem of interpolating its surface, which is represented as a function of two variables x,y. In practice, the initial relief is set in the form of picket points obtained using a total station survey. In GIS, there is a module that provides the transformation of isolines into a regular grid or Delaunay triangulation network using the vectorization and segmentation method (**Figure 2**).

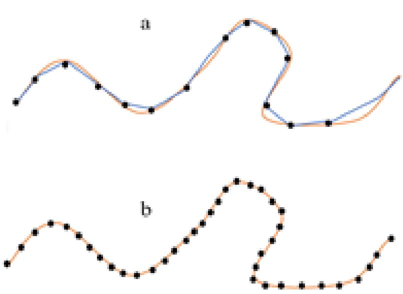

Figure 2. Segmentation of isolines on topographic maps for a specified area **a**–rough, **b**–fine.

In geodetic enterprises, the horizontal is drawn onto a 1 : 10 000–1 : 25 000 scale topographic map using a stereophotogrammetric method based on the results of field geodetic measurements and aerial photography data. This procedure has reached such perfection and automaticity that the system of relativity is not taken into account, as a result, some maps lack height isolines within extended objects[9]. They use modern wide-format plotters to print digital topographic maps. Since the isolines are drawn close to each other in small-scale maps of mountainous regions, it will allow us to evaluate some aspects of engineering work on a large scale. The prepared topographic maps in raster format are entered into GIS Panorama for transformation and processing.

GIS Panorama was created to solve topographic and cartographic problems. It includes tools for searching, viewing and structuring geographical data, and creating metadata. The 3D module is used, which includes a number of tools for three-dimensional modelling, such as visibility conditions between points on the terrain, terrain modelling at various scales. GIS uses a three-dimensional model to display three-dimensional object shapes in the form of triangles, which can be described using three vectors. Each vector is described by three components of the coordinate axes, expressed relative to the accepted frame of reference. Geometric data containing information about the position of the surface represents a triangular face, which can be expressed as a function:

$$h = F(x, y) \tag{1}$$

Where h is the height; x and y are rectangular coordinates.

Heights depend on the method of obtaining data, for example, for total station surveys in the form of picket points or horizontals. If the point values are linearly distributed or scattered along the resulting axis, then all types of interpolation must be used (**Figure 3**).

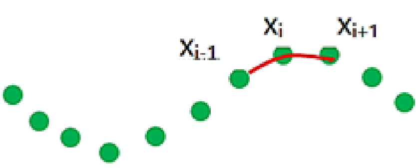

Figure 3. The interpolation scheme for topographic maps.

In linear interpolation, the node points are connected by straight line segments, and in quadratic spline interpolation, a parabolic curve is connected. It is necessary to be aware of the limitations of the function, where linear methods can give different solutions for the same point. To build a DEM in GIS Panorama, smoothing with cubic splines is used, where segments of a cubic parabola are drawn through the nodal points. Some articles analyze that accuracy depends on the terrain itself, the measurement scheme, and the density of points when digitizing horizontals. Higher-order interpolation takes into account neighboring vertices directly or indirectly, giving a better estimate of linear algorithms and can be extended to extrapolation. The result is a model that makes it possible to describe the terrain using a limited number of discrete points. The most accurate method of constructing isolines is the approximation by a polynomial of the first or second order. For mountainous areas where the horizons are plotted very close to each other, it is advisable to use an "n" order polynomial [10]:

$$h(x) = a_0 + a_1x^1 + a_2x^2 + \cdots + a_nx^n \qquad (2)$$

Where a_i (i = 0, 1, 2 .....n) are the coefficients of the polynomial, which are determined by the least squares method; x^i (i = 1, 2, 3 ......n) are variables that depend on the coordinates of the points.

Model development involves creating a bitmap image and vectorizing topographic map elements with an array of discrete numbers that determine the location of important objects. No matter which model is used to store the image, it is always reproduced by dots, but splitting into dots leads to the distortion of geometric shapes. In the process of vectoring topographic maps, situations arise where contour lines or horizontals have breaks in some places due to technical errors. Various methods of connecting lines can be used, using interpolation or extrapolation. Such a procedure should be based on data obtained by geodetic and aerospace measurements.

It is known that when developing DEM in GIS, the TIN model (Triangulated Irregular Network) is used, which consists of triangles. The edge of each element is a part of a neighboring shape, and the vertices represent coordinate points with a known value that are connected according to the Delaunay triangulation principle. The disadvantage is the error due to incomplete data, but this is the fastest interpolation method, which is suitable for describing complex areas where mathematical calculations help to recognize unexpected surface changes. Here, not one, but several interpolation methods are used, which take into account the possibility of unexpected irregularities, which are clearly visible on the vertical profile of the relief.

The initial data for the construction of the DEM of the studied territory were paper topographic maps of mountainous areas. Nowadays, aerospace methods are increasingly being used. However, when using paper topographic maps, it is necessary to pay attention to the date of publication of the maps, since over time the topographic map data becomes "outdated" and does not fully correspond to the real situation. In such cases, the most optimal way to obtain data is to use aerospace imagery [11], GNSS imagery, or Google Earth data.

3. Results and Discussion

Since the specified area has an area of 46250 km^2, a small area located on the border between the Andijan and Osh regions was chosen for the construction of the DEM in GIS Panorama. Vectorization of the isolines of the studied area with a modified number of discrete points was performed using GIS Panorama. Special attention was paid to the steepness of the slope of the mountain section. It is shown that reducing the length of the segmentation leads to a more accurate graphical representation of the shape of the relief. **Figure 4** shows the DEM in 2D and 3D format, where it can be seen that a large-scale view of the terrain reflects the terrain in detail [12].

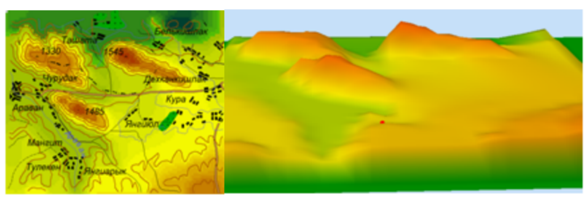

Figure 4. Digital elevation model of the selected polygon in 2 and 3 formats.

An analysis of the results shows that before creating a DEM, a preliminary assessment of the available data should be carried out for reliability. It is necessary to select the optimal algorithm and software package that meets the modern requirements of design surveys. GIS Panorama is universal, multifunctional and compliant with international standards for information exchange. DEM should be visual in terms of detail and visibility. Comparative analysis has shown that reducing the length of segmentation leads to a detailed and clear graphical representation of the relief of mountain peaks. In this case, it is necessary to take care of reducing the memory capacity of computer tools using modified GIS. On the other hand, the developed DEM should be flexible, comfortable and convenient for working in many GNSS systems[13,14]. The DEM also makes it possible to determine terrain features from a finite set of sample points and makes it possible to analyze visibility zones by constructing a vertical profile of the region under study (**Figure 5**).

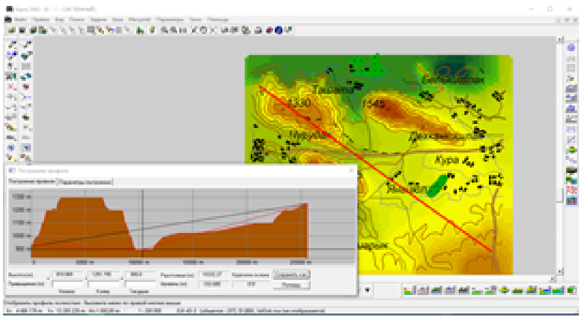

Figure 5. The vertical profile of the DEM between two points located on different hills.

It can be noted that the DEM is universal, which is the result of adding up all the work on the ground and remote sensing, reduced to a two-dimensional or three-dimensional coordinate system.

4. Conclusions

Thus, it can be concluded that using the high-order interpolation method leads to smoothing of the surface, thereby reducing the gap between the calculated and conventionally designated line passing through mountainous areas[15]. In this case, the most suitable equation is a cubic polynomial, where the horizons in GIS Panorama are constructed using the spline method, achieving the proximity of a discrete point to an isoline. In such cases, the correct way to represent a line is the horizontal approximation procedure. The vectorization methods described above can be attributed not only to mountainous areas, but also to other hard-to-reach areas, as well as to places where mining is carried out. Although many have switched to satellite methods for obtaining digital terrain models, topographic maps will be in demand for engineering and construction work for a long time[16].

It should be noted that there are many GIS, such as ARCGIS, CREDO, QGIS, but the most suitable for topographic maps is GIS Panorama.

Author Contributions

All authors made significant contributions to this study as and D.A. planning and organization of work; E.M. developed the study concept; B.T. developed a digital elevation model; Z.S. design of drawings; D.M. text correction. All authors read and approved the final manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All data supporting the reported results are provided within the manuscript. Additional data can be made available upon reasonable request.

Conflicts of Interest

All the authors declare that there is no conflict of interest in relation to the research, authorship, and publication of this study.

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