WILLIAM MORRIS DAVIS
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KARST IN URBAN AREAS

CARST EM ÁREAS URBANAS

KARST EN ZONE URBAINE

PHILIP VAN BEYNEN[1]
VANDA CLAUDINO-SALES[2]
SAULO ROBERTO DE OLIVEIRA VITAL[3]
DIEGO NUNES VALADARES[4]

[1] Professor at the School of Geosciences, University of South Florida - USF
Email: vanbeyne@usf.edu. ORCID: https://orcid.org/ 0000-0002-8644-3958

[2]Professor at the Academic Master in Geography, State University of Acarau Valley – UVA
Email: vcs@ufc.br. ORCID: https://orcid.org/0000-0002-9252-0729

[3]Professor at the Department of Geography of the Federal University of Paraiba - UFPB
Email: saulo.vital@academico.ufpb.br. ORCID: https://orcid.org/0000-0002-2028-0033

[4]Master's Student on Geography at the Federal University of Rio Grande do Norte - UFRN
Email: diego_nunes_valadares@hotmail.com. ORCID: https://orcid.org/0000-0002-4333-4938

In its third edition, the "William Morris Davis – Journal of Geomorphology" presents its second interview with geographers, to head the "Interviews" section, which opens each published issue. This time, it is the first international interview, carried out with Professor Philip van Beynen, from the University of South Florida, in the United States. Professor Philip van Beynen was interviewed on the topic "Karst in Urban Areas", and brings important data on the subject, with beautiful illustrations and with examples from all over the world. The interview took place on September 17, 2020, with the participation of Vanda de Claudino-Sales (Professor of the Academic Master in Geography at the State University of Vale do Acarau-UVA) and Saulo Roberto Oliveira Vital (Professor of the Department of Geography and the Post-Graduate Program in Geography at the Federal University of Paraiba - UFPB), and was transcribed by Diego Nunes Valadares, master's student on Geography at the Federal University of Rio Grande do Norte.

Professor van Beynen was born in New Zealand, where he received his degree in Geography at the University of Auckland. He earned a master's degree from the same university, and a doctorate and post-doctorate from McMaster University, Canada. He has been a professor at the School of Geoscience at the University of South Florida since 2009, where he has been developing research related to different components of karst environments. The interview shows his great expertise on the subject, and is very much worth to be read and seen even for those who are not specialists in karst.

ENTREVISTA

Vanda Claudino Sales: Tell us a little bit about your professional trajectory in your graduate studies, the moment when you became interested in karst and your main current approaches. The Brazilian public would like to know more about you and your research, please!

Philip van Beynen: I'm from New Zealand and got a master's degree at the University of Auckland with a professor called Dr. Paul Williams – for those interested in Karst, his name may sound familiar. After that, I moved to Canada to get a doctor's degree with Dr. Derek Ford. After that, I spent two years at McMaster University on a post-doctoral fellowship.

At the University of Auckland, I was shown glowing stalagmites by Dr. Paul Williams, which I did not know was possible. He explained to me that there are different colors coming from stalagmites and then I got interested in why they glow and their relationship with the climate change. That got me into the whole of paleoclimatology, looking into climate change through the stalagmite luminescence, what it could indicate regarding the climate. For this reason, I moved to Canada to continue my research on this topic, but then I began to look at stable isotopes by oxygen and carbon isotopes in the same stalagmites. After my studies, I moved to Connecticut, United States, to study about isotopes in rainfall and cave waters to check the connection between them. Then I moved to Florida, since it is one of the few places in the United States that is entirely made up of Karst. There I spent my research on karst not just looking at climate change from the past but also how humans interact with their urban environments deal with karst. I did so by looking at disturbance, groundwater contamination and modeling, and how they could sustainably work with their environment.

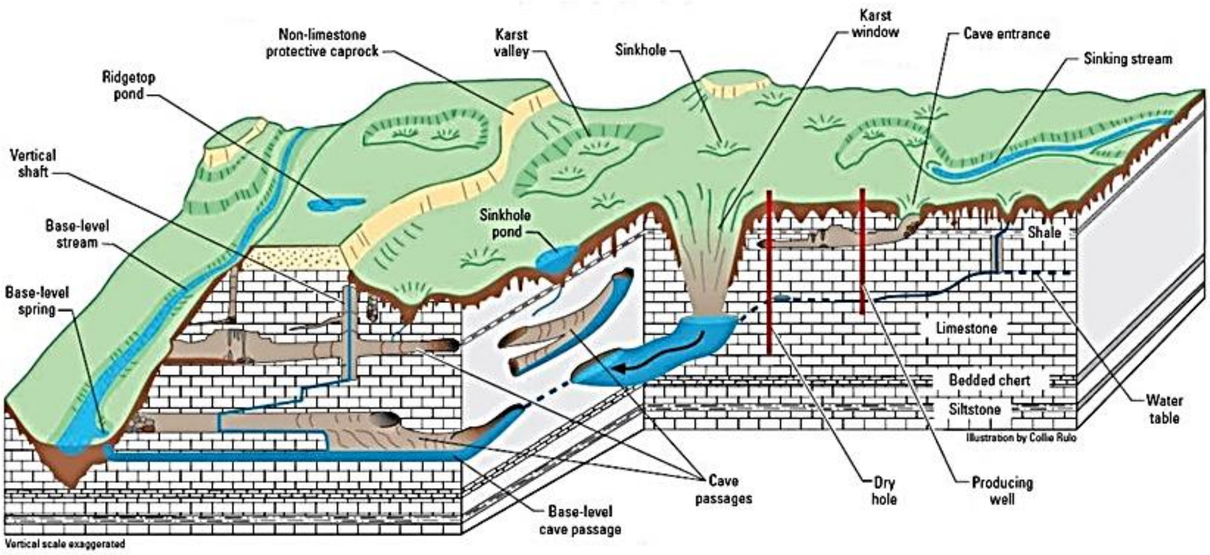
Saulo Roberto de Oliveira Vital: In a conceptual idea, what is karst?

PvB: If you look at the first slide, it shows how people actually live in the karst environments. In the background you can see towers, where limestone was left behind when rocks started dissolving. This picture of Quilin City in China (Fig. 1) clearly portrays how people live in such an environment. Not that I have been there but I chose it because so many people live on Karst. So, if you move on to the next slide, it gives an idea of all the different components of Karst (Fig. 2). When I think about it, I like to think what is not there, so we are thinking about limestone and dolomite as two combined rocks that have dissolved in interaction with the acidic rain water, which slightly acid and then moves through the soil. The amount of carbonic acid increases making the water to be much more acidic which then interacts with these carbonate rocks. At the surface, it creates a lot of different types of land forms, such as that karst tower in the background in that first slide. There are also sinkholes shown in the right top part of this diagram, and then as that water percolates down from fractions, fissures and bedding plains, this does more dissolution enlarging these places where water can flow through quickly, but also the creation of caves. The water can eventually come out at the surface in springs.

Figure 1 - Guilin City, Guangxi, China.

Source: Wikimedia Commons.

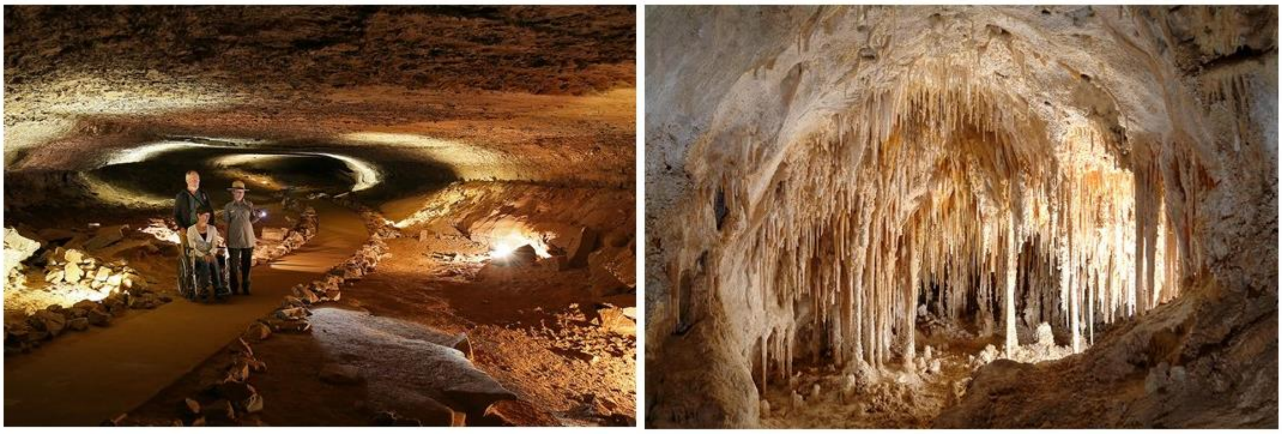
Figure 2 - Common features of a karst landscape.



Source: USGS public domain.

Obviously, one of the things that people think about when it comes to Karst is caves. Mammoth Cave, Kentucky, USA (the longest in the world) and Carlsbad Caverns, New Mexico, USA, are one of the most important caves in the United States (Fig. 3). You can see in the pictures, the spatial features, the stalactites on the ceiling, stalagmites coming out of the ground, flowstones which are the slopes made of calcium carbonate.

Figure 3 - Left) Mammoth Cave, Kentucky, USA; Right) Carlsbad Caverns, New Mexico, USA.



Source: US National Parks Service, public domain.

Springs are extremely important, especially here in Florida, where you can really see the Karst that we have. Obviously, when the groundwater intersects with the surface of the limestone, where the water comes out, this creates the springs. You can see divers going down into the spring on the left. On the right you see the Krka National Park in Croatia (Fig. 4). Actually, springs at this site deposit calcium carbonate in the form of dams. There are multiple dams created by the springs along the river.

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Figure 4 - Left) Ginnie Springs, Florida, courtesy Jill Heinerth; Right) Krka National Park, Croatia.

Source: John Maxwell, public domain.

We talked about the underground caves, the interaction between the subsurface and the surface with springs, and of course, we have got these surface landforms. Here you can see some extremely dramatic surface landforms in Guilin, a province in China. These are the old landforms and on the left you can see the Arch (Fig. 5). The Arch was created by a river that eroded the bedrock, probably a river cave at some stage. In the middle image is the Li River with karst towers in the background (Fig. 5). Actually, the towers can be produced by the river running along their sides. One of the most famous places with surface karst is the Stone Forest in China, where the soil has eroded away the surface limestone and created these beautiful limestone pinnacles (Fig 5).

Figure 5 - Left) Wulong Karst National Geology Park, Chongqing Municipality, China, Courtsey Derek Ford; Middle) Li River Guangxi Province, China, Charlie Fong. Public Domain; Right) Stone Forest National Park, Yunnan Province, China.

Source: Courtesy Derek Ford.

Dolines, which is a term used around the world, are called sinkholes in the United States. In sinkholes there is the dissolution of rock beneath the surface and then eventually the surface is no longer supported because of the erosion of the rock beneath it. Therefore, it collapses into that void in the rock. One of the largest sinkholes in the world is Xiaozhai Tiankeng, China (Fig. 6). Cenotes are Mexico's version of sinkholes, where it is possible to access groundwater (Fig. 6). Sinkholes can be great in size and may be one of the biggest problems when it comes to urban hazards.

Figure 6 - Left) Xiaozhai Tiankeng, China, source: Wikimedia Commons/Public Domain; Right) Gran Cenote, Quintana Roo, Mexico.

Source: Ken Thomas, Public Domain.

Figure 7 - Examples of species adapted to cave environments in Alabama, United States. Left) Southern Cave Crayfish; Right) Alabama Cavefish.

Source: Courtesy Matthew Miller.

The final thing I would like to say about Karst is that there is a very specialized biota (Fig. 7). The image shows organisms like the crayfish which has no color because they have been underground for a long time, losing their pigments in the skin or in the skeletons. The other biota shown is a cave fish from the southern USA.

The next slide shows some perspective of Karst locations around the world (Fig. 8). I think what stands out is that it seems to be concentrated in the South East Asia– in the central part of the Eurasian continent – in the South-Eastern United States and in Northern Canada. The thing you noticed is that there is very little in Africa and in South America. In fact, one of the only places with the presence of Karst is in Western Brazil, but you notice how little Karst is in South America.

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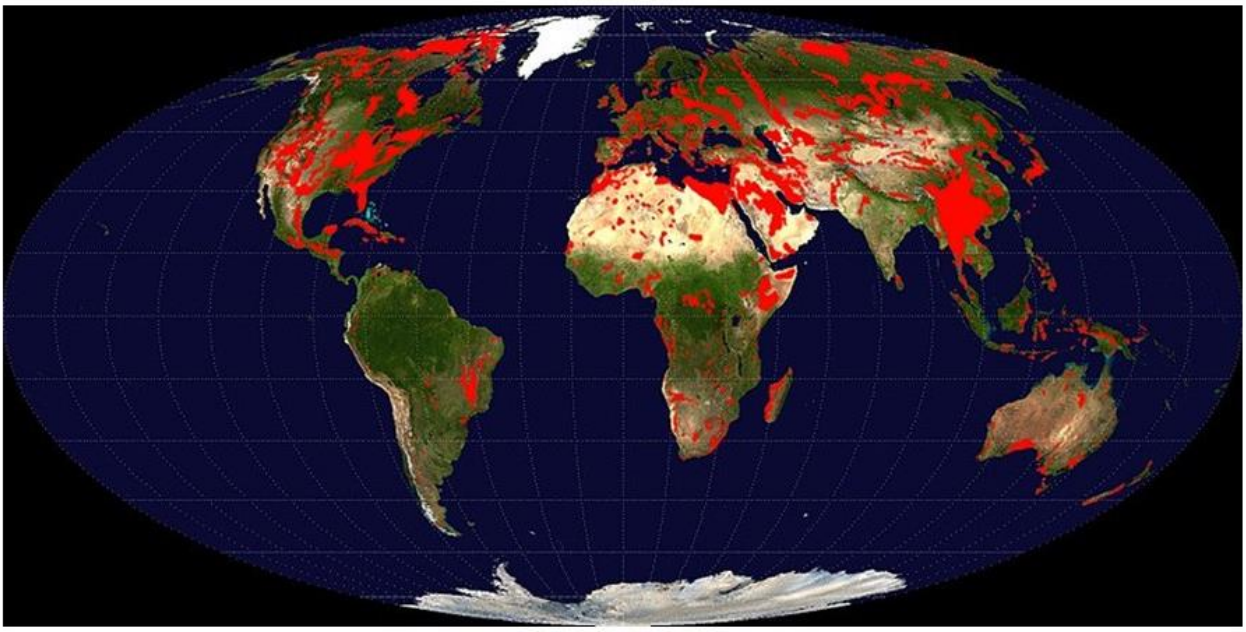
Figure 8 - Global distribution of Karst.



Source: Wikimedia Commons, author Ulrichstill, wiki@ulrich-tichy.de.

The other thing that I want to point out is that it covers around 20% of the Earth surface. It should be mentioned that Karst aquifers can provide a large amount of water (drinkable water) to humans.

VCS: What is the importance of this kind of environment for the studies in geoscience?

PvB: I think the first thing we should mention is the extremely fragile unique environment. When I say its fragile, what I mean is that it can be easily disturbed and impacted by human interaction with that environment, especially when you compare it to other types of geological environments. The reason I mention this is because when we think about geoscience, one of the things we are interested is hydrogeology and, when we think about it, we are looking at things like water flow, contamination of the water. As I mentioned in previous slides, the Karst aquifers are so important to provide drinkable water for some parts of the world. So, hydrogeology allows us to understand how we may impact that water by looking at how it flows in Karst. There are big conduits that have been dissolved by the aggressive acidic water passing through it, making the water flow quickly. Thus, if the water is contaminated, it can go from one place to another one faster than water with sandstone, granite or other materials that do not dissolve easily.

When you look the type of research I do, geomorphology studies regarding paleoclimates, Karst provides this great environment when it comes to looking at the isotopes of stalagmites. It provides climate records from hundreds of thousands of years ago from different parts of the world. Then you have geophysics and morphology when you study speleogenesis, which is the formation of caves dealing with denudation rates – how quickly the Karst environment is being eroded over thousands of years. There is also the sinkhole formation, which we are going to talk about later, by the geophysics and geoscience and are important in that studies too.

Importance of Karst to humans

When we think about Karst as physical geographers or geoscientists, we tend to think a lot about just the physical environment. However, people have been interacting with Karst for thousands of years and we can think about people who have used it for building materials. Here you see the Acropolis in Greece, Roman aqueducts and the Maya temple in Belize (Fig. 9). The reason I put these images is because there are so many others subjects that are interested in Karst environments such as anthropology. Why anthropology would be studying the Maya culture? It could be people looking at religious practices in Karst environments. You can look at the history of human society when we look at the Greek or Roman civilizations, to whom the Karst environment was important for the development of theses societies. Of course, there are the biologists, who got interested in speleology when I showed those diagrams of fish, crayfish and the difference in their evolutionary processes. The interest of the people that are not geoscientists is the reason why I want to put these slides, to give you some idea the extent of research in karst.

Figure 9 - Left) Acropolis, Athens, Greece, Source: Kevin Casper Public Domain; Middle) Roman Aqueduct at Segovia, source: Public Domain; Right) Mayan Temple, Belize

Source: Courtesy Philip van Beynen.

SROV: Regarding the occurrence of Karst in urban areas, what are the main repercussions of the appropriation of this environment by humans?

PvB: We talked about the impact of people interacting with Karst. We can go back thousands of years ago when people lived in the caves. Today, with urban environments, you have the destruction of caves by infilling. The influence of sinkhole that was mentioned above, if you are creating a building and a sinkhole appears under that building, you will need fill in that void. In Tampa, for example, a highway was being built and one of the supports collapsed fifteen meters down into a sinkhole. This is one of the problems we may face. But also, if you are building in urban environments, you obviously use limestone for building roads. Obviously, it is necessary to feed the population of urban areas, that is why we do agriculture, like rice agriculture in China. If the population is bigger, you use caves for tourism as you can see in Postojna Cave, Slovenia, which has a train going through it (Fig. 10).

Figure 10 - Train ride in Postojna Cave, Slovenia.

Source: Wikimedia Commons.

Also, we need water and if population is big in the Karst area, most of the water will be from the groundwater and not from the surface. The reason for this is that the limestone dissolves away so quickly that the water does not sit on the surface. You do not find many rivers in Karst areas because they are underground, and that is why you have these types of impacts from removing the water. So, this is the impact people have on Karst areas.

There are two ways we can look at it. One is that water can flow so quickly through Karst environments so that if we pollute the groundwater, the pollution can disperse extremely quickly throughout the environment. Water can move hundreds of meters or kilometers in a single day, it means that the contamination that occurred maybe is extremely difficult to clean it up because it was used for humans. So, we have water-borne diseases from human and animal waste. Also, we have chemical pollution and spills, which are a problem when released to the Karst groundwater. Second, regarding water storage, if we remove too much water from the ground, this overexploitation can lead to problems, which we are going to talk about in a little bit, but if you are removing water from the ground, this can lead to the development of sinkholes in an area.

VCS: What are the main disasters associated with Karst in urban areas?

PvB: Building of large structures increases the weight when there is a gap under the ground and, if you remove the water, you remove the buoyancy support. It means that there is not anything to hold up that ceiling or roof of the void anymore. So that means ceiling will collapses into the void producing a collapse sinkhole. This was the cause for the 1983 collapse sinkhole in Winter Park, Florida, USA (Fig 11). Another example is the famous museum of sports cars in Kentucky-USA (Fig. 11). A sinkhole occurred in the middle of the night (luckily) right in the middle of the museum, leading to millions of dollars of damage. So, sinkholes are quite common in urban Karst areas. Most of the time people notice sinkholes occurring slowly, so they have time to get out. But sometimes that can be abrupt.

I have talked about the use of groundwater pollution and the town of Walkerton – a small urban area in Ontario, Canada, is a good example. The town got water from the ground and it was sitting above a dolomite bedrock. The wells that provided water were actually in an area outside of the town.
It was concluded that there was E-coli bacteria in the water derived from the animal waste. Six people died and around two thousand people were hospitalized from contamination from pollution in the groundwater. Water contamination is one of the biggest issues in Karst environments, but also sinkholes caused by groundwater exploitation. So, these are the two ways that I would say at the most prominent issues in urban areas.

Figure 11 - Left) Winter Park Doline, Florida: source: Anthony Navoy, USGS. Public domain; Right) Doline collapse under Corvette Museum, Kentucky, USA

Source: Courtesy Jason Polk.

SROV: About your perception related to international studies about Karst, are they enough?

PvB: If we go back to 1950s, 60s, 70s and even 80s, there were probably very few on studies about hazards in Karst. But in the last decades, especially in southern Europe, Mediterranean and in the Southern part of the United States, it has been increasing the interest on Karst. As you can imagine, a lot of Karst are in the Southern part of Europe and sinkhole development and water contamination are issues there, that is where a lot of research has been done on modeling of water pollution. There have been a lot of models created looking at the complexity of Karst. And when I talk about the complexity of Karst, what I mean is that it is not just simple environments such as sand aquifer, they are places where the water moves very quickly and places where moves slowly. So, imagine if we have a solid rock, water moves slowly through that, dissolving bedding plains, faults, and caves, moving extremely quickly through that.

So, people have been trying to model that to get some notion of how pollution can move through the urban environment. Recently, the number of researches has been increasing greatly in China. China has probably the highest number of Karst academics in the world. Any place in the world has a very large institute of Karst studies. I think there is a hundred scientists just in this one institute. So, a lot of work has been started in the last decade or so on hazards in Southeast Asia because of that. So, in the past there were few studies, but I think things really started to change in the last few decades, purely because people need water and there is a lot more contamination occurring in places like Asia. So, I think definitely that it changed with the advent of these new models that have been happening, the greater knowledge, and use of geophysics techniques. As science has advanced, then the number of studies also advances in different parts of the world.

SROV: Bringing a situation that happens in Brazil. In the specific case of Brazil, we have an underline Karst occurring in the urban area in the Paraíba sedimentary cretaceous basin located in Northeast of Brazil. It is an area made by calcareous cretaceous limestone covered by tertiary Neogene sediments. What could you say about studies that could be conducted in this area to better understand the evolution of its Karsts? Are geophysics methods, for example, important?

PvB: Well we can start with this idea of evolution, I guess if you are talking about evolution, then you are talking about processes that have occurred over hundreds of thousands or millions of years, but if you are looking at it today, one of the things I know sinkholes are important in this area. So, if you are interested in maybe the evolution of Karst, you can look at where the dolines are, why they are actually there? Why are there dolines? One of the things you can do is a geomorphic analysis. You look at the location of the sinkhole, relate them to where the fractures or lineaments in bedrock and it can reveal how important the underlining geology is, the development time and the evolution of these surface features such as dolines or sinkholes. Here in Florida, we have a similar situation, where we have underlining Karst and clay sands to overburden and, what happens, as you can see, are sinkholes forming along fractions and in the bedrock. Therefore, if you are looking for the evolution of Karst as these fractures get larger with water percolates through the mantle or overburden, you may see more and more of those sinkholes forming.

As far the hydrologic analysis goes, if we talk about evolution, we talk about changes in landscape itself. The denudation rates reveal how quickly is the surface of the Karst is dissolving and how quickly it is changing and one of the things you can do there is to look at the constituents, the chemical that there are in the water. So, if you look at Calcium, Magnesium and other types of chemicals in the water, you can see how much rock have been dissolved between the inputs and the outputs. So, that is one way to look at the evolution of the rock.

As far as the geophysical techniques you can do borehole analysis where you can drill down into the rock and tell you about the properties of the rock such as how porous it is. That can be impacted by the age of the rock. Rocks that are very porous tends to be less compressed, which means they tend to be younger. Or you can see how quickly the water can flow through the rock between two boreholes. It can reveal how fast the water will flow and, of course, the faster the water flows, more will be the impacts on the physical environment too.

Another type of geophysical technique is the Electrical Resistivity Tomography (ETR). The ETR sends electrical currents from one electrode to another electrode and that will tell you information about bedrocks, for example, if there are voids between the electrodes or solid rock, then the rock is saturated with water or if it has clay in the voids. Those are the types of things you can look at through geophysics. But there are also other techniques that you want to use in conjunction with techniques such as the borehole or electro-resistivity analyses, such as the Ground Penetration Radar (GPR), micro-gravity, or seismic studies. All of them can tell you about what is below the ground, if there are voids and if the freshwater or saline water. If there is saline water, then it may have connections with the coast water and further inland. So those are some of the things you can do when looking at evolution of the environments and how can you incorporate geophysical techniques.

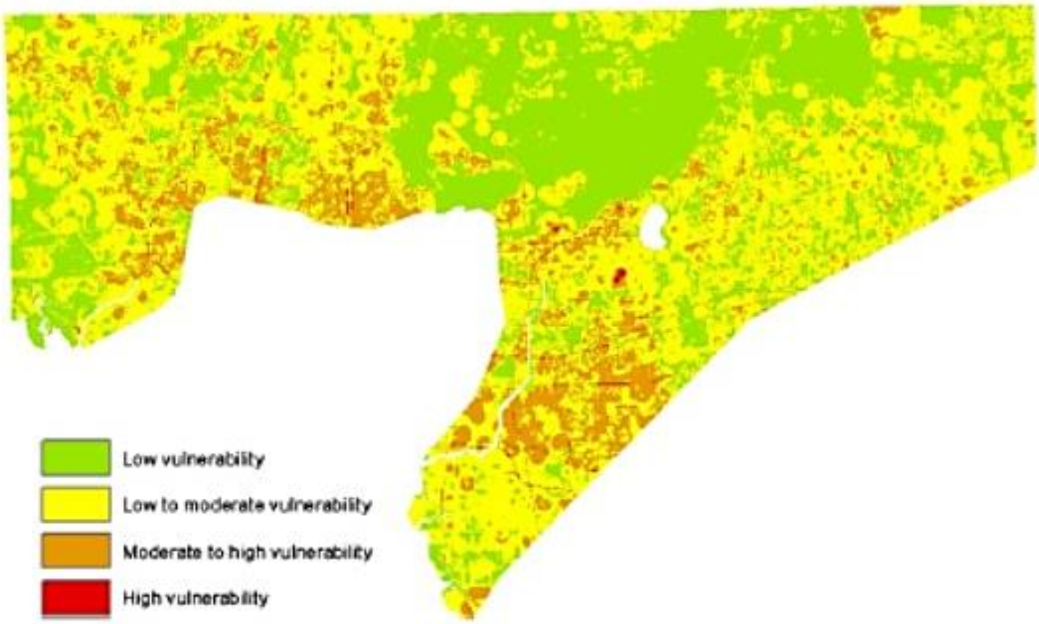
VCS: Can you mention some studies carried out about karst in urban areas of Florida?

PvB: I will start with couple of studies that I have done, because actually there haven't been many studies done in Florida, so when I came to Florida in 2003, not a lot of work existed on urban environments. There are two things that I would mention, the first that I created is Karst Disturbance Index, and what I was interested in is how people impact the Karst environment, especially in urban areas because there was no systematic way of actually measure the impacts if you look at changes over time or some aspects of the Karst environment. Then I created different categories of looking at the Karst environment such as geomorphology, atmosphere, hydrology, and biota. These different categories had some attributes that would be things such as surface land forms, soils, subsurface Karst, water quality and quantity. What we did was create a system that we could actually rate the amount of disturbance in the urban environment for these different attributes within these different categories and then you would end it up with overall score, which gives you indication of just how impacted the environment is. The close you are to zero, the less impacted the environment is. The close you are to 3, the more impacted the environment is.

So, creating this kind of scoring scale allows you to systematically measure how people impact their environment. We first applied it in Tampa Bay, Florida, and then the index has been applied in many parts of the world over the last 15 years. Another thing that I noticed in the Tampa Bay area is that we have a lot of sinkholes, which are considered windows to the aquifer. If there is pollution in sinkhole areas, that groundwater gets contaminated quite easily. So, there are different models out there that measured the contamination flow within in a bedrock geology. However, most of them do not look at Karst environments, maybe one handful, but none included people living on environment. And how do you have contamination if there are no people? Therefore, I want to combine human land use with the physical environment and that lead to the Karst Aquifer Vulnerability Index (Fig. 12). Here you can see the colors, the light green is where you have very low vulnerability and the bright red is where you have very high vulnerability. All those great dots are actually sinkholes that interact with the urban environment. So, we brought in things such as the depth to water table, soil permeability, we look at hydrology connectivity, the epikarst which is the sinkholes on the surface. Also, the land use is the different thing that we look at to try to quantify or show where the groundwater would be most vulnerable to human impact.

The other study has been done over many decades. This is very close to the University of South Florida where I work, in a place called Sulphur Springs Watershed because the water contains a slightly sulphurish smell. You can see these 3 images here (Fig. 13). The top of the watershed is called Blue Sink, it is actually a number of five different sinkholes. But this is the last one in this chain of sinkholes. This is the way where water sinks into the ground or used to sink into the ground, but over decades, garbage, clay and other materials has sunk into the bottom of the sinkhole clogged it up. They have managed to unplug it at some point but there is still a very slow flow. This is the headwaters, the top of the watershed, then there are multiples sinkholes between the inputs (Blue Sink) and the output (Sulphur Springs). This is a very poor urban zone in Tampa, and you can see that there is a lot of garbage floating in the sinkhole (Fig. 13). It is an extremely polluted environment, and the sinkholes are connected to the groundwater that comes out at Sulphur Springs. The picture you see on the right (Fig. 13) is the spring itself. It used to be a tourist attraction and people would come all the way from New York to swim in this spring. There are hotels around it. However, you can see in the picture above a lot of pollution going into the groundwater, so the spring became so polluted that is not safe to swim in it anymore. They closed down the springs for swimming and built a swimming pool right beside it.

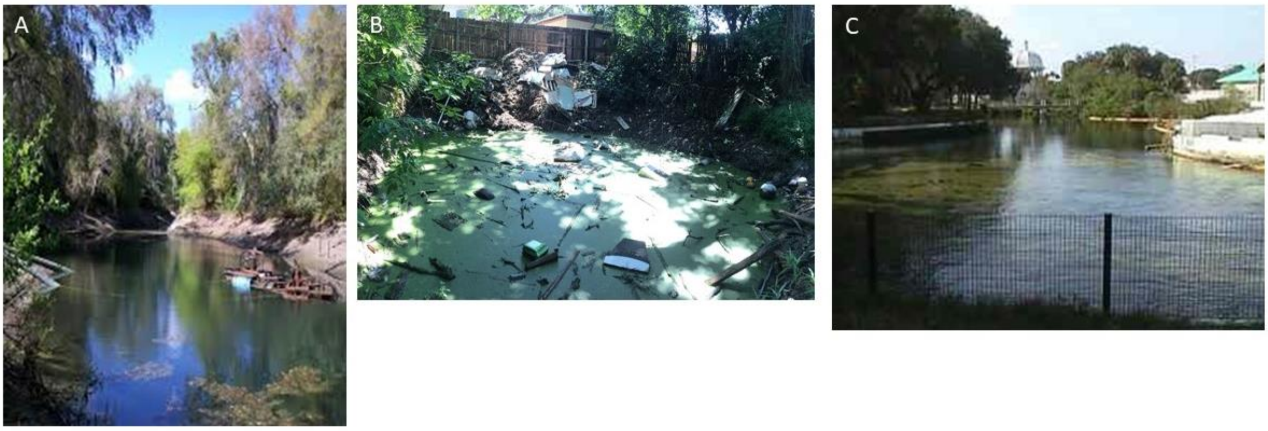
Figure 12 - Karst Aquifer Vulnerability Index.



Source: Courtesy Philip van Beynen.

The other reason I would like to mention the springs is because they are taking water from Blue Sink and there is a pipe that goes all the way to Sulphur Springs which is then pumped to a close river, so they can keep the water high enough in the river for animals move around in the river without the water being too low that it negatively impacts the wildlife. These are the most recent studies carried out in this area using water from the system to augment the water in the nearby river.

Figure 13 - Sulphur Springs Watershed Tampa, Florida. A) Blue Sink, B) Alaska Sink, C) Sulphur Springs. Courtsey Philip van Beynen.



Source: Courtesy Philip van Beynen.

SROV: I saw the pictures about sinkholes in urban areas and want to know if artificial pipes for sewage and water in the city have the potential to produce sinkholes, if there is any rupture or even in the normal operation, if the artificial pipes play any roles in produce sinkholes in urban areas.

PvB: Yes, there are different types of sinkholes that can be formed. One is the very dramatic ones where big collapse occurs. However, we also have one linked to pipes, and the important thing is the leaking the pipes allows water to leave out of them, washing away some of the sediments into the underground cavities. The sinkholes created by these big pipes that provide drinkable water to people, are called subsistence sinkholes. The fine sediment that is washed away by water percolation, a process called raveling. This can also lead to building cracking and houses slowly tilting on their foundations. So yes, it is possible.

SROV: Are dolines indicator of live karst?

PvB: As the Karst evolves and conduits get larger and larger over the time as the water moves through the bedrock dissolving it away, then there will be an enlargement of those cavities and over time it gets to a point that the ceiling of those voids can no longer support what is above it. So, the evolution of such cavities maybe happening over hundreds of thousands or millions of years but may have got to a point that even though little dissolution occurs, the sinkholes can still form today. So, the process has been going on for hundreds of thousands or millions of years, but the collapse occurs when there are people living in that environment. So, it may be Paleokarst in a way because it is a very old feature but it is still being developed as the water flows through it.

I know that in the coastal areas, during glacial periods of sea level drops, then when it goes to inter glacial the sea level rises again. This means those caves may suddenly became abandoned because there is no water anymore, but when the sea level rises again filling them up again, this process continues over millions of years. When the dissolution occurs in these conduits and the sea level drops there is no dissolution, but when sea level rises again the dissolution continues. We get to a point when the collapses of the ceiling may occur creating dolines. There is a connection to what has been happening on hundreds or thousands or millions of years, but we see its results today. So it is a paleoenvironment that has been reactivated when you have changes in the sea levels leading to the continuation of that dissolution.

VCS: I would like to know your opinion on karst features in other rocks (granite, sandstone) and limestone. Are they pseudo-Karsts or there is another terminology?

PvB: Pseudo-Karst is a term we can definitely use. But there is another term, for example, when you have lava tubes (vulcanokarst) or you can have thermokarst which is the melting of permafrost creating sinkhole-like features. This is a good terminology that can be used for environments without limestone.

SROV: What are the biggest challenges regarding the future environmental scenario related to the fragility of Karst and urban and environmental planning?

PvB: The biggest challenge I would say is education. In Florida we have twenty million people living on top of Karst and I would say maybe a thousand people know what it is. Therefore, people do not understand that what they do and how they can impact their environment. So, the aim is educating the people to know the activities that directly impact their environment. If you throw nasty chemicals into the sinkholes, that could end up impacting other people and maybe the organisms living in those areas. When it comes to environmental planning, it is not only the people that need to be educated but also the planners.

For example, a large road was built right beside the sinkholes. It is not a very good idea because if big trucks with chemicals driving along this road crash, the chemical can go to the sinkholes and penetrate to the groundwater. Therefore we must educate politicians, managers and planners about how our activities can impact our environment.
SROV: The situation of buildings that have been cracking and sinking looks like a war scenario. Does the extraction of salt-gem cause dolines or it is related to other processes?

PvB: Yes, it does, but the dolines resulting from this mining produce are much larger, shallower dolines.

VCS: We arrived to the end of our activity! We thank you very much for this interview, Professor van Beynen.

SROV: Thank you very much for the interview, it was just great.

Available at: https://www.youtube.com/watch?v=uC9CFdjOzjo