Quantitative Assessment of the Potential for Karst Features to Lead to Caves in a Topographically Subdued Karst Landscape

George VENI
George Veni & Associates, 11304 Candle Park, San Antonio, Texas 78249-4421 USA

Abstract

The environmental impacts of urban developments in topographically subdued karst areas are often difficult to predict. The small karst features typical of such areas are seldom visible on aerial photographs and topographic maps and are hard to find and assess in the field. Carefully designed grid searches are needed to find the features. At least some excavation is critical to accurately describe them. If local karst development is adequately understood, a model can be developed to quantitatively assess the descriptions of the karst features and accurately estimate their potential to lead to caves, which are the sites of highest hydrologic significance and environmental vulnerability. This information can be applied to guide urban development away from the most sensitive areas. However, we must keep the perspective that karst areas as a whole are vulnerable, and karst features represent only the most visible and sensitive features within a highly sensitive and permeable terrain.

Introduction

As urban areas increasingly encroach on karst terrains, there is greater need for the assessment of their likely impacts on water quality and quantity and on subterranean karst ecosystems. Dye tracing is one long-used and effective method of determining which wells and springs may receive contaminants from potential urban developments. Geophysical techniques can be used to determine the likely presence or absence of caves in certain locations. Doerfliger and Zwhalen (1997) developed the EPIK method to assess hydrologically vulnerable areas in karst spring drainage basins through the use of air photo interpretation, tracer tests, geophysical data, and geomorphological mapping. In 1999, Veni proposed an evaluation strategy using only geomorphic observations for karst areas where tracer and geophysical tests, that other assessment methods rely upon, are not available or not feasible within the scope of a particular study.

In the United States, Texas is one place where karst areas are primarily assessed by locating karst features and evaluating them solely on their morphology. Tracer and geophysical tests are rarely performed since they are not mandated by state water protection regulations, and few businesses or agencies will fund any research methods not required by law. The difficulties in assessing such areas is increased in Texas by the presence of a topographically subdued karst landscape, where high permeability features that often lead to hydrologically and biologically significant caves have little or no expression on the land surface. The purpose of this paper is to describe a quantitative method proven effective in studying such areas in Texas and which may prove useful elsewhere. Some specific aspects of this method will not directly apply to other karst areas, and will need adjustment according to the local hydrogeologic setting.

Collecting Field Data

Topographic maps and aerial photographs are of limited value in assessing subdued karst terrains. They should be examined, but karst features are generally too small or shallow to appear. Their primary value is in locating relatively large geologic features, like fractures, folds, and geologic contacts, and in reflecting the overall hydrologic setting.

Small karst features are best found by conducting an intensive grid search of the study area. Typically, a team of 3-5 people, spaced about 15 m apart, walks perpendicularly from a linear landmark (such as a road or fenceline) or along a compass direction to a defined destination. The outer edge of the transect is marked with biodegradable flagging (i.e. toilet paper), so that upon reaching the end of the transect, the team shifts to that side, uses the flagging as a guide, and walks back in the opposite direction searching the adjacent area. This technique discovers most karst features within an area, although some small features with little surface expression may still be missed. The 15-m-spacing could be changed if warranted by local conditions, but it is effective for most topographically subdued terrains. Wider spacing usually misses too many features, and narrower spacing significantly increases search costs for generally little additional information. Any discovered features are marked with metal tags and long strips of brightly colored plastic flagging tape; their identification numbers are then engraved on the tags and marked in waterproof ink on the tape. Each feature's location is marked on a topographic map and its Universal Transverse Mercator coordinates are recorded from a GPS unit, including the estimated position error.

Upon discovery, each feature is sketched and described on a form that requests the following information:

- Lithology
- fractures and attitude of bedding
- size and depth
- airflow
- cavernicolous fauna
- size of recharge area
- type of recharge (steam, floodplain, sheetflow, etc.)
- type and permeability of sediment fill
- feature type

The date, survey team, and other information are also recorded, and the feature is photographed. Once a karst feature is recorded, a reconnaissance excavation is often conducted. These excavations are critical in evaluations of topographically subdued karst areas. An average of 5-10 minutes of hand excavation can distinguish small but actual karst features from non-karst depressions such as old weathered stump holes, animal burrows, and latrine pits. A metal rod should also be used to probe into the soil of karst features in search of shallow voids and to quickly and further estimate the features' origins and permeabilities with minimal additional effort or disturbance. Excavations should not be conducted if a site seems likely to contain cultural or paleontologically significant materials, and should immediately cease if such materials are encountered and not resume until a specialist evaluates the site.

When open caves are found, they should be explored briefly, but sufficiently to describe their general character. Whenever possible, the caves should be revisited and surveyed, not only for their length, depth, and layout, but to include descriptions and measurements of hydrogeologic features including strata, fractures, flow features (including but not limited to scallops, pitting, ponding, and enlarged bedding planes and fractures), sediments, speleothems, bone distribution, water flow, air flow, air quality, and resolution features. If the scope of the study allows, dye tracing is generally encouraged. In some cases, certain karst features may be revisited and fully excavated to determine their significance. Those that open to caves should be surveyed as above.

Quantitatively Assessing Field Data

Veni's (1999) strategy for geomorphologically assessing karst areas requires gathering sufficient information on how karst features occur and are expressed in a particular area in order to accurately predict their significance. This is a critical first step prior to quantitatively assessing the significance of karst features, as described in this paper, especially in topographically subdued landscapes.

Figure 1 illustrates a spreadsheet used to quantitatively assess karst features in central Texas. It is divided into two primary sections: feature characteristics and feature type. Each feature's characteristics are tallied with point values commensurate with each characteristic's significance in demonstrating the permeability of a feature, and hence the feature's likelihood to be a hydrologically significant cave relative to either water quantity or sensitivity to groundwater contamination. The sum of these points is multiplied by a point value assigned to the feature type. Proper interpretation of the feature type is the key to accurately quantifying the features' significance. Figure 1 includes four examples:

- Karst features (KF) 1 and 2 are very small, capture minimal sheetwash, but appear to have permeable soils and are located in a favorable lithology. Their total feature characteristics points are equal. However, under "feature type," KF1 is identified as a solutionally formed sinkhole while KF2 is an epikarst feature. In the study area, sinkholes are highly permeable and hydrologically significant, but epikarst features are usually clay-filled, poorly permeable, and hydrologically less vulnerable. Therefore, the feature characteristics, multiplied by a high feature type number for KF1, rank it as a moderately permeable or significant feature. In contrast, KF2 is multiplied by a low feature type number and gets a relatively low rank.

- KF3 and KF4 have high and nearly equal scores for feature characteristics, yet KF3, an open cave, is ranked at zero significance while KF4, a small sinkhole similar to KF1, is ranked as highly permeable and significant. The reason is that KF3 is a paleospring, a hydrologically inactive conduit that once discharged water but now provides no recharge to the modern aquifer. Its feature characteristic points are multiplied by zero for that feature type.

The strategic importance of excavation in subdued karst areas is also evident in the quantitative assessments. KF1 may have been entirely overlooked, mistaken without excavation as a non-karst depression, and KF2 could have been recorded as a possibly significant sinkhole rather than a poorly permeable feature. KF4 could have been ranked equally with KF1, except that excavation revealed airflow and guiding fractures that suggest a much higher likelihood of the feature leading to a cave.

	Feature Characteristics																						
			Recharge type				Size		Fracture			Lithology				Sediment infill				Topography			
Feature name or number	Airflow (10)	Cave fauna (8)	None (0)	Sheetflow (1)	Channelized (5)	Streambed (9)	Length or width >2 m (3)	Depth >1 m (4)	Present (2)	Guides feature (4)	Regional trend (6)	Upper Glen Rose (3)	Basal Nodular (4)	Dolomitic (8)	Kirschberg (7)	None (10)	Loose (7)	Moderate (4)	Compact (1)	0-5° (8)	5-20° (3)	20-90° (1)	Feature characteristics total
1				1										8			7			8			24
2				1										8			7			8			24
3				1			3	4	2	4	6			8		10					3		41
4	10			1										8			7			8			40

	Feature Type																Results		Recharge area (sq. m)					
	Artificial		Cave					Sink		Solution cavity				Spring					(only recharge features)					
Feature name or number	Depression (2)	Well (10)	Paleospring (0)	Phreatic (8)	Spring (2)	Transitional (9)	Vadose (10)	Collapse (6)	Solutional (7)	Enlarged bedding plane (3)	Enlarged fracture (5)	Epikarst (2)	Honeycomb voids (2)	Paleospring (0)	Spring (0)	Total (0-720)	"None" (0), Low (1-150), Moderate (151-250), High (>250)	Significance (0-10)	<10	10-100	100-1,000	1,000-10,000	10,000-100,000	>1,000,000 (>1 sq. km)
1									7							168	M	4	X					
2												2				48	L	1	X					
3			0													0	N	0	X					
4									7							280	H	8	X					

Figure 1: Quantitative assessment spreadsheet for certain karst areas in Texas, USA, with example data and criteria.

Application of the Results

The particular values used in Figure 1 are not important for this paper. They would likely be different for other karst areas and even need to be adjusted when used in different karst areas within Texas. Other characteristics and feature types may need to be added for other karst settings. What is significant is that the results can be used to quantitatively identify areas where karst features are more likely to lead to caves of greater hydrological and biological vulnerability to groundwater contamination. Assessments such as this have been successfully used to guide the placement of highways and other urban developments to less environmentally sensitive routes through karst areas. Veni (1999) reported using this method to correctly assess 76 of 98 karst features that had no reconnaissance excavation, confirmed by complete excavation of the features, and 93 of 98 features that had reconnaissance excavations.

Karst areas are generally the most environmentally sensitive of terrains and among the most complex and least understood hydrologic and geomorphic systems. While the quantitative assessment method described here is effective at identifying karst features that are likely to lead to caves, use of this method alone will not prevent groundwater or ecosystem degradation. Data from several studies clearly demonstrate that in pollution risk assessments of karst aquifers, conduit development is of secondary importance to the type of land use in the recharge area due to high non-conduit permeabilities (e.g. Ogden et al., 1991). This assessment method only identifies the most sensitive features in highly sensitive terrains. Karst features with "low" sensitivity or permeability should not be considered as having no sensitivity to adverse impacts. They are low only relative to other karst features and may still be environmentally vulnerable.

Conclusions

Successful management of karst terrains in urban environments is best achieved by preserving the most vulnerable features and drainage basins in their natural state, coupled with minimizing pollutant loading of the aquifer. In topographically subdued areas, intensive and systematic searches are needed to locate karst features, and reconnaissance excavations are needed to properly assess them. Compilation and study of factors locally important to cave development can be used to develop accurate methods to quantitatively assess karst features. Once established, such methods can be used to identify areas of greater sensitivity to environmental impacts and to divert those impacts to less sensitive locations.

References

DOERFLIGER, N., & F. ZWHALEN. 1997. EPIK, méthode de cartographie de la vulnérabilité des aquifères karstiques pour la délimitation des zones de protection. Proceedings of the 12th International Congress of Speleology, University of Neuchâtel, Switzerland, volume 2, pp. 209-212.

OGDEN, A.E., K. HAMILTON, E.P. EASTBURN, T.L. BROWN, & T.L. PRIDE, JR. 1991. Nitrate levels in the karst groundwaters of Tennessee. In: (E.H. Kastning and K.M. Kastning, eds.), Appalachian Karst, Proceedings of the Appalachian Karst Symposium, National Speleological Society, pp. 197-203.

VENI, GEORGE. 1999. A geomorphological strategy for conducting environmental impact assessments in karst areas. Geomorphology, 31: 151-180. *Reprinted in:* 2000. Proceedings of the 28th Binghamton Symposium: Changing the Face of the Earth – Engineering Geomorphology, J. Rick Giardino, Richard A. Marston, and Marie Morisawa (eds.), Elsevier Publishers, pp. 151-180.