Practical Use of GIS in Cave Exploration

Geographic Information Systems are becoming commonplace and finding application in discovering new cave entrances. ***Atanas Rusev*** *presents examples of using GIS to find new entrances by analysing satellite and orthophoto images.*

As Geographic Information Systems become more popular and useful in different fields of knowledge, it's also valid in finding new cave entrances and exploration. In CREG Journal 106 (Rusev, 2019) we described the main approaches and practical workflows in using GIS in cave exploration and the tools we used for the last 20 years in this respect. We continue the topic here by presenting real cases in finding new cave entrances using analysis of satellite/orthophoto images. This is a practical proof of the methods we now use daily in cave exploration. In recent years, many data, function and representation limitations were solved in the GIS area thanks to the evolution of information, software and mobile technologies. Only five years ago, it was a real challenge to serve, present, and analyse large complex 3D data GIS layers, and now all this is taken for granted even on a simple mobile phone or tablet.

For analysis, we use the most advanced and commercial software available, but this is not a limitation, because there are already many free tools and high-resolution satellite imagery public available to anyone, as well as, for example, historical imagery (Google Earth recently also made them available via the Web). Of course, to find new cave entrances from space requires different conditions and approaches. Furthermore, in local terms, using drones with different sensors, including lidar, thermal, multispectral, photo, etc., can be extremely helpful in finding new cave entrances.

Software and Approaches

For analysis, we mainly use ESRI's ArcGIS line of products, especially ArcGIS Pro and ArcGIS Enterprise. Big data analysis also requires a strong server environment, and we employ a so-called multi-machine deployment for ArcGIS Enterprise, including several ArcGIS servers and ArcGIS Image servers. Further on, all these serve our GIS data to web applications, and we use them on desktops and mobile devices, with different workflows, including offline data acquisition in the field and analysis. In such an environment, we can manage a huge volume of data and serve terabytes of imagery, visible flawlessly even on a basic mobile device, or to fellow cavers knowing nothing about GIS, but experts in cave exploration.

Exploration Area

If using only satellite/orthophoto analysis in search of new cave entrances, we need to choose a limestone area which meets some criteria. This is especially important when using such imagery in the visible spectrum, the area must have minimum vegetation and tree cover. For other data products, as for example lidar, we have already illustrated the possible workflows and use with the Mexico Cave GIS Project in CREGJ 106. Another example with its own criteria for the explored area is using drones with thermal sensors, etc.

In this respect, we chose Ponor mountain in Bulgaria. This area of almost 300km² is located 80km north of the capital Sofia. This is one of the most prospective karst areas in Bulgaria, because of the still undiscovered huge cave system located here, with an estimated length of more than 150km and about 700m in depth.

As a proof of the potential of GIS is the discovery and exploration by the "Pod Ruba" ("Under Edge") Caving Club in the last 15 years in this area, with the exploration of "Kolkina dupka" cave which became the longest and deepest cave in Bulgaria in 2023 (24km, -571m). This huge cave system is also located in Ponor mountain, but its underground rivers and spring are part of the main underground water collector of the huge and still-undiscovered cave.

The Productive Workflow

We started working in the Ponor mountain karst area more than 30 years ago. The area is a remote, huge limestone plateau at about 1600 – 1200m altitude, with numerous sinkholes and karst features. Our exploration strategy included collecting data from the whole area and estimating the most prospective places to dig and penetrate in the huge still undiscovered cave system.

An important exploration note here is that most of the potential entrances to this huge system are severely blocked by collapses and blockages caused by melting during the ice ages.

The only solution to organising this huge amount of data and analyse it further was GIS. We set up a GIS-oriented workflow for collecting data and all our explorations on the surface were presented in the GIS. Also, all possible geo layers for the area,

3D GIS of the exploration area
With dig entrances(blue), cave entrances(green), sinkholes(yellow) and springs(blue)
Basemap: orthophoto 2011

including topo maps, geology maps, orthophotos, satellite imagery, etc. were combined to create the Ponor GIS Exploration project.

To present all these data for further analyses, we serve them via ArcGIS Server (Enterprise) and ArcGIS Image Server technology. We then created 2D and 3D web and mobile applications to exploit these geo services from the ArcGIS servers, and our powerful tool was ready. It was evident from the very beginning that analysing satellite/orthophoto imaging was very promising, because we instantly spotted some unknown and open sinkholes visible from space in a high-resolution imagery. So, from this moment, we began investigating huge satellite/orthophoto data to spot perspective entrances, mark them in the GIS, then navigate and check them in the field before adding to the GIS. Especially fruitful was analysing historical satellite and orthophoto imagery because we can easily determine if we spotted a hole or a bush, for example, or if a sinkhole is open or closed, etc.

Success Stories

Winter BING Cave

Whilst analysing new BING imagery in 2013 with a snow area cover, we spotted a very prospective new entrance, not visible in the other satellite imagery. In the field,

Winter BING: orthophoto imagery of the area in 2009

The area of interest is towards the top centre of these images

we navigated with our mobile devices to our target object, just to find a closed sinkhole. However, it was evident from the satellite image that there was severe airflow from this place in winter, so we investigated further. On the wall of the sinkhole, after some digging, we found out the reason for the airflow: a new cave entrance. After some Hilti capping on the entrance, we succeeded in entering about 25m to a huge blockage and were then stopped there for the moment.

Winter BING: satellite imagery 2010 showing the prospective entrance

Digging at the entrance to Winter BING Cave

Yo-ho-ho Cave

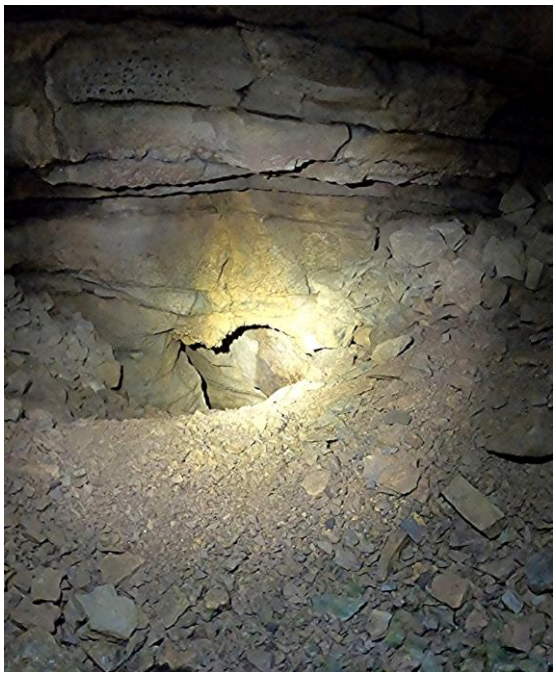
In 2013, after analysing satellite and orthophoto imagery of the very western part of Ponor mountain, near the border

Fossils found in Yo-ho-ho

Sanctuary Cave Entrance

Orthophotos from 2009, 2011 and 2020, showing evidence of digging by treasure hunters

Sanctuary cave entrance



Inside Sanctuary and the Thracian tomb

with Serbia, a prospective zone with several sinkholes was spotted for checking. One member of the club visited the location and reported two very promising entrances at this location. We undertook several digging expeditions, and at the first location, named cave "Hu", we succeeded in entering about 50m to a small underground river. Further on the way was blocked and required severe digging. But then we were attracted to the second entrance, where, after several days of digging, we successfully entered a huge new cave system, named Yo-ho-ho! This unique new cave is full of fossils and its length for the moment reaches 1.5km with a depth of 120m and still going. In the end, we entered a huge underground river collector, but access to it is very limited because of a very narrow meander about 300m long, which needed to be dug out for easier and safer access. Active exploration continues as the prospects are huge.

Sanctuary Cave

In 2020, on high-resolution orthophoto imagery from 2011, we spotted a very promising open cave entrance in a very remote part of the exploration area. The oddity was that on the image, it was clearly visible that the cave had been severely dug out, and most probably with an excavator! Further investigations on historical commercial ortho-photos has shown that this strange activity occurred after 2009 and stopped around 2013. For us it was evident that treasure hunters made all this! Our exploration party included archaeologists, of course, and we discovered a real unique Thracian tomb that had been built in a natural cave. The roof was collapsed, and the treasure hunters had spotted the entrance and tried to enter deeper with digging, but they missed the right direction and dug toward the surface, where the entrance to the tomb lays. A GPR (ground penetration radar) investigation of this area has shown other possible remains and features from Thracian times and shows the presence of a whole unique ancient complex at a very high altitude, still hidden underground. We report this information here for the first time.

Wild Horses Cave

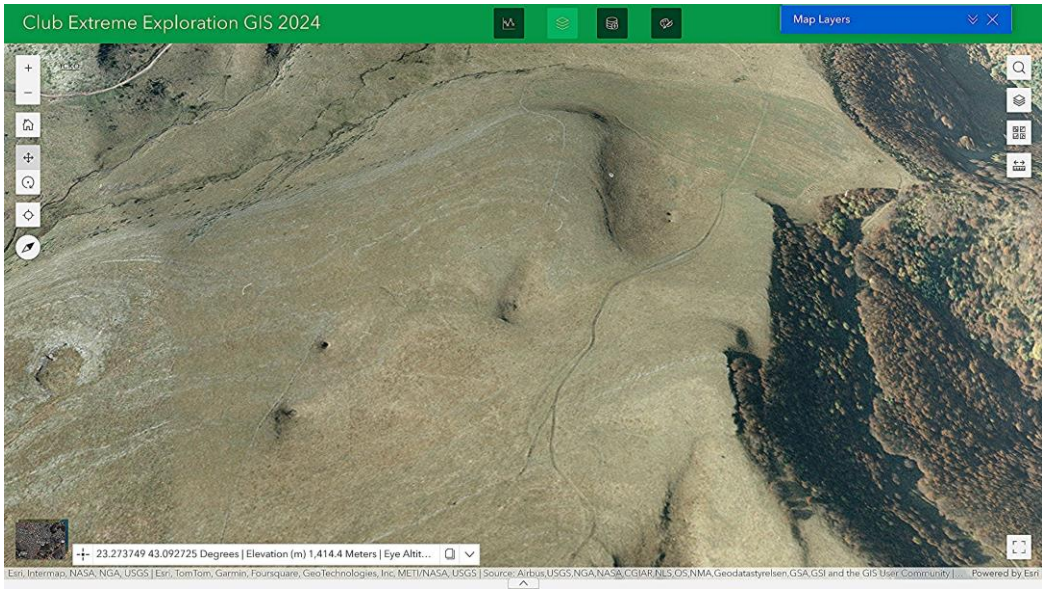
In 2020, on a bare hill, not visible from anywhere, we spotted an open entrance on a high-resolution satellite image, located in the northern part of the exploration area. On the spot, there was a cave entrance some 3×3m wide and about 8m deep. The cave was filled with animal bones and was home to a wildcat (or lynx). We explored about 50m in length and about 20m in depth. The cave is actually a big collapse on the roof of a very big cave room. There is steady air flow from the depths, but we are still trying to penetrate through the severe and dangerous collapse. Inside, we found that the cave had been visited once before us, again by the treasure hunters some 50 years ago, because we found five empty beer bottles from that time and their digging traces again in the wrong direction. This cave is really interesting because it is located at a high altitude of 1500m and shows the presence of big cave rooms near the surface that have been missed for now

Wild Horses entrance on orthophoto, the entrance and inside the cave

in the lower parts of the limestone area, where active surface rivers sink underground at about 1300m altitude.

Current Explorations

As this article is written, we still have zones that we visit because of new entrances spotted from space. There are about 300 points of interest in this huge limestone area and still about 50 unexplored that deserve our attention. Regular monitoring of new and historical satellite/orthophoto imagery is important because very often some entrances are closed and other appears as open on the map, because of many factors: collapses, floods, etc. This is a dynamic process, and we follow it.



Areas spotted from space imagery with cave entrances, still not checked.

Future GIS Explorations

GIS is a very robust tool to find out new cave entrances. It requires a lot of expert knowledge and resources to build the software environment and use it, but once it's done, the whole GIS environment serves everyone equally, from novices to experts. Furthermore, the flawless presentation of large and very complex GIS data in 2D or 3D in a speleological context helps immensely in exploration. Here we have described some analyses based only on satellite/orthophoto imagery in the visible spectrum, but using drones and different sensors (such as lidar, thermal, multi-spectral, etc.) locally can help explorations further. As technology and science evolve, we stay tuned to the latest possible tools in our search and exploration of huge still undiscovered cave systems.

Reference

Rusev, Atanas (2019) *The Role of GIS in Finding New Caves*, CREGJ **106**, pp 20-22.