

Use of Aerial and Satellite Imagery for DEM Extraction and GIS Applications

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Abstract—This paper describes a workflow for digital terrain model extraction from aerial and satellite stereo imagery and its integration in GIS applications. The results obtained using aerial and satellite stereo scenes are presented and commented. Stereo scenes are oriented using an approximate model named parallel projection which is a model that gained popularity due to simplicity and precision. For the digital terrain model generation the points are automatically extracted in the images using a modified Harris correlation operator and their 3D coordinates are then calculated with parallel projection parameters. After the 3D surface generation the terrain model is used further for visibility analysis.

Index Terms—digital terrain model, aerial stereo scenes, satellite stereo scenes, GIS, visibility analysis.

I. INTRODUCTION

The objective of this study is the numerical modeling of the terrain based on aerial and satellite stereo scenes using the geometry of epipolar lines. In order to solve the problem of numerical modeling of the terrain, the author's investigations were oriented in the following directions [1] and [2]:

- analysis of epipolar geometry in the case of aerial and satellite imagery;
- study of parallel projection model as an alternative model for epipolar geometry reassembly of aerial and satellite images with a favorable base over height ratio;
- study of transforming the perspective projection characteristic of the scan line into parallel projection and improving the mathematical model by including information of relief trend;
- normalization of aerial and satellite stereo scenes by processing using epipolar geometry with an approximate model.

During this research, there were presented and analyzed many mathematical models, transformations and approaches specific to the epipolar geometry processing of aerial and satellite imagery.

From all these models, parallel projection was chosen for the case of satellite stereo scenes due to the simplicity and precision of the perspective projection representation of images taken with narrow angle view sensors that move with constant speed and orientation [3-5].

Another reason of using the parallel projection is the direct way of generating the normalized images which is a necessary step for increasing reliability and reducing the search space specific to the image correlation process [3].

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This research also includes the development of software components using .NET technology and C# programming language, as an extension for ArcGIS which provides the following functionalities:

- the transformation between the linear and non-linear form of the parallel projection;
- the mathematical model that combines parallel projection and transformation of perspective projection into parallel projection; the relation between the navigation parameters of the linear sensor and the parameters of the parallel projection;
- elimination of the cross-sectional parallax between recordings considering the parallel projection model; reassembling the records in epipolar geometry to eliminate the transverse parallax and to maintain the linear relationship between the longitudinal parallax and height;
- determining the geomorphometric quality indices;
- determination of quality indices;
- calculating the errors of the numerical model and deriving the field parameters;
- modeling the relationship between errors and terrain parameters through a multilinear regression model, determining the regression coefficients corresponding to each parameter; and
- creating a precision surface based on the regression equation determined in the previous step.

II. DATASET DESCRIPTION

The research was done using a photogrammetric stereomodel from the area of Urlați photogrammetric polygon and two satellite stereo scenes level 1A panchromatic images comprising a test area south of the city of Toulouse (France).

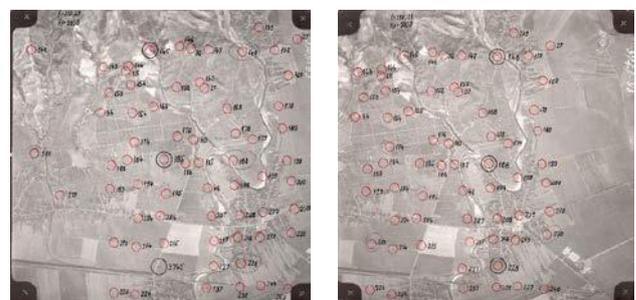


Figure 1. Aerial stereo scenes

To evaluate the performance of parallel projection model two level 1A SPOT records were used and a numerical reference model for the common coverage area corresponding to the two records made available by Mr. Col.(r) Eng. Vasile Florea. He used these data together

with a scanned topographic map on the scale 1: 25,000 to carry out an evaluation study of the automatic correlators implemented in different commercial and professional programs of 6 MNT products with 5 programs (3 commercial and 2 professional).

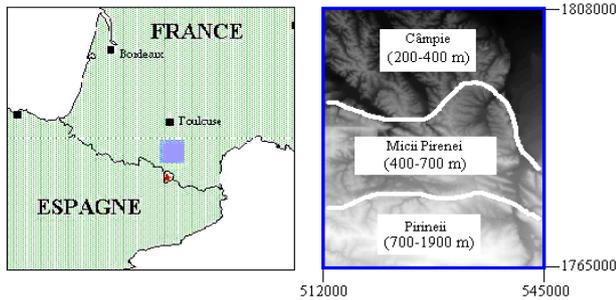


Figure 2. Test area (Lambert cartographic projection)

The test area is located south of Toulouse, Fig. 2, and is characterized by quite varied relief and soil cover. The northern area (40%) is a plain area with an altitude between 200–300 m and a dense hydrographic network. To the south there are the mountains of the Small Pyrenees (les Petites Pyrénées) with elevations between 500 m and 700 m and then follow the mountains of the Pyrenees (les Pyrénées) with elevations exceeding 1800 m, the area where the soil is predominantly covered with forests.

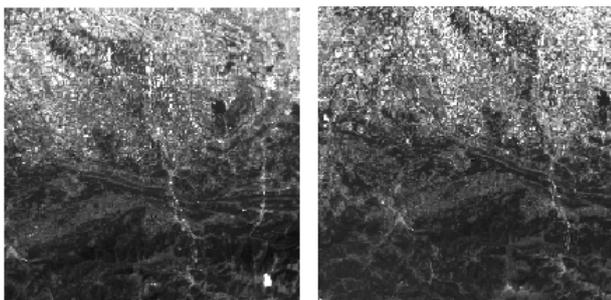


Figure 3. Satellite stereo scenes

The main features of the two satellite stereo scenes are presented in Table I.

TABLE I. MAIN FEATURES OF SATELLITE IMAGERY

Parameters	Img 01	Img 02	Observation
K-J Identifier	043-263	042-263	Interval = 26 days B/H Ratio = 0.87 Coverage: ~75%
Acquisition date	21.08.99	26.07.99	
Focal distance (mm)	1082	1082	
Incidence angle	+ 20.6 grade	-26.2 grade	
Orientation angle	14.5 grade	8.7 grade	
Center Coordinates	N043°05'14" E001°35'28"	N043°05'07" E001°22'53"	

III. EPIPOLAR GEOMETRY RESAMPLING

The main purpose of the reassembly of images in epipolar geometry is to obtain normalized images where the corresponding points are on the same line (or column) [4], [6] and [7]. A first advantage is that of reduce search space and computation time and thus reduce the ambiguity of image correlation [5]. For the reassembly of aerial and satellite images using epipolar geometry lines, the author has developed the Photo-AddValue application, which was

designed as an extension for the ArcMap application and is presented below.



Figure 4. Photo-AddValue Extension

The Photo-AddValue application, made using .NET technology, the C# programming environment and the ArcGIS SDK (ArcObjects 9.3), is structured on two major modules, namely:

- **Surface:** implements functionalities of reassembling aerial and satellite records in epipolar geometry and generating the numerical model of the terrain.
- **QualEval:** implements functionalities for analyzing and evaluating the quality of the numerical model of the land.

A. Photo-AddValue: Surface module

The **Surface** module is structured on four categories that implement the main functionalities included in the stages of generating the numerical model, namely (Fig. 5): normalization of records, extraction of primitives (points of interest), identification of their conjugates, spatial intersection using the mathematical model that establishes the correspondence between the image coordinates and the terrain coordinates and the interpolation of the points determined in the previous step.

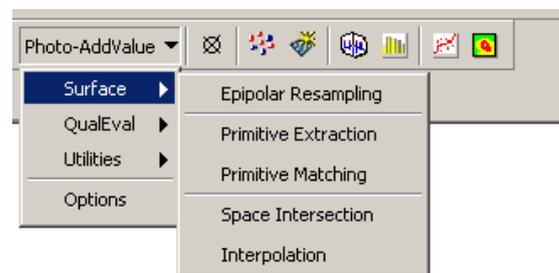


Figure 5. Surface module: graphic interface

The first step in the process of generating the numerical model of the terrain based on aerial and satellite recordings is the normalization of the images. The Epipolar Resampling menu allows to set the characteristics of this process, namely: selecting the geometric model characteristic of the records, selecting the stereoscopic records, selecting the support and control points that will be used in the automatic correlation process, establishing the parameters involved in the iterative process of determination by the least squares (conversion accuracy, number of iterations) as well as other auxiliary parameters such as saving the reassembly report.

1) Aerial stereo scenes

The process of reassembling in epipolar geometry and generating normalized images can be structured as follows [8], [9]:

- starts from any location (pixel) in the normalized image (x_n, y_n) ;
- the corresponding location in the original image (x, y) is calculated using parallel projection mathematical model; the resulting x and y values are not integers;

- calculates the gray value $g(x, y)$ in the original image using an appropriate interpolation method such as the nearest neighbor, bilinear interpolation or cubic convolution;
- associates the gray value interpolated with the corresponding pixel in the normalized image, i.e., $g(xn, yn) = g(x, y)$;
- repeat the above steps for all pixels in the standardized image;
- repeat the above steps for another image with stereoscopic coverage.

An important step in the process of reassembling in epipolar geometry of the aerial recordings is the determination of the elements of interior and exterior orientation corresponding to the two images [7]. The internal orientation elements were determined based on the film coordinates of the reference indices having the known focal length and for the outer orientation elements 40 support points reported in the Gauss Kruger coordinate system, Datum ETRS89 were used.

TABLE II. EXTERIOR ORIENTATION PARAMETERS

Scenes	Exterior orientation parameters					
	X_0	Y_0	Z_0	Omega	Phi	Kappa
(aero_imag_02)	12424.1814	15848.5246	3978.9823	178.1071	3.0316	93.9261
(aero_imag_01)	12395.3273	16892.8484	3996.4637	178.3432	356.5609	93.4501

In order to determine the external orientation elements for each support point used, the collinearity equation was written resulting in a system that was solved within an iterative process by the method of the least squares having the unknown external orientation elements, namely: the coordinates of the perspective centers and respectively the rotation angles corresponding to the two frames. The evaluation of the accuracy of determining the external orientation elements was performed by comparing the terrain coordinates obtained using these parameters and the collinearity equation in both the support points and the control points. Based on the values of these elements, the normalization parameters were determined according to the methodology described and the following values were obtained:

Photogrammetric base components	Orientation elements of normalized images		
$B_X = 28.8541$	Omega	Phi	Kappa
$B_Y = -1044.3238$	178.2251	-31.2097	-88.1497
$B_Z = 17.4814$			

Figure 6. Normalized image: exterior orientation parameters

The two recordings were superimposed to obtain a stereo view using the anaglyphs method, which can be viewed stereo using a pair of anaglyph glasses



Figure 7. Stereo representation by the anaglyphs method of normalized aerial recordings

2) Satellite stereo scenes

The process of reassembling satellite recordings in epipolar geometry can be described by the following steps [2] and [9]:

- for each image, 2D parameters are estimated related to the longitudinal tilt angle using support points according to the model;
- for each image the longitudinal tilt angles are used to transform the perspective projection into parallel projection, and from the parallel 2D parameters the parameters of the parallel projection are determined;
- the parameters of the normalized parallel projection are determined;
- the images are redesigned using the normalized values of the parallel projection parameters.

One of the working hypotheses used in establishing the model of transforming the perspective projection into parallel projection was that of the flat terrain hypothesis, which, in general, does not verify why the error introduced by this hypothesis was quantified and the mathematical model of the transformation was modified to include information on the relief trend; this information is extracted from the support points.

For the indirect determination of the parameters of the 2D affine transformation, given by the equations:

$$x = A_1X + A_2Y + A_3Z + A_4$$

$$y = \frac{A_5X + A_6Y + A_7Z + A_8}{1 + \frac{\tan(\psi)}{c}(A_5X + A_6Y + A_7Z + A_8)} \quad (1)$$

16 support points were used for the left recording (imag_01) and 16 support points for the right image (imag_02) respectively.

These support points are arranged in the common coverage area of the two registrations. To validate the parallel projection model and to carry out a more detailed analysis, the correspondents of these points were identified in each record (to estimate the cross-sectional parallax and the errors and in these points that participated in the indirect determination of the parameters of the 2D transformation).

The Photo-AddValue application allows the indirect determination of the parameters of the 2D affine transformation using the information on the terrain trend; the final values of these parameters corresponding to the two images are presented below.

TABLE III. 2D AFFINE PARAMETERS

	Left scene		Right scene	
	A*	B*	A*	B*
σ , pixels	1.14	1.14	1.02	1.02
Ψ	-8.45E-002	-8.48E-002	-4.86E-002	-4.85E-002
A1	8.527E-002	8.527E-002	8.031E-002	8.031E-002
A2	-2.650E-002	-2.650E-002	-1.856E-002	-1.856E-002
A3	6.240E-002	6.240E-002	-7.153E-002	-7.153E-002
A4	4.372E+003	4.372E+003	-5.667E+003	-5.667E+003
A5	2.593E-002	2.593E-002	1.628E-002	1.628E-002
A6	9.621E-002	9.621E-002	9.889E-002	9.889E-002
A7	-1.834E-004	-1.852E-004	-1.966E-004	-1.963E-004
A8	-8.486E-002	-8.451E-002	-1.882E+005	-1.882E+005
*A - knowledge of the trend of the terrain was not incorporated, B - knowledge of the trend of the terrain was incorporated				

As can be seen from Table III, the right-hand recording is much better suited to the parallel projection model compared to the one on the left, given the much smaller value of the standard deviation.

In order to evaluate the quality of the transformation, 7 control points (verification) were used, which are the corresponding points in each record. The verification was done by comparing the coordinates determined using the parameters of the 2D blueberry transformation corresponding to the two records and the corresponding image coordinates respectively. Thus for each pair of control points two sets of equations were written; the resulting system was solved using least squares method. The obtained values are compared with the true values, the results are presented in Table IV.

TABLE IV. RESEMBLING OUTPUTS

Parameters		A*	B*
		Values	
Check points	Average $ p_y $ (pixels)	0.2	0.2
	Avg _{xy} ±StdDev _{xy} (m)	0.000±4.467	0.000±4.453
	Avg _z ±StdDev _z (m)	0.000±6.056	0.000±6.052
Control points	Average $ p_y $ (pixel)	0.931	0.940
	Avg _{xy} ±StdDev _{xy} (m)	0.981±4.221	0.714±3.966
	Avg _z ±StdDev _z (m)	1.428±8.451	1.428±8.451
*A - knowledge of the trend of the terrain was not incorporated, B - knowledge of the trend of the terrain was incorporated			

In addition, it can be seen from the analysis of the two data sets, those obtained using the trend information, and those obtained without this information that the standard deviations of the errors at the control points do not differ significantly. This is due to the locations of the control points; they are not positioned at the ends of the scan line. If the two records had a much greater common coverage so that we could identify control points, the connection located closer to the ends of the scanned lines would have seen a significant difference.

Based on the values of the parameters of the 2D transformation, the parameters of the parallel projection for the two images were then determined.

TABLE V. PARAMETERS OF THE PARALLEL PROJECTION DERIVED FOR EACH SCENE

2D Affine Params	Left scene		Right scene	
	A*	B*	A*	B*
L	-5.528944E-001	-5.528901E-001	6.477514E-001	6.477509E-001
M	1.505820E-001	1.505965E-001	-1.051807E-001	-1.051830E-001
N	8.195321E-001	8.195323E-001	7.545563E-001	7.545563E-001
Ω	1.49	1.49	-4.08	-4.08
ϕ	-1.15	-1.15	1.77	1.77
K	-1.44	-1.44	-7.74	-7.74
Δx (m)	4.372998E+003	4.372998E+003	-5.667161E+003	-5.667161E+003
Δy (m)	-1.889241E+005	-1.889247E+005	-1.882386E+005	-1.882385E+005
S	9.34468E-002	9.934482E-002	9.956935E-002	9.956925E-002
* A - knowledge of the trend of the terrain was not incorporated, B - knowledge of the trend of the terrain was incorporated				

IV. WORKFLOW FOR DIGITAL ELEVATION MODEL EXTRACTION

The process of generating the numerical model of the land involves four stages: the extraction of the primitives (details), their correlation, the spatial intersection and the interpolation of the resulting points within the area of interest.

A. Primitive extraction

In this stage there are point type primitives because the mathematical models used for the spatial intersection operate on point type primitives. The choice of correlative primitives is crucial because the accuracy of the process of generating the numerical model of the terrain depends on this.

Point-type primitives can be extracted using different operators such as: Harris, Förstner, Susan. The principle of these operators is to identify distinct points with a distribution of the unique gray value in their vicinity (e.g., corners), thus reducing the ambiguity of the correlation [5] and [9]. To extract point type primitives the author implemented a modified Harris operator.

The result was not satisfactory for the two images, even after the radiometric processing of the two images.

One of the obvious reasons is the lack of corner details (the variation of the image function in the x and y directions), the Harris operator using these changes to determine the points of interest.

Starting from this observation, another sub-region was chosen from the normalized records. For this new sub-region the primitives were extracted and the results obtained, are satisfactory.

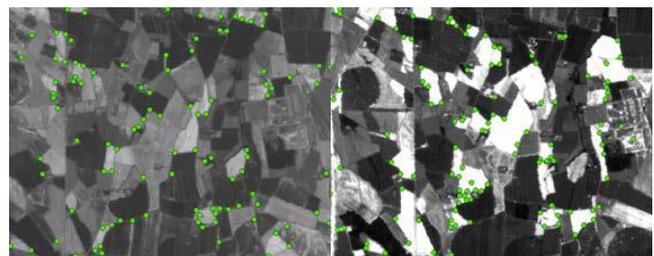


Figure 8. Primitives extracted (example) for the selected area

B. Primitive correlation

For normalized records, the size of the search window in the right registration along the epipolar line must be exactly the same as the size of the template centered at the point analyzed in the left registration. In other words, the search is performed in a single direction along the epipolar line which is represented (identified) by the line index for the normalized records. However, in general, there is no certainty regarding the total elimination of the cross-sectional parallax between the conjugated points, so the size of the search window along the lines is chosen so that it is slightly larger than the template size (the window in the record from Left). On the other hand, the size of the search window depends on the variation of altitudes in the area, so for a rough terrain the size must be larger compared to the value used in the case of relatively flat terrain. Typically 3×3 , 5×5 or 7×7 pixel windows are used.

As a criterion of correspondence, both the correlation coefficient and the method of the least squares can be used to determine such size of the degree of similarity, depending on how much the aspect of the conjugated details in the two records varies.

In order to eliminate the possible correspondence errors for the initial points, a consistency check is performed using the neighborhoods, i.e. the value of the longitudinal parallax of the initial point is compared with the values corresponding to the neighbors. For a given point the mean and standard deviation (μ and σ) of the values of the longitudinal parallax for each neighbor of the considered point are calculated and if the value of the longitudinal parallax is significantly different from the values of the neighbors the point is deleted.

The extracted points were then used as candidates in the correlation process according to the above proposal. The obtained results were visually inspected and errors were observed in establishing the correspondence between the points of interest identified in the two images, the success rate was 96.8%.

C. Space resection

After the correlation is made, the conjugated points obtained are used to determine by spatial intersection the corresponding points in the terrain space.

1) Aerial stereo scenes

The mathematical model used in the process of determining the field coordinates by spatial intersection is represented by the collinearity equation, using for the two normalized images the orientation elements of the normalization plane.

2) Satellite stereo scenes

The number of points obtained 876 does not ensure a satisfactory density to generate the numerical model of the land for the given area, if we make an approximate calculation we obtain a minimum number of 3000 points given the area being approximately $18.5 \text{ km} \times 12.5 \text{ km}$. For practical reasons, a sub-area was chosen so that the number of link points collected manually would be reasonable.

The equations of the parallel projection, the linear form, are used for this determination; for a pair of conjugate points we can write four equations with three unknowns (X, Y, Z – the field coordinates of the corresponding point), these coordinates can be determined by the method of the smallest squares.

D. Interpolation

The spatial coordinates of the corresponding points of the corresponding points were obtained by conjugating points. These points are distributed irregularly and are not dense enough to represent the object space, so they must be interpolated. Different methods can be used for interpolation, with Kriging being the most commonly used one, the result being a regular point structure.

The visualization of the numerical model of the terrain is a common way of evaluating the way of general representation of the relief shapes and offers useful methods for the general understanding of spatial data [19].

Representations of the numerical models obtained for the work area using shading techniques as well as 3D representations with color palettes are illustrated below.

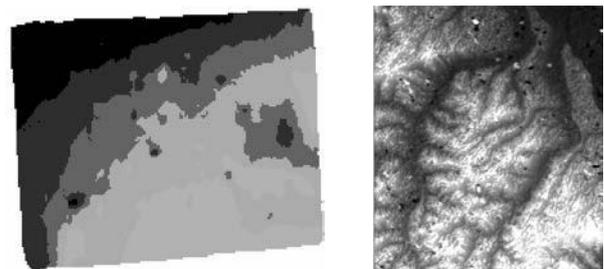


Figure 9. Shaded representation of the generated numerical models

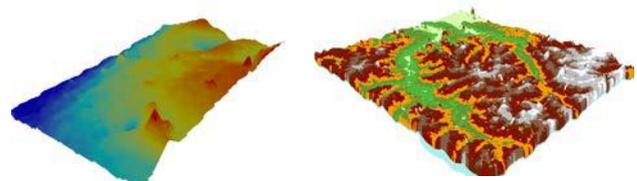


Figure 10. 3D representation of numeric models using color palette

V. GIS APPLICATIONS. VISIBILITY ANALYSIS STUDY

After the surface generation, the terrain model is used for further investigations within a commercial GIS package, namely QGIS. This includes not only the integration of cartographic information, but also a study about visibility analysis.

Visibility analysis is important from the planning point of view. Visual analysis tools allow you to generate visibility studies over an area, creating an output raster that displays what entities can be seen over a certain landscape, from the point of view of one or more observatories. They are used mainly for the planning purpose, from new infrastructure implementation to the development of new touristic activities/routes.

In QGIS you can carry out a visibility analysis via **Viewshed Analysis** plugin. After you install it you can access this tool by going to **Plugins > Viewshed Analysis > Advanced viewshed analysis**.

In this example we will analyze the visibility of a new wind turbine that will be installed. We would like to see from where it will be visible. Keep in mind that the height of the wind turbine is 15 m (in this case observer height) and the average height of humans is 1.6 m (target height in this case).

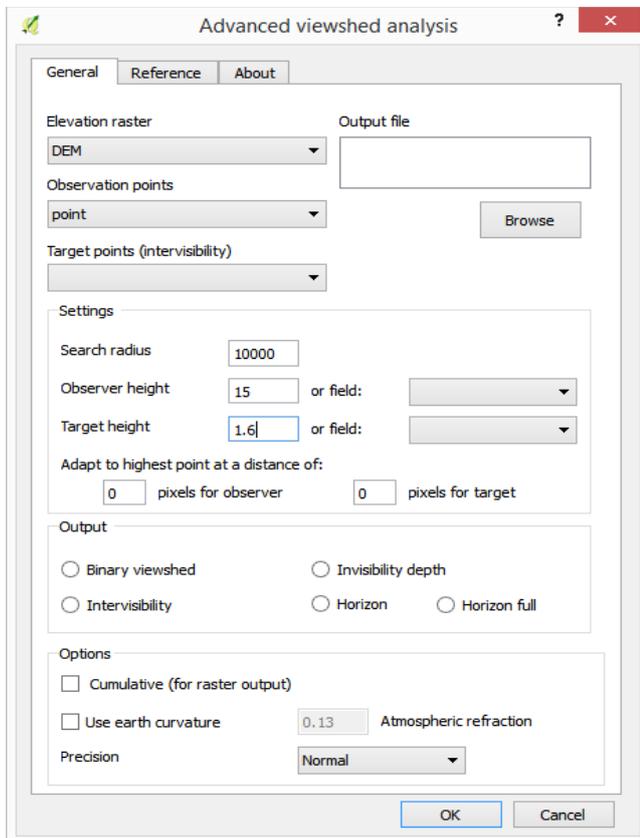


Figure 11. Advanced viewshed analysis graphic interface

The results show the visibility of the turbine in a 10 km area. All people who are found in the blue areas on the map can observe the wind turbine.

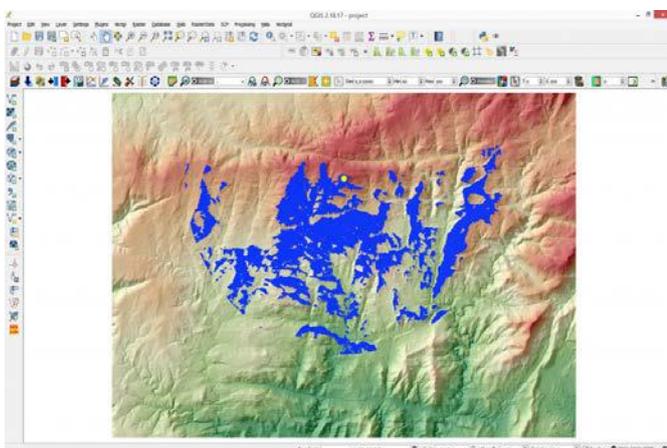


Figure 12. Viewshed analysis outputs

VI. CONCLUSION

The normalized records obtained by processing in the geometry of the epipolar straight line were used in the process of generating the numerical model. These have two important properties, namely: the conjugate points are found along the same line and the longitudinal parallax is linearly proportional to the altitude of the conjugate point in the object space.

An important step in the process of generating the numerical model is the extraction of the primitives that was performed using a modified Harris operator.

There should be noted the problem that appeared in the process of extraction of points of interest, problem that led to the change of area of interest for the extraction of the numerical model, namely the insufficient number of points extracted. One of the reasons we considered as the characteristic of the extraction algorithm is that the Harris operator uses the variation of the image function in the x and y directions and the area chosen initially was highlighted by the lack of corner details. Another cause was the lack of radiometric processing, which was highlighted when, for the new area selected, the contrast was changed, the result obtained by applying Harris operator was significantly better.

In conclusion, it can be stated that for this stage of obtaining the numerical model that despite obtaining quality normalized images, however, when the quality of the primitive extraction process is poor then its result is reflected on the whole process.

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