GOSTEAM Hands-on Activity Template *(Inquiry-based)*

Title:

The ancient tunnel of Eupalinos in Samos, Greece

Short Description (Max 500 words):

This scenario involves different Applied Geometry concepts (angles and orientation, congruent triangles) and Topographic Maps representations (elevation and contour lines) in order to “manipulate” the alignment of the **Eupalinos Tunnel** which is considered as one of the most important engineering achievements of antiquity. **Eupalinos** worked as a modern engineer 2500 year ago without using any digital devices, GPS etc., hence, a question arises: “*Is it simple to succeed such a task with the use of modern technologies and digital tools?*”

Keywords (Up to 5):

Digital Elevation Model (DEM), Contours, Applied Geometry, QGIS, Maps

Information about the Implementation

Age and language of the students:

		9-12	12-15	15-18	18+
Language: Greek	Age:	☐	☑	☐	☐

Number of Lessons – Duration (per lesson):

Number of Lessons: 2   Duration per Lesson: 45’

Subjects:

For which subject(s) the activity is usable, is it an interdisciplinary activity?

Science ☑

Physics ☐ Chemistry ☐ Biology ☐ Geosciences ☑ Environmental ☐ Other ☐

Technology ☑

Engineering ☑

Arts ☑

Mathematics ☑

Information about the Scenario

Curriculum and country:

Link of the current activity to the curriculum:

Country: Greece Class: Secondary Grade: 9 - 12

Topic: Applied Geometry, Geography, History

Objectives (Max 100 words):

Description of the learning objectives

- Students will learn how to read, construct, and interpret a topographic map.
- Students will be able to discuss, compare, and negotiate methods used, results obtained, and explanations among groups conducting the same investigation.
- Students will represent their ideas and solutions within text in the form of a report by incorporating graphs and maps.
- Utilize tools geographers use to study the world for solving complex engineering and geometry-based historical problems.

Materials (Max 100 words):

Which resources and materials (software, hardware) are needed?

Material: Search Engines, Spatial Data, Maps and Online Support Material

Software: QGIS

Spatial concepts, skills, and abilities:

Which spatial concepts and skills are covered by the activity?

Spatial concepts:

Primitives: Identity/Name ☐ Location ☑ Space/Time ☐

Simple: Distance ☐ Direction ☑ Connectivity ☐ Movement ☑ Boundary ☐ Shape/Area ☐ Adjacency ☐

Difficult: Overlay ☐ Buffer ☐ Topology ☐ Coordinate ☐ Map ☑ Scale ☐ Shortest Path ☐ Navigation ☐ Surface ☑ Slope/Gradient ☐ Aspect ☐ Contour ☑

Complex: Interpolation ☐ Map Projection ☐ Spatial Dependency ☐

Other:

Spatial skills:

- [ ] Map literacy
- [x] Navigation/orientation
- [x] Estimating distances and directions
- [ ] Recognizing and understanding patterns/Understand and identify models of spatial organization
- [ ] Select an ideal location based on the given spatial features
- [x] Visualization
- [ ] Understand and identify spatial correlations/ dependencies
- [ ] Categorize spatial entities/ geographic features and identify hierarchies
- [ ] Compare spatial entities and draw analogies among them
- [ ] Identify/determine connections/relations
- [ ] Understanding scale in space and time
- [ ] Delineation of spatial regions/ zones based on given features/ properties

Short Description

Navigation/orientation: Finding one's way in unfamiliar environments, interpreting and giving walking and driving directions.
Estimating distances and directions: Measure paths, weighted distances, angles.
Map literacy: Using, interpreting/understanding, learning from, and communicating acquired spatial knowledge from maps, comprehension of geographic features represented as points, lines, or polygons.
Recognizing and understanding patterns/Understand and identify models of spatial organization. Delineation of spatial regions/zones based on given features/properties: Regionalization processes, pattern recognition and clustering identification in the 2d and/or the 3d world.
Select an ideal location based on the given spatial features: Single or multi-criteria siting and optimal areas identification.
Visualization: Visualizing spatial entities from written/oral verbal descriptions, from their 2d or graphical representations or through mental transformations; such as axis rotation or perspective taking.
Understand and identify spatial correlations/ dependencies: The ability to realize, identify and explain patterns, clusters and relevant spatial dependencies.
Categorize spatial entities/geographic features and identify hierarchies: Identify the hierarchical form of data and gradients between spatial entities.
Compare spatial entities and draw analogies among them: Calculate and compare different geometric objects' shapes, area and boundaries.
Identify/determine connections/relations: The ability to identify links and common characteristics among spatial entities and between humans and spatial entities.
Understanding scale in space and time: The understanding of changes/transitions through space and time for different spatio-temporal scales.

Geospatial concepts and spatial abilities documentation (see Section 3.2):
http://www.gosteam.eu/wp-content/uploads/2021/05/GOSTEAM_IO1_A1_final.pdf

Description of the activity in detail

Question Eliciting Activities

Provoke curiosity

Describe ways and materials that teachers will present to their students to attract their attention to the topic investigated.

Usually, the most effective way to provoke students' curiosity is by presenting an exciting video or a series of photos

Pose questions like:

How long is the longest underwater section of any tunnel in the world?

How you believe was constructed?

https://www.youtube.com/watch?v=qNS2jj2w-GI (How the world's longest underwater tunnel was built)

Make a comparison with the current technological advancements and tools and during the ancient times. Was it possible to do something similar (of course at a smaller scale)?

One of the greatest engineering achievements of ancient times is a water tunnel, 1036 meters (4000 feet) long, excavated through a mountain on the Greek island of Samos in the sixth century B.C.

Watch the following video to get introduced to this mathematical and engineering challenge 2600 years ago!

https://www.youtube.com/watch?v=CR8BIMxrorA (Maths bring water to Samos)

Propose preliminary explanations or hypotheses

Formulate the scientifically oriented questions that teachers will present to the students to trigger their engagement in thinking about the topic investigated based on their existing knowledge. Make these questions digitally available and easily usable, e.g., by integrating them in the materials described in the previous step.

It is best to ask these questions in the context of a relative discussion.

Can you identify the difficulty of the task illustrated in the last video?

a. Can you identify the tunnel's path? (Its straight direction and level ground)
b. In which part of the mountain and why? At which altitude? (The altitude: 55.8m in order to minimise excavation works)
c. How to identify the entrance and the exit point? Why to start from both sides? (starting to work from both ends in order to save time)

Active Investigation

Plan and conduct simple investigation

During this phase, teachers must provide a specific plan of the investigation that will take place. Offer instructions about the activities they students will need to perform and what kind of materials they may need. Describe ways that the teachers can use to facilitate the students to focus on evidence.

This is the phase in which students are being prepared for the subsequent phase of evidence gathering during observation.

In order to comprehend in depth the principles governing such an engineering task, we need to review some fundamental geometry concepts along with previous explanations on how Efpalinos solved this problem.
Let's see what this is all about:

https://www.eclass.tuc.gr/modules/document/file.php/ARCH193/TunnelSamos.pdf

See pg. 33-34 for the first method considered (Hero's method)

See pg. 34-36 for the second method considered (Using pillars and the leveling bow)

North Entrance (Google Maps)

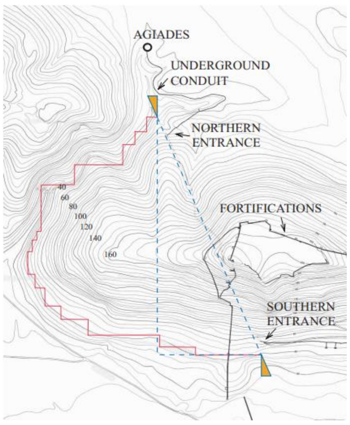
South Entrance (Google Maps)

But why is the Hero's method important?

Hero's method explanation (Link)

What else you will need in order to verify the correct orientation from both sides?

https://www.mathsisfun.com/geometry/triangles-similar.html (Similar Triangles)



Creation

Gather evidence from observation

The selected resource (e.g., a simulation, an experiment, an animation, a graph, or other exhibit of similar nature) must provide students with an opportunity to collect evidence addressing the scientific questions presented in previous stages through direct or indirect observation. Provide guidance to the teacher organize and manage the activity most effectively and efficiently.

It is recommended to introduce group work at this stage. Guide the teachers to divide students in groups, each of which will be facilitated by the teacher to formulate and to evaluate explanations to the scientific questions based on the collected evidence.

<u>Before we begin, students have to download and install QGIS platform!</u>

QGIS Platform Download (version 3.14.0)

https://qgis.org/downloads/

Digital Elevation Model (DEM) data

https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=mapview

QGIS Plugin Open Street Maps

https://opengislab.com/blog/2018/4/15/add-basemaps-in-qgis-30 (Guidelines)

Before the beginning of the activity, students are separated to groups of 2. One of the group members is responsible for the tasks' flowchart implementation, data acquisition and the appropriate steps to be followed during the activity. The second member is responsible for the results validation and communication, including the final report and the maps preparation.

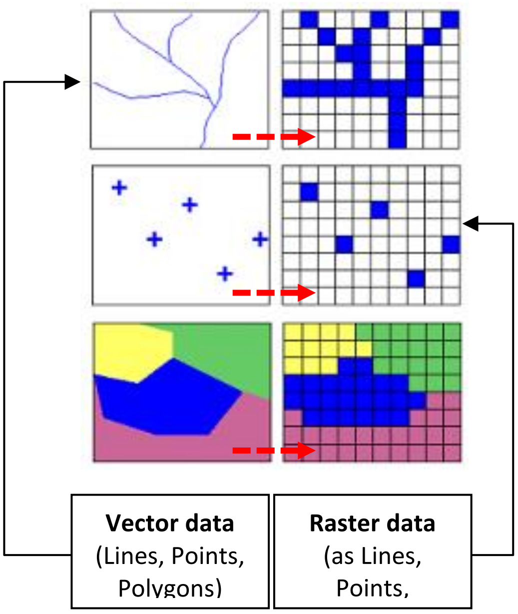
In order to better understand what type of data we will use and how we "translate" or model the Earth surface and processes, we have to discuss about spatial data structures (type of data and how spatial information is stored, data types etc.)

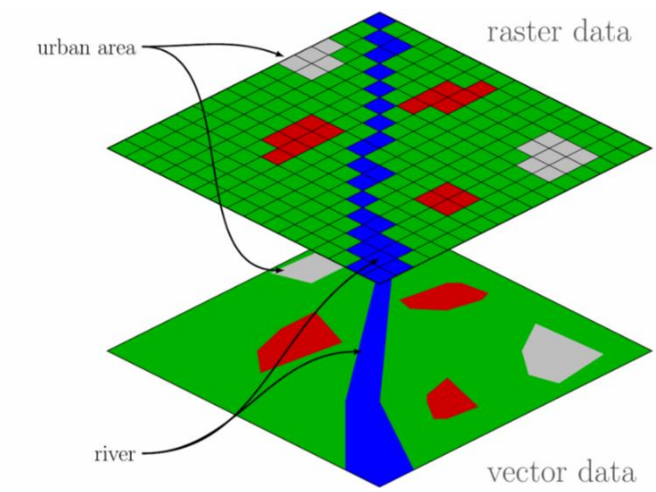
A short explanation:

https://www.youtube.com/watch?v=HwVFvHwuYJo

<u>Vector and Raster data:</u>

Some useful examples on how we can model a river, a mark on the map or an area using vector and raster data structures!





An example

Support Material for Vector and Raster data: https://gisgeography.com/spatial-data-types-vector-raster/

WHY THIS IS IMPORTANT?

In order to understand spatial data structures, models' data inputs, data volume, spatial resolution, scale, computational efficiency and spatial data, big data manipulation-processing-visualization etc.

Particularly for the terrain models or Digital Elevation Models (DEM) that we will use in this experiment, see the images below in **Figure 2**!

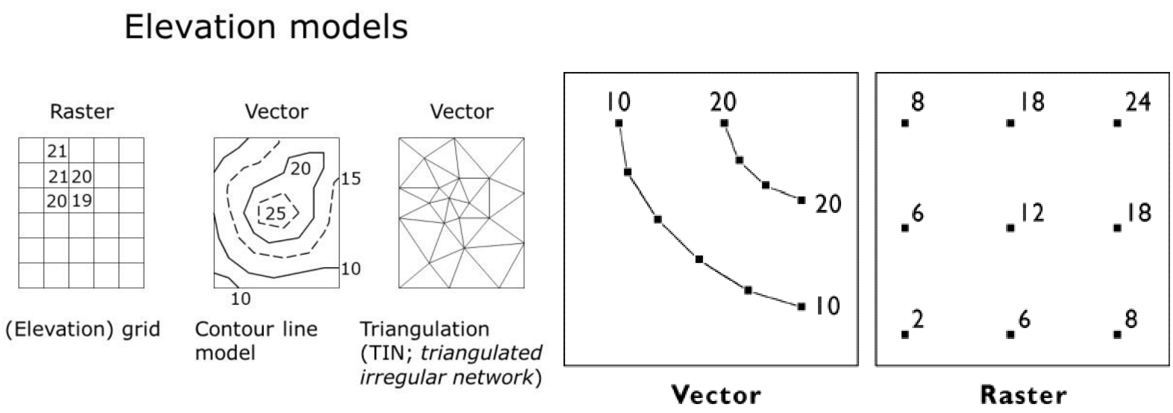


Figure 2: Digital Elevation Model (DEM) and heights representation using Vector and Raster (gridded) data

- *You can also ask from students to "google" for Digital Elevation Models and see different 3D visualizations of the Earth's surface. They can also identify the comparisons between Digital Elevation/Surface Models (DEM/DSM) and Digital Terrain Models (DTM).*

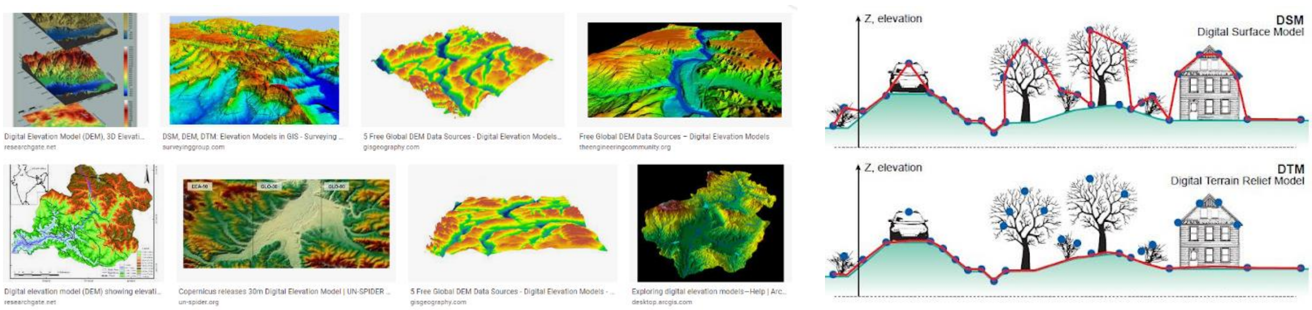


Figure 3: DEM/DSM and DTM examples

- *Students can also search for "contour maps" and see many different topographic patterns in order to better understand how the height difference are mapped and visualized as also, how critical is the contour intervals in a topographic map. But, what is the contour intervals?*

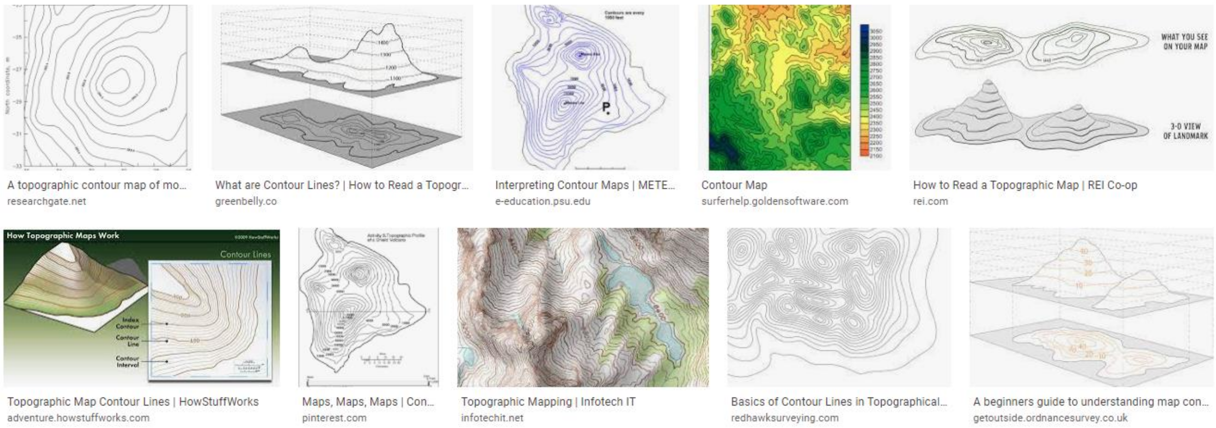
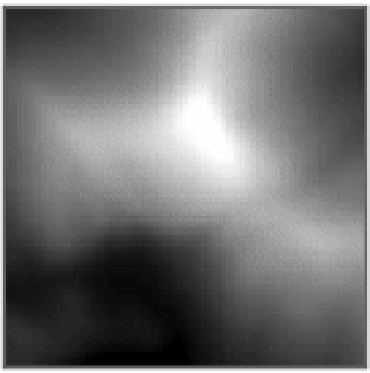


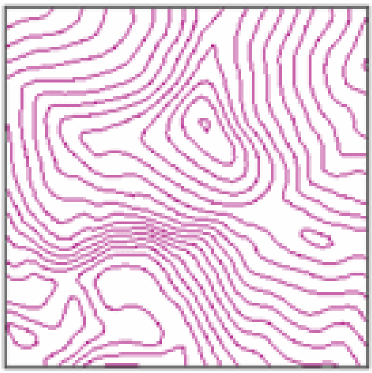
Figure 4: Contour maps examples by simply typing "contour maps on Google"

<u>OPTIONAL ACTIVITY</u>

You can print the DEM image on the left and ask from students to draw on this image how they imagine that the contour lines will look like!

You can see the results on the image below. Most of the times, Digital Elevation Models are visualized in a greyscale color-ramp where the black colors identify low-altitude areas and the white color the high-altitude areas.





Hint: Steep differences between the colors (from white to black without intermediate grey colors) indicate increased height differences! (looks like a cliff)

<u>Some technical guidelines considering the tools (QGIS Platform) we will use during this Activity!</u>

Load data: In general, data can be loaded in four ways. The first way (Figure 5-selection 2) is to use the Layer > Add Layer menu and select the appropriate type of data you wish to load. The second way (Figure 5-selection **1**) is to open the Browser panel, navigate to the data you wish to load, and then drag the data on to the map display, or on to the Layers panel. The third way (Figure 5-selection 6) to load data is to enable the Manage Layers toolbar and click on the button representing the data type you wish to load. The fourth way is to locate the data in QGIS Browser, drag to the data, and drop it onto the QGIS Desktop Map Display or Layers panel (Source: https://www.gislounge.com/loading-data-mastering-qgis/).

QGIS Interface

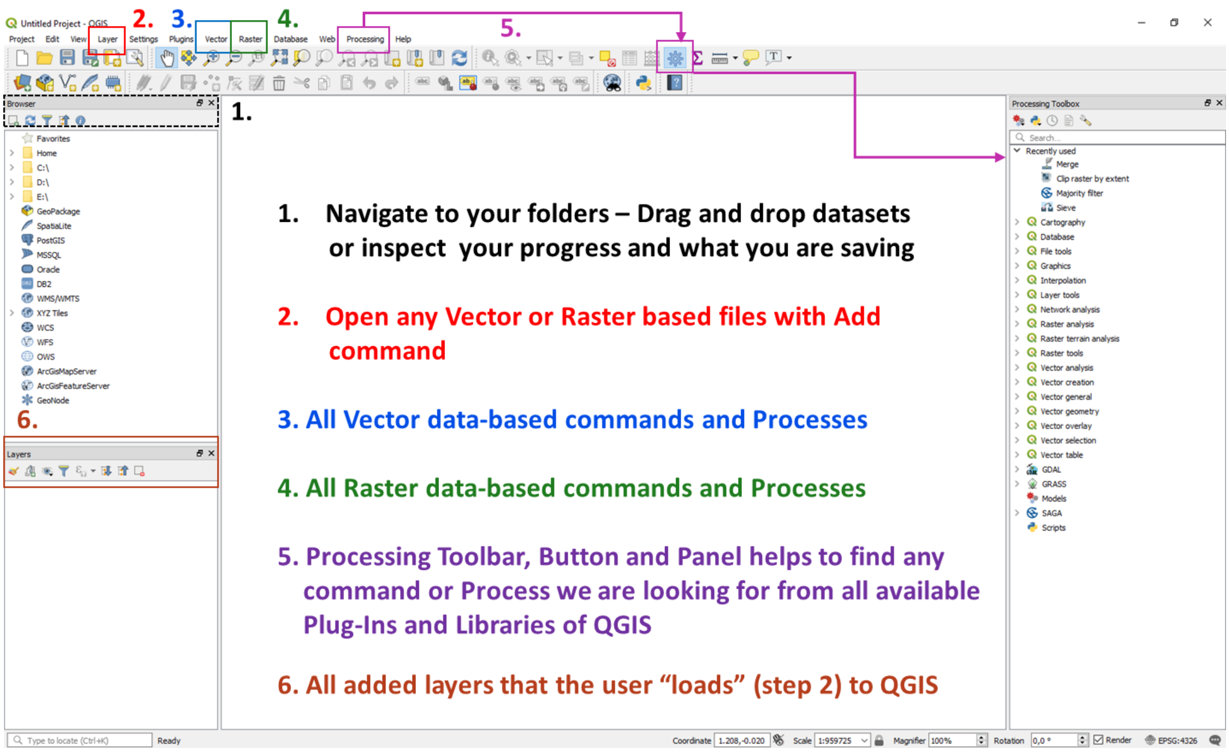


Figure 5: QGIS interface and key functionalities

Step 1 - Based on the above-mentioned instructions you can start with:

1. *During the first step of the Activity, load Samos island surface data in the QGIS platform.*
2. *Use the Main toolbar (top of the screen) -> Layers -> Raster Layer -> Navigate to your folder and select **Samos_dem_proj.tif***
3. *Change layout colors using Layer Properties (double-click on the .tif image you've loaded) **-> Symbology -> Single-band Pseudocolor -> Classify**.*
4. *Identify mountains and plains, find height values and height differences, mostly in the Eastern-South part of the island (identify button).*

Step 2: Install the Plugins needed to run the activity (qgis2threejs, QuickMapServices)

To begin using plugins, you need to know how to download, install and activate them (Figure 6). To do this, you will learn how to use the **Plugin Installer** and **Plugin Manager.** But what a Plugin is?

Plugins in QGIS add useful features to the software. Plugins are written by QGIS developers and other independent users who want to extend the core functionality of the software. These plugins are made available in QGIS for all the users (Source: QGIS Tutorials).

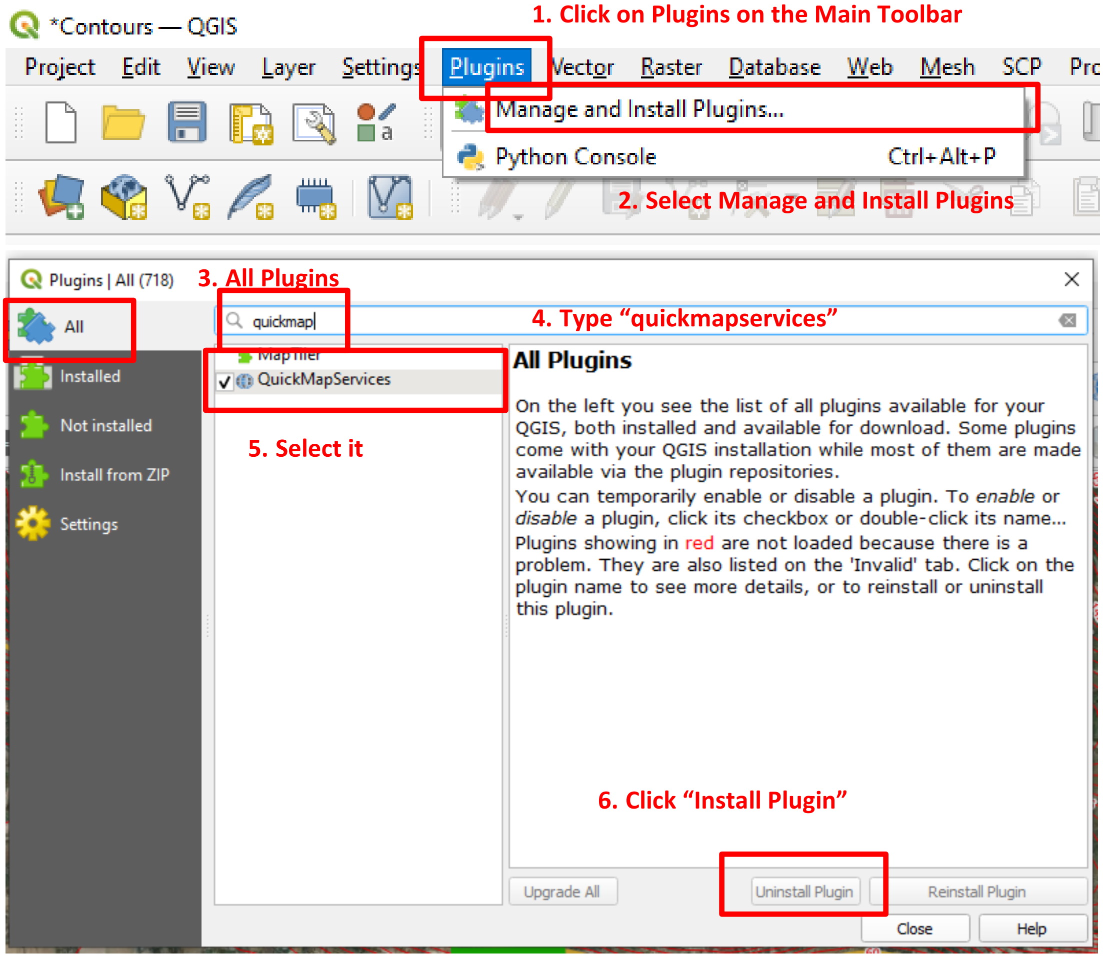
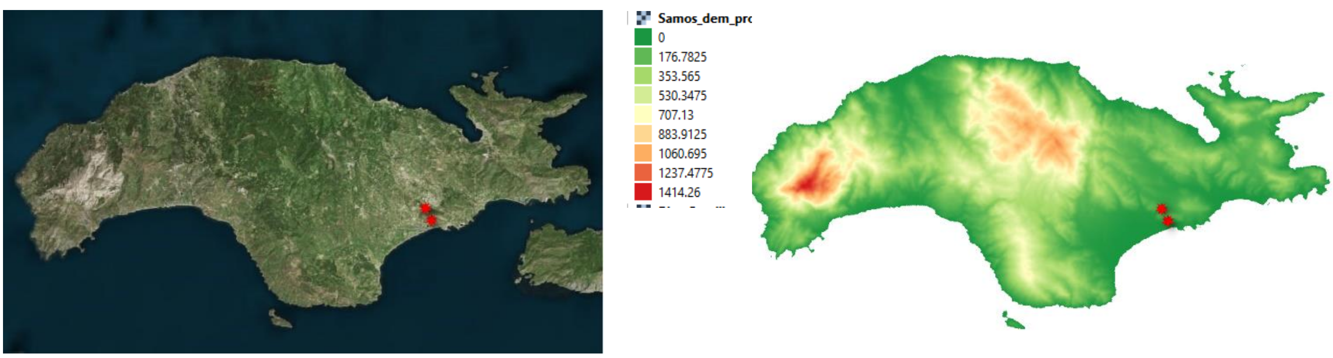


Figure 6: Steps for installing Plugins in QGIS

<u>Step 3: Load Satellite Imagery as Basemap and change color ramp to Samos DEM</u>



Satellite image **DEM**

Figure 7: Satellite image of Samos (left), Digital Elevation Model with height values (right)

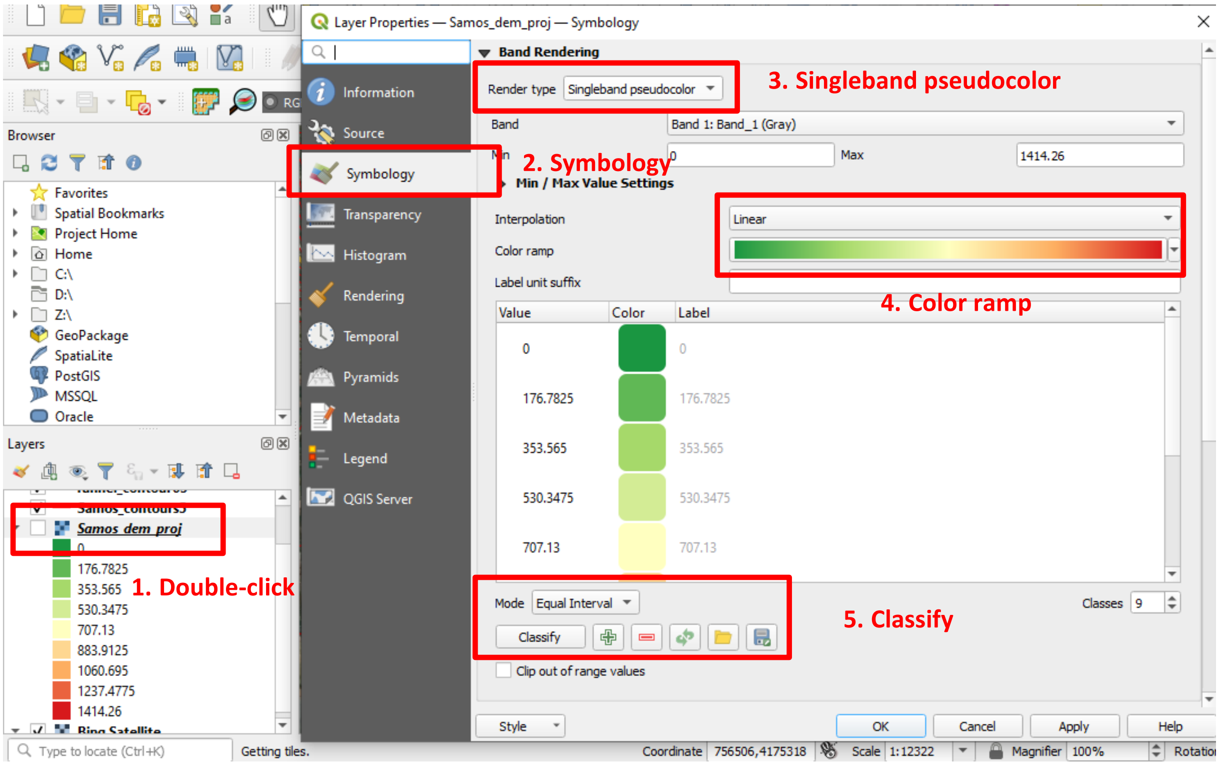


Figure 8: Change colorbar to a Raster layer

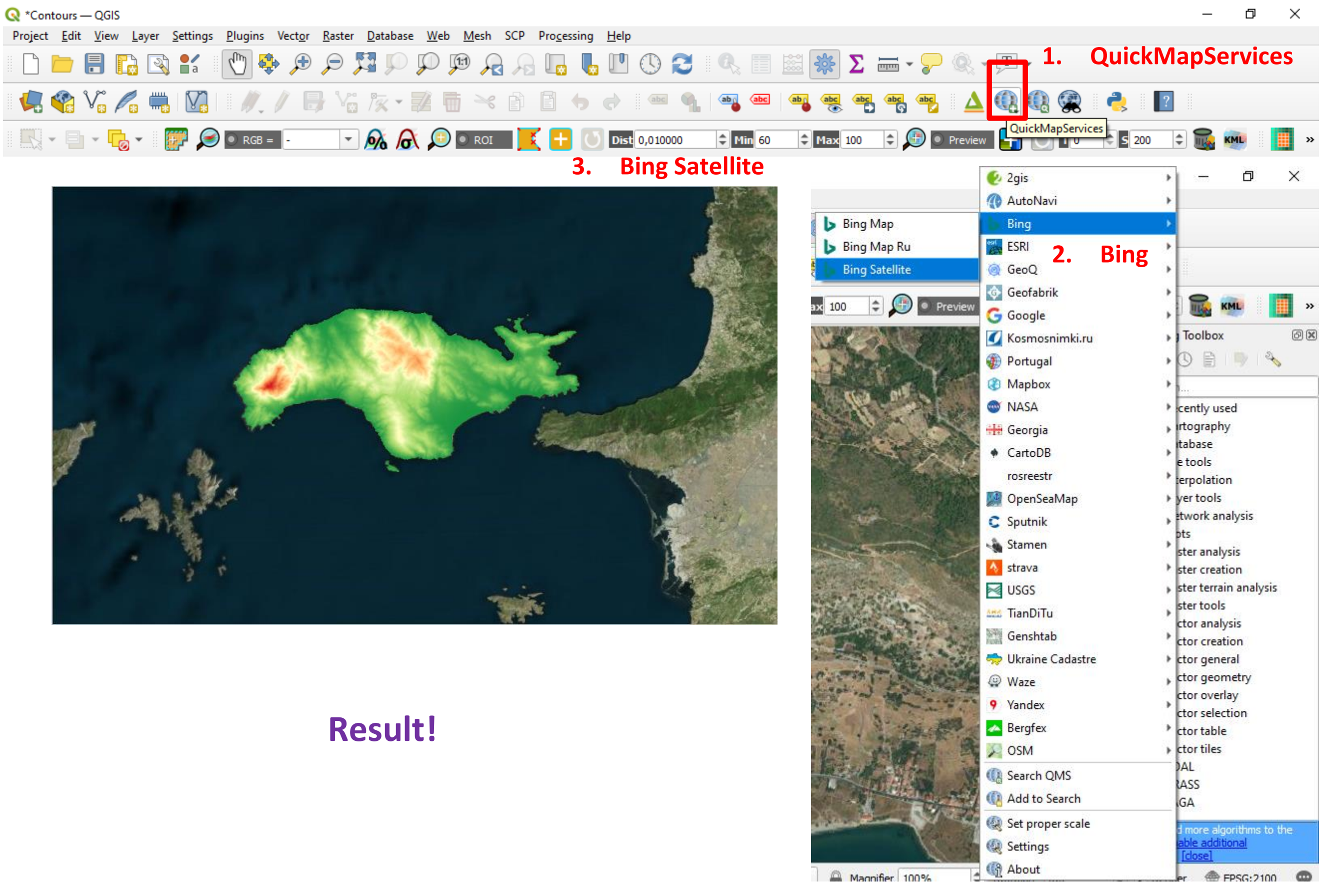


Figure 9: Load Basemap Satellite data

Step 4: Extract contour lines using DEM

Figure 10: Create contours of specific interval using DEM

Step 5: Extract contour lines using Select features option

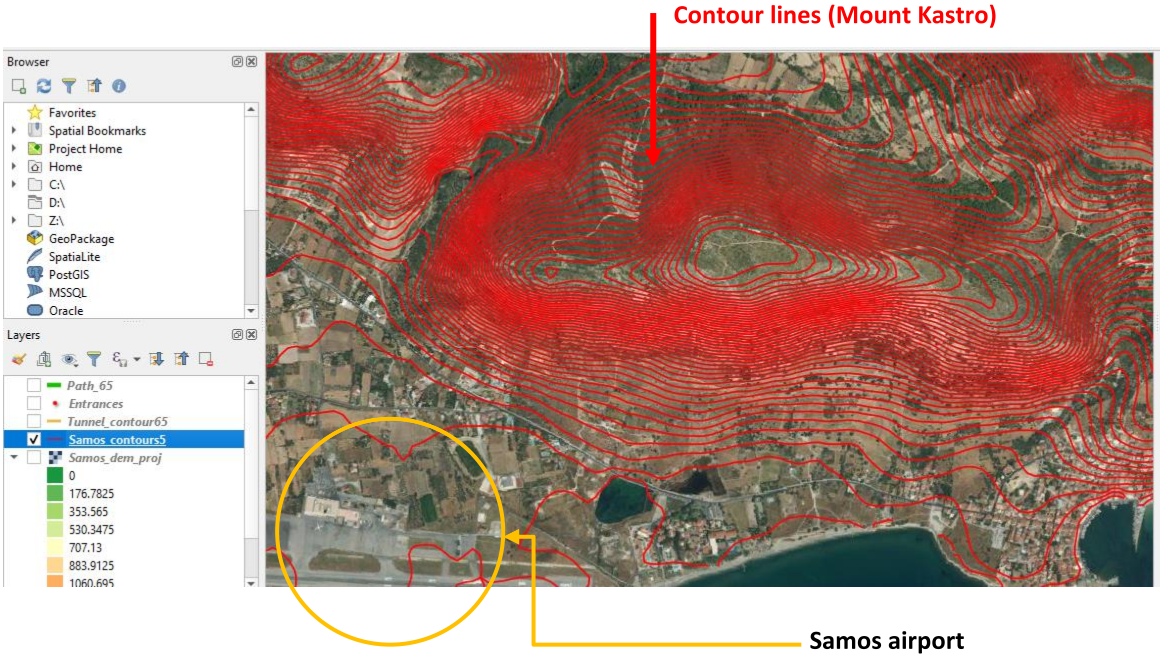


Figure 11: Exported contour lines of 5 meters interval

HOW CAN WE VISUALIZE CONTOURS HEIGHTS (e.g. using labels)????

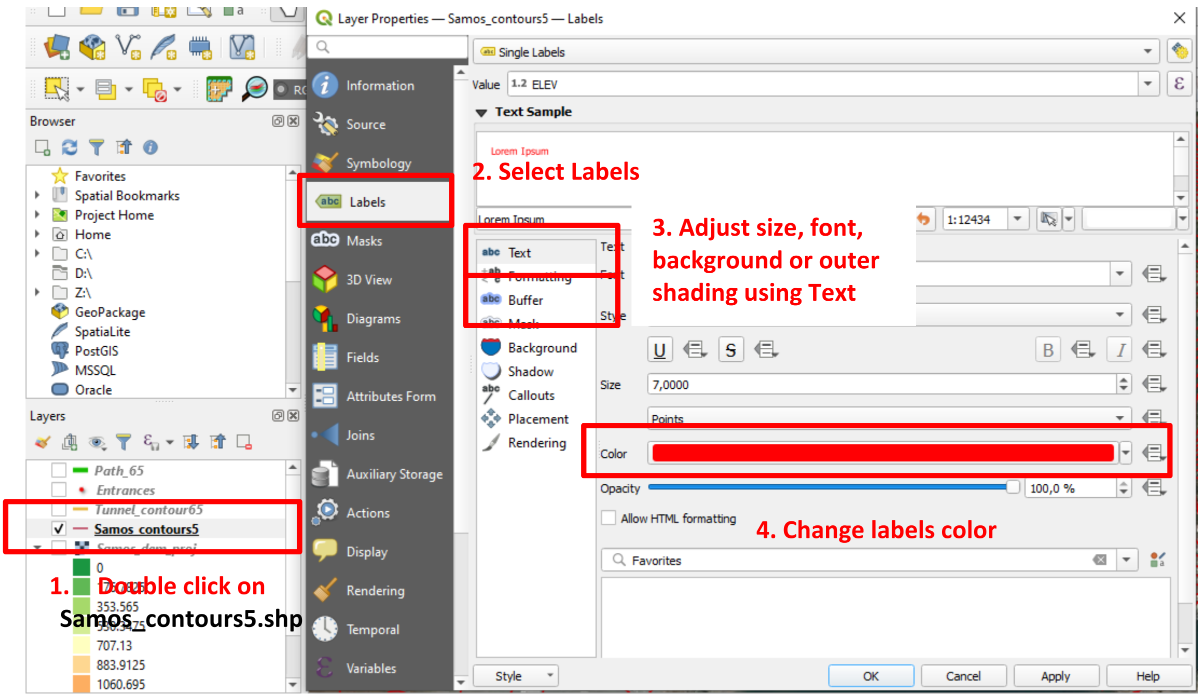
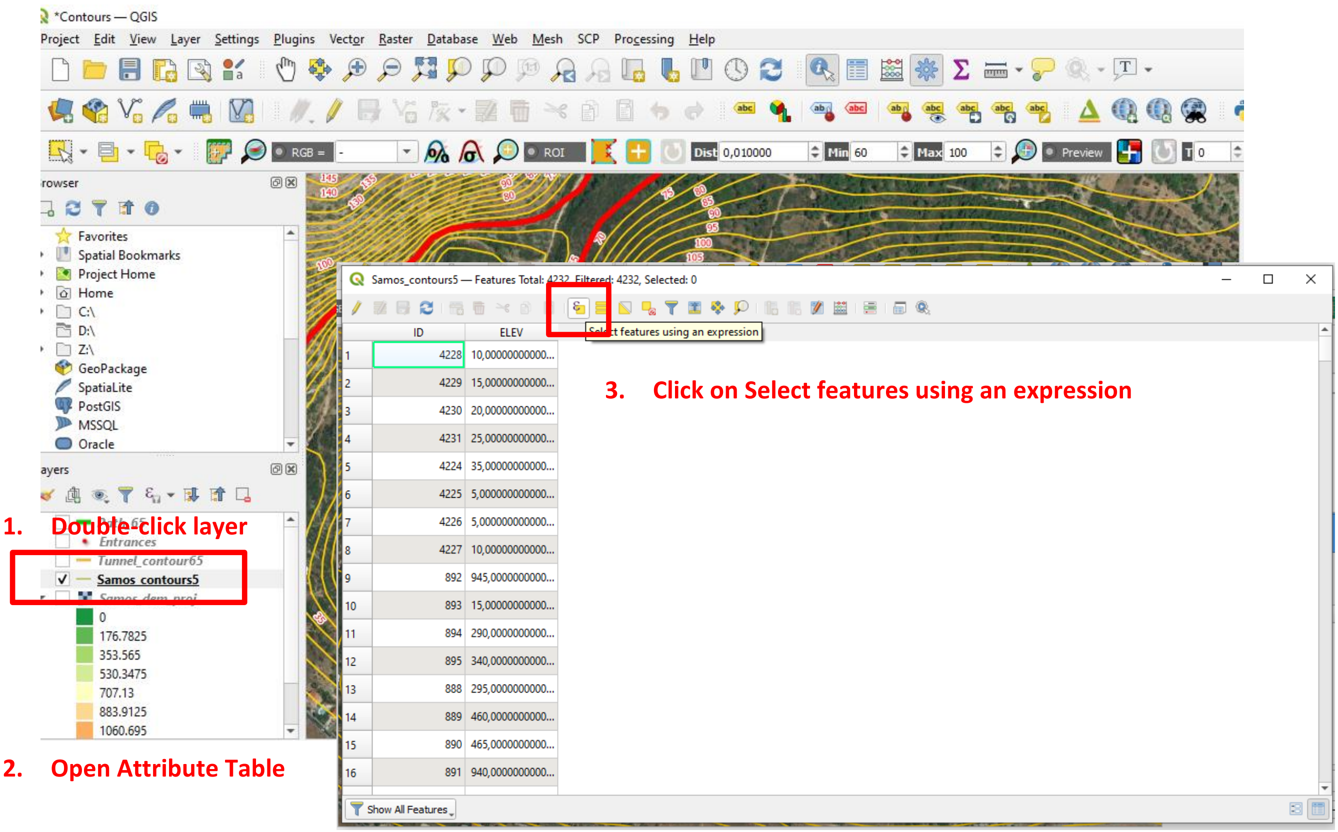


Figure 12: Contours' labeling with heights values



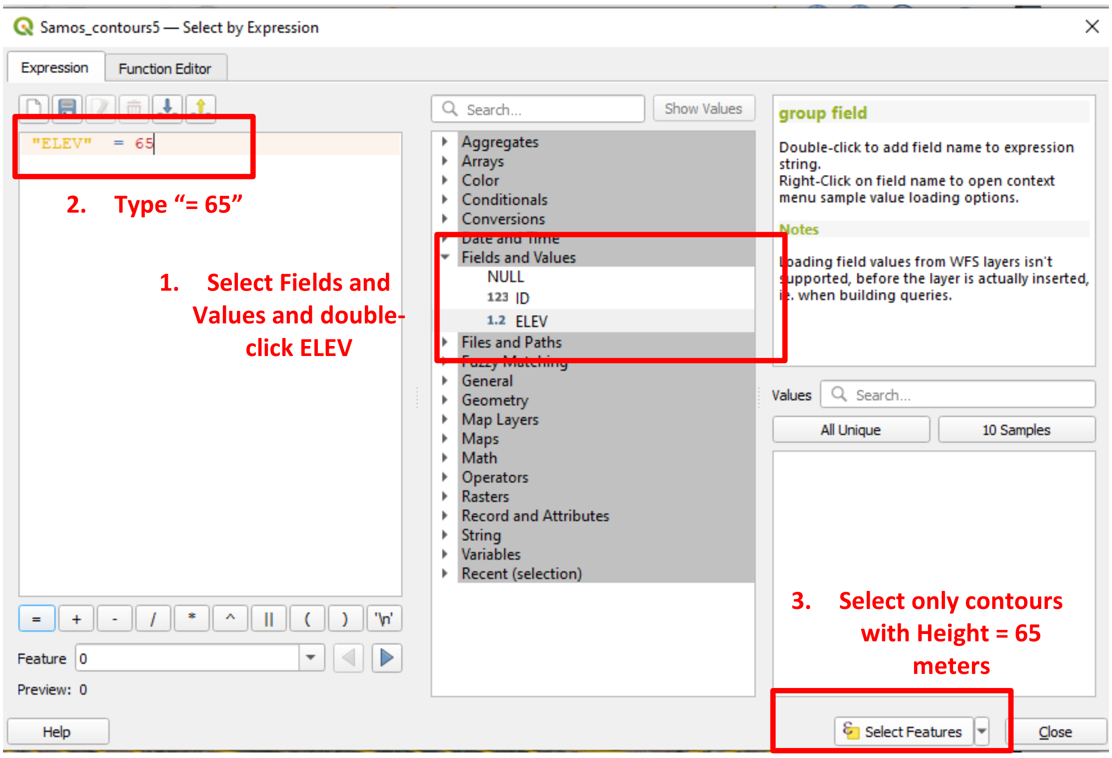


Figure 13: Select the contour of 65 meters

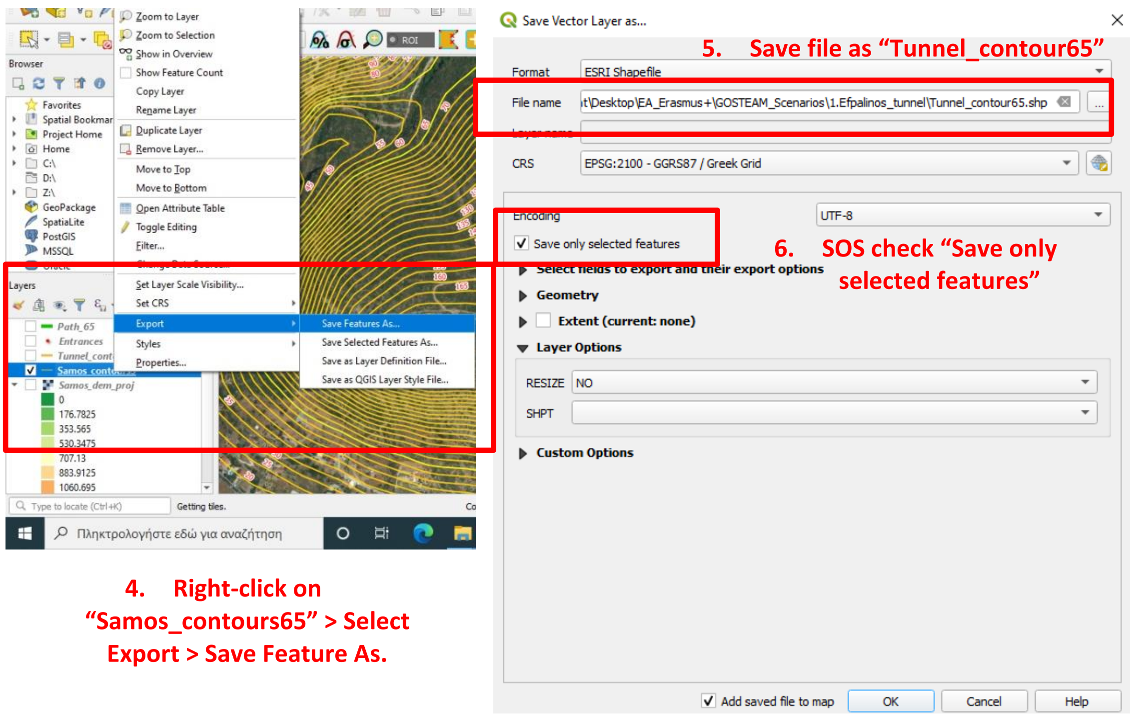


Figure 14: Save as separate layer (shapefile) the contour of 65 meters

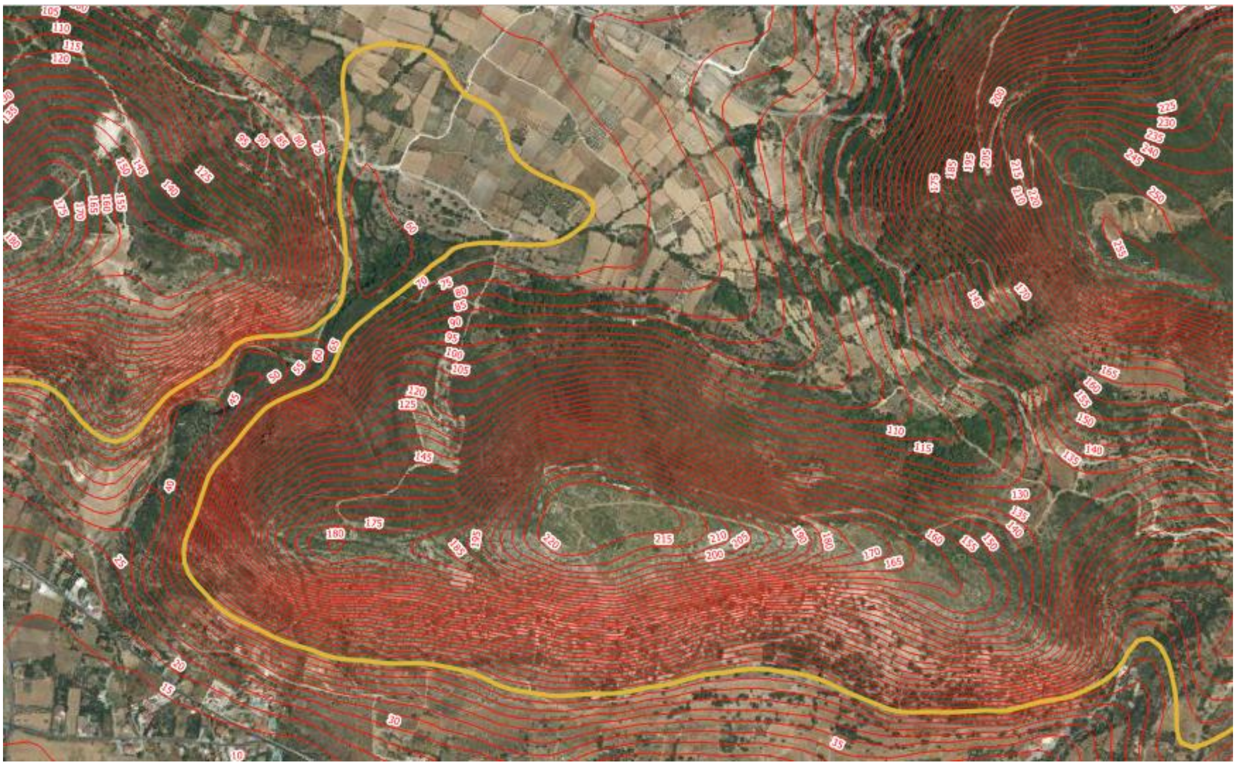


Figure 15: Contour with height value of 65 meters (Yellow color)

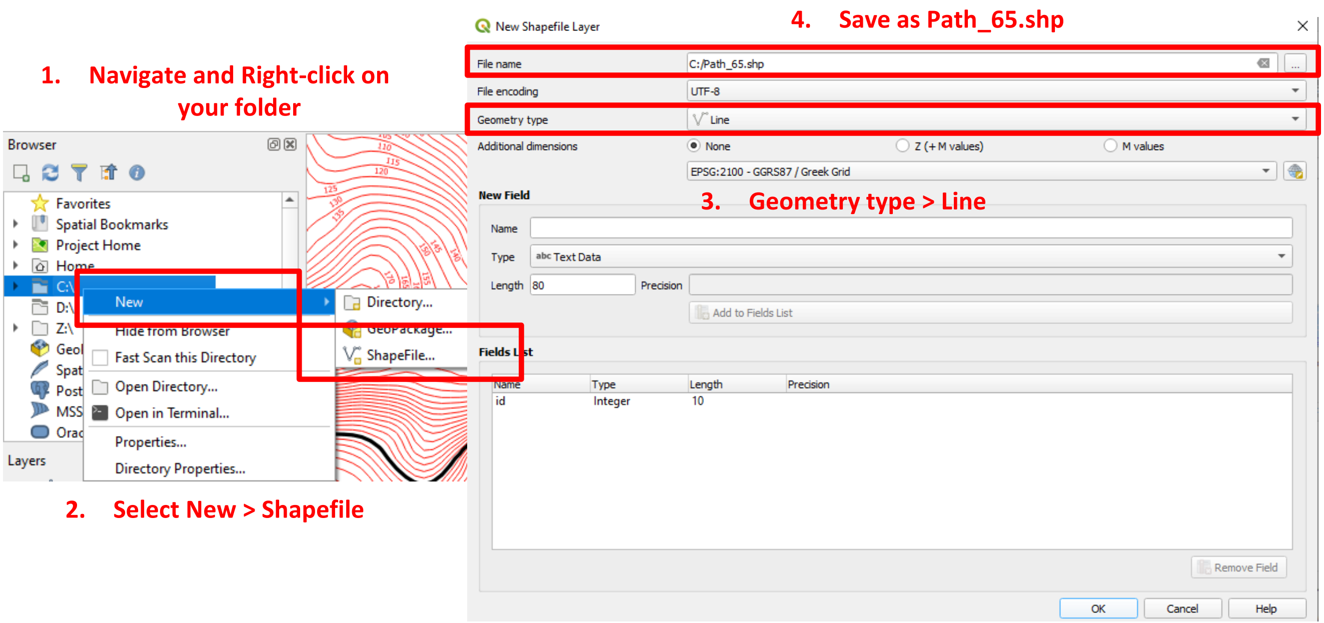
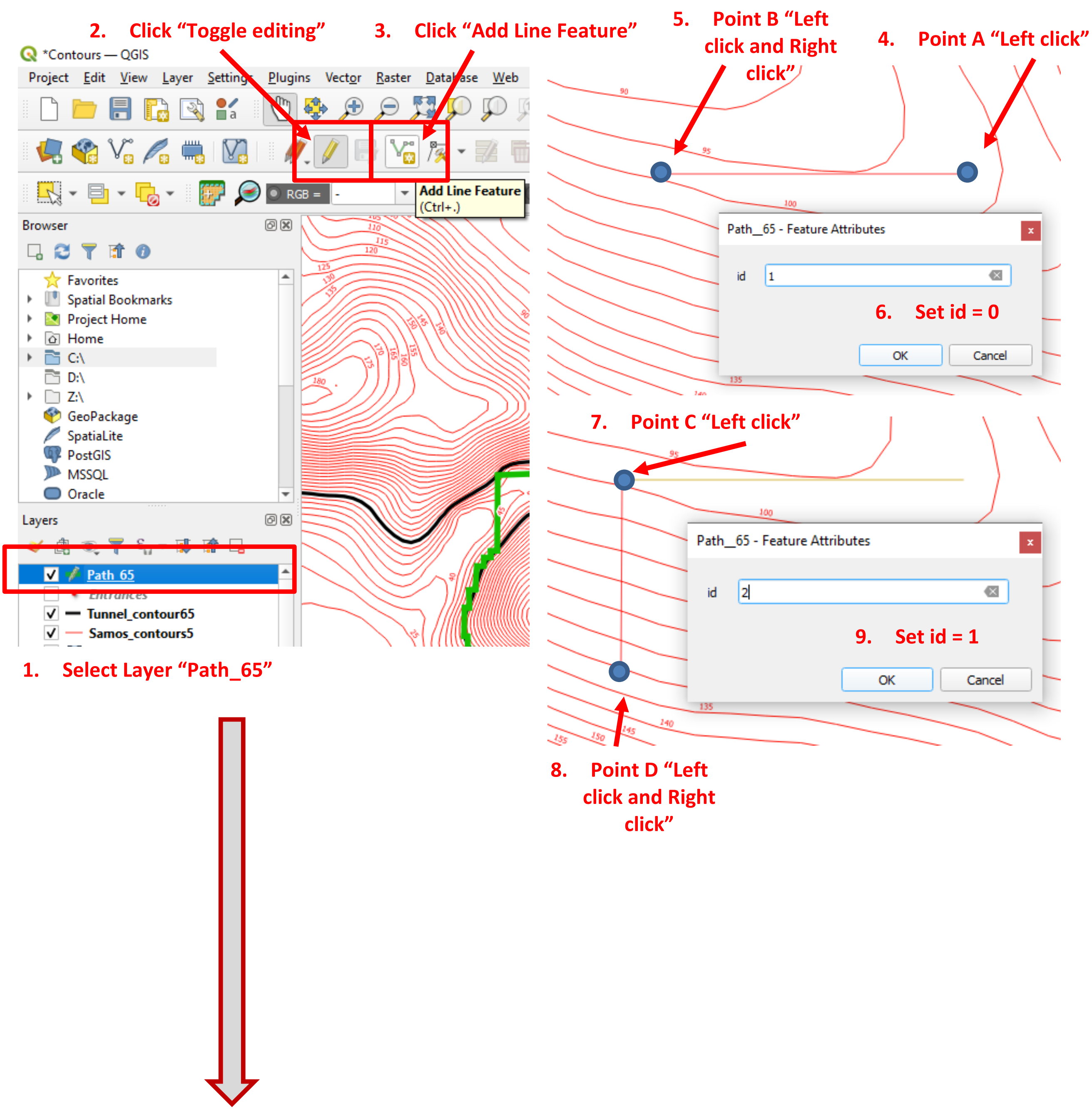


Figure 16: Create a new empty shapefile to your folder for digitizing new data

LOAD THE NEW EMPTY SHAPEFILE ON QGIS!

Using Hero's method, start at a convenient point near the northern entrance of the tunnel, and traverse the western face of the mountain along a piecewise rectangular path (indicated in green on Figure 17) at a constant elevation above sea level, until reaching another convenient point near the southern entrance.

1. Measure the total distance moved west, then subtract it from the total distance moved east, to determine one leg of a right triangle, shown dashed on the map, whose hypotenuse is along the proposed line of the tunnel.
2. Then add the lengths of the north-south segments to calculate the length of the other leg, also shown dashed.
3. Once the lengths of the two legs are known, one can lay out smaller horizontal right triangles on the terrain to the north and to the south (shown in orange) having the same shape as the large triangle, with all three hypotenuses on the same line.
4. Draw these sm all triangles!



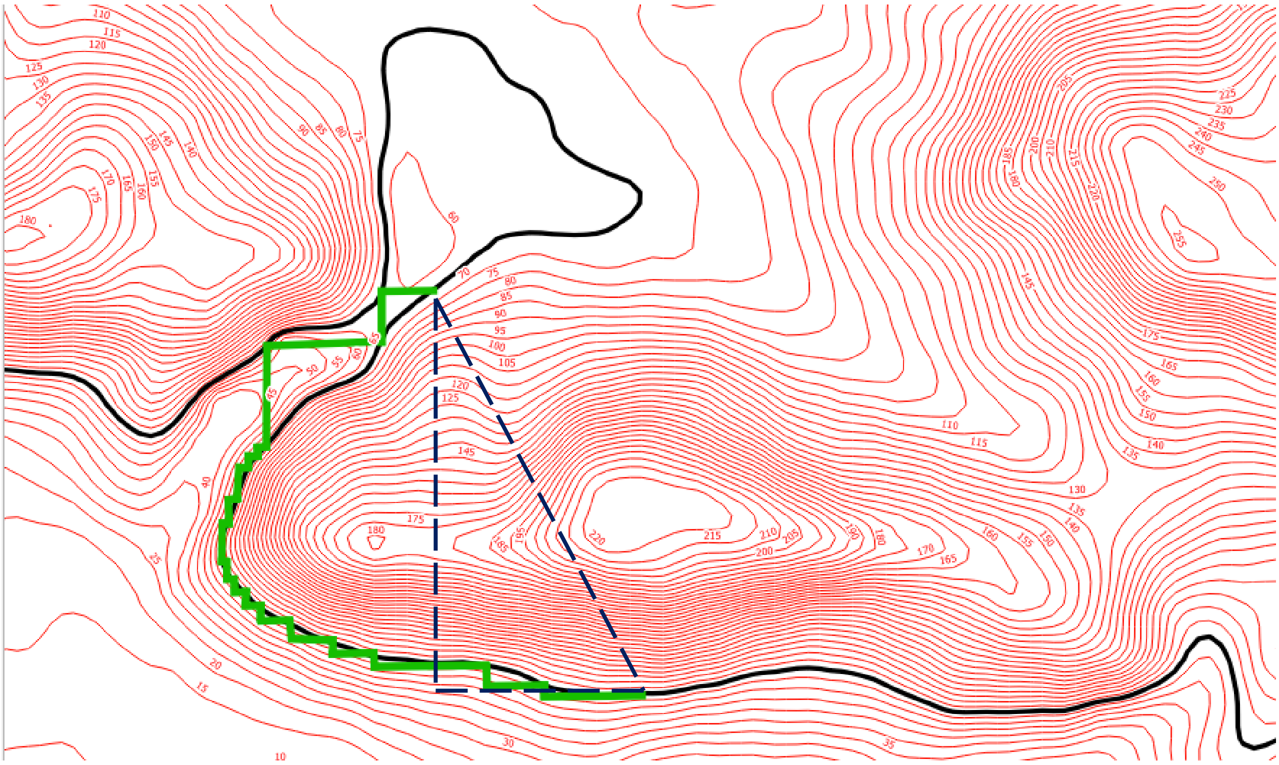


Figure 17: A digitized path for a series of left-angled traverses of same height (approximately)

Using Hero's method, start at a convenient point near the northern entrance of the tunnel, and traverse the western face of the mountain along a piecewise rectangular path (indicated in red) at a constant elevation above sea level, until reaching another convenient point near the southern entrance.

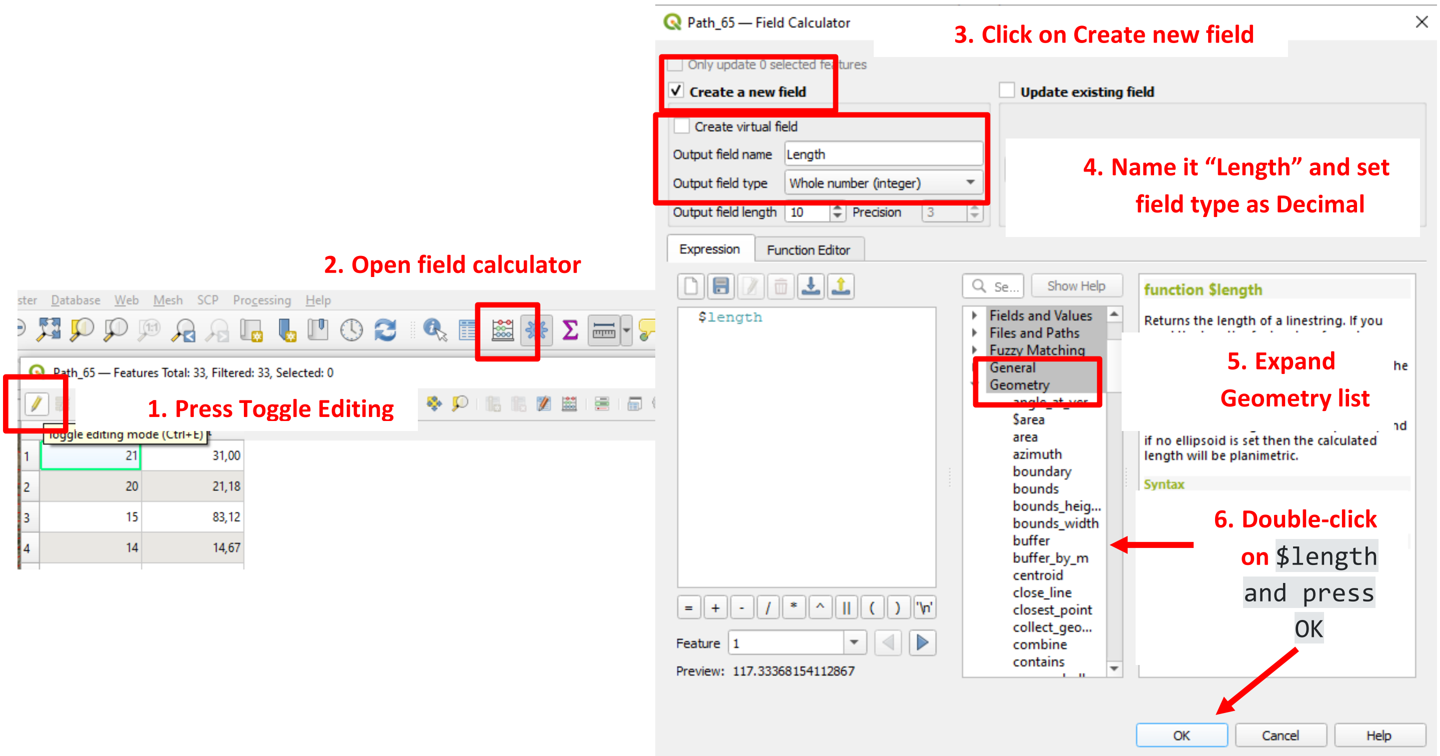


Figure 18: Add length field and estimate segments' length

After you finish the path digitization you must calculate each path's segment length. To succeed that, you will create a new Field on the "Path_65" layer!

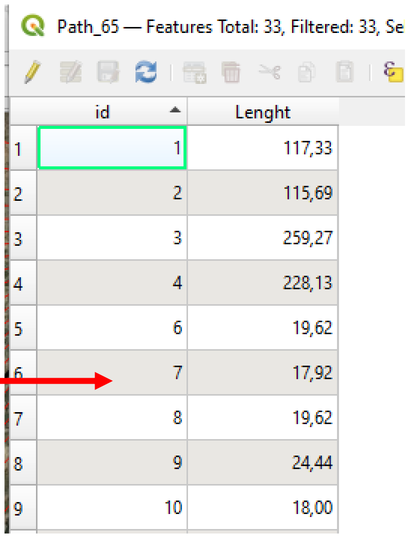
1. Right-click on "Path_65" layer and select Open Attribute Table.
2. Select "Toggle Editing" in order to be able to add the new Field.
3. Press "Field Calculator" and follow the instruction of **Figure 18**.

When you calculate all segments' length open again the ***Path_65*** layer Attribute Table and you will see that all length values have been updated for each segment!

There is one last Step you have to follow in order to estimate the final tunnel's length!

The unique *id* you set for each segment suggests which segments have a horizontal orientation and which one have a vertical orientation!

DO NOT FORGET TO SORT DATA BASED ON THE ID COLUMN!

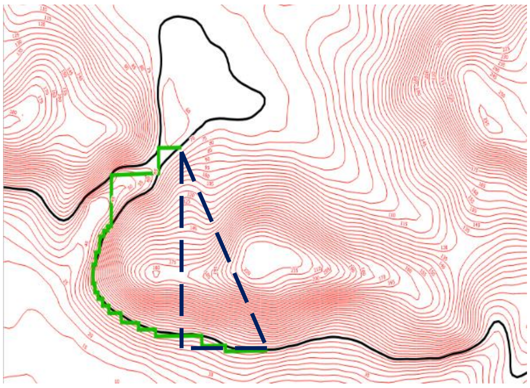


	id	Lenght
1	1	117,33
2	2	115,69
3	3	259,27
4	4	228,13
5	6	19,62
6	7	17,92
7	8	19,62
8	9	24,44
9	10	18,00

Based on the lengths' estimation and the sorted length attribute values:

i) measure the total distance moved west (odd id segments), then subtract it from the total distance moved east (odd id segments), to determine one leg of a right triangle, shown dashed on the map, whose hypotenuse is along the proposed line of the tunnel.

ii) then add the lengths of the north-south segments (even id segments) to calculate the length of the other leg, also shown dashed.



Once the lengths of the two legs are known, you can easily estimate the total tunnel length, even though they are buried beneath the mountain!

In addition, in order to validate that workers will start digging on the same direction, one can lay out smaller horizontal right triangles on the terrain to the north and to the south having the same shape as the large triangle, with all three hypotenuses on the same line.
Therefore, workers can always look back to markers along this line to make sure they are digging in the right direction.

Discussion

Explanation based on evidence

Encourage your students to provide correct explanations for the topic(s) investigated.

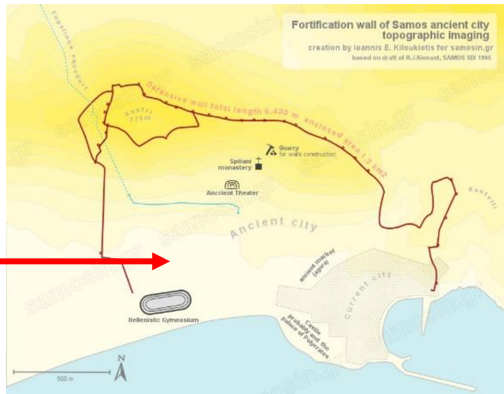
Describe ways that they can use to this end and give them directions how to discover them.

Ask from students to load on QGIS the ***Entrances.shp*** layer presenting the real North and South entrance (as show in Figure 19). Ask from the to measure the Euclidean distance of the entrances (1036 meters the actual length) and compare their results with the actual tunnel length.

Consider the following questions from the students:

Why not to make the Southern entrance on the Western part of the mountain in order to reduce the tunnel's length?

Students have to consider the exact position of the ancient city of Samos so that the tunnel ends inside the fortification walls.



Source: https://www.samosin.gr/item/fortification-wall-of-samos-ancient-city/

Why Efpalinos selected the 55 m. contour line (65 m. in our activity) and not another elevation to delineate the tunnel?

Because water volume is proportional to the elevation, hence, per 2 meters increase on the elevation, water volume increases by 100 m^3.

Why we selected the contour of 65 m. and not 55 m.?

First of all due to potentially modelling uncertainties. This means that for producing the contour lines based on the Digital Elevation Model, there is an inherent level of uncertainties, errors or modelling inaccuracies linked to the initial DEM data quality, resolution (pixel size) etc. Moreover, the terrain of Samos may have also change during the last 2500 years and therefore we observe short discrepancies between the elevation values.

Why is not optimal to build a longer tunnel?

Consider that for the tunnel's elongation per 100 m., workers needed 10 days of extra excavations.

Source: https://drive.google.com/file/d/1JnBvbcYSKaMokyNFCEpJ_K7xBwWd7B1/view

Figure 19: Actual North and South entrance of the Efpalinos Tunnel

Consider other explanations

Facilitate the student groups to evaluate their own explanations in the light of alternative explanations, particularly those reflecting scientific understanding. Illustrate examples they can use and give them instructions how to locate them.

Students can repeat the experiment, having already known the entrances coordinates. Can they really succeed to apply the Hero's method with the minimum possible error?

How could we solve this specific problem with the current technological means and support?

https://engineering.stackexchange.com/questions/17045/how-are-tunnels-dug-from-two-endpoints-joined

Reflection

Communicate explanation

Facilitate each student group to reflect on the previous experiences and to produce a report with its findings, presenting and justifying the proposed explanations to the other groups and the teacher.

Provide content which the teacher can use to help the students to get familiarized and to become efficient in scientific writing.

Ask from students to write a short report by incorporating the scope of this Activity (which is the objective?), the data and the tools they used, what methodology (algorithms) and to present their results in the form of maps (images) by reporting their errors and potential difficulties they found.

The report outline could be in the form of:

i) Introduction,
ii) Study area and Data used,
iii) Methodology,
iv) Results and Discussion

Follow-up activities and materials

Describe and direct the user to any follow-up activities or materials that can be used to wrap-up the hands-on activity.

These could include appropriate learning assessment and/or reminder materials (e.g., quizzes, games, other user-friendly tests), hints for further activities etc.

How to identify if students familiarized with contours and elevation models:

https://www.purposegames.com/game/972382ecf2 (Contours game)

https://orienteering-games.vercel.app/game/contour/ (Contours puzzle game)

Sustainable contact

Name & email: **Loukas Katikas (lkatikas@ea.gr)**

References (if any):

Apostol T.M. (2004): The Tunnel of Samos, Engineering & Science;1

How are tunnels dug from two endpoints joined? https://engineering.stackexchange.com/questions/17045/how-are-tunnels-dug-from-two-endpoints-joined

Assessment (if any):