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title: **Sinkhole distribution and density in the Istria County (Croatia)**

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INTRODUCTION

The Istria region, with population of 206,344 persons and minimum twice as many tourists during the summer season, is supplied with potable water from karst aquifers. The karst aquifers are particularly prone to anthropogenic impacts because of short time of water retention in the underground and the fact that water generally flows through the underground using privileged paths – caverns, thus its self-purification capacity is minimal. Additionally, recharge of the groundwater is almost exclusively from precipitations that fall directly on the aquifer. This is autogenic recharge, as opposed to allogenic recharge encountered in more complex geological relations with surface inflow from neighboring non-karst areas which drain into the karst aquifer. While autogenic recharge is diffuse and happens through fissures along the entire surface, allogenic recharge is marked by concentrated (point) sinking. These two patterns of recharge result in different water chemistry and recharged volume per surface area, with significant consequences for dissolution porosity development rate and distribution. Concentrated recharge in autogenic system is encountered only in areas with well developed karst sinkholes, since they reflect presence of non-uniform spatial vertical hydraulic conductivity resulting in preferential paths or seepage zones. Karst sinkholes act as small catchments by collecting and directing the precipitation towards the aquifer, and it is exactly the same path by which contamination enters into the underground.

The present paper describes spatial distribution and density of sinkholes in the Istria County, and it was prepared using topographic maps in scale 1:25.000. The sinkhole density maps are useful for preparation of urban development plans, groundwater protection, and in water resources management. The sinkhole density maps could point to potential hazardous geological zones and/or areas where groundwater contamination potential is higher.

METHODOLOGY

Sinkhole density is a number of sinkholes per surface area. This study uses a surface area of one square kilometer, and sinkholes distribution in the Istria County is determined from 30 topographic maps in scale 1:25.000. Geomorphologic analysis of the topographic maps has singled out 29,889 sinkholes. Fig. 1 clearly shows that there are zones with densely arranged sinkholes and those with no developed topographic depressions, which is due to the lithological structure of the area under consideration. Areas with carbonate rocks can be singled out, which occupy about 60% of the surface area, with dominant autogenic recharge of the underground, while areas built of flysch and Quaternary alluvial deposits with dominant surface runoff cover 40% of the surface area. Concentrated allogenic recharge of the underground occurs at the contact of carbonate and flysch deposits.

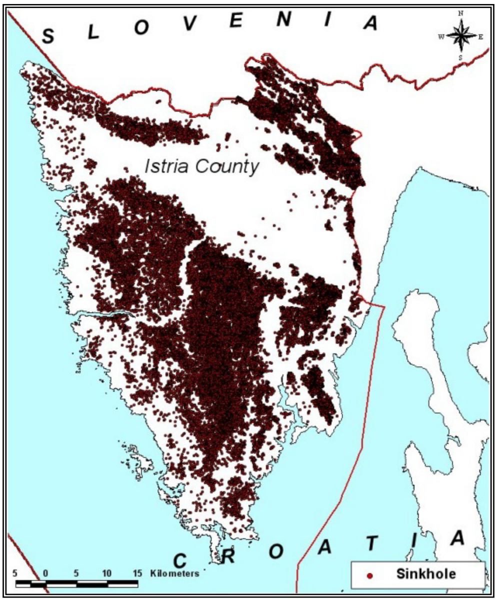

Figure 1. Sinkholes distribution at the Istria County territory.

Once the sinkhole distribution has been determined, sinkhole density mapping started so that the Istria County was plotted in a 1000 × 1000 m grid. The area was divided into 2974 squares, and sinkholes in each square were counted. The sinkhole density map for the Istria County was generated using the data on number of sinkholes in each square (Fig. 2).

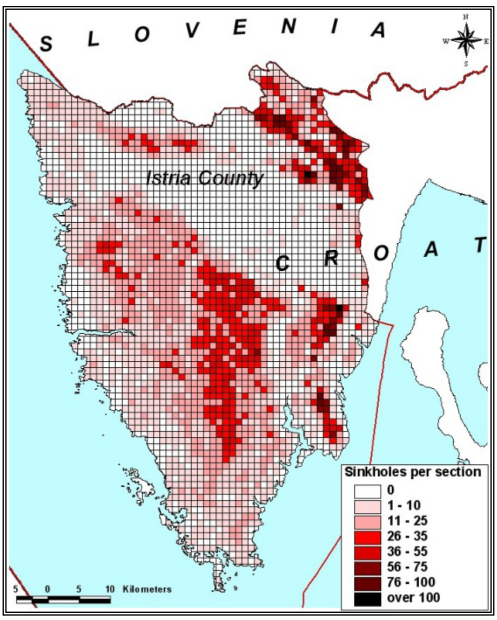

Figure 2. Sinkhole density map.

The sinkhole density per square kilometer ranges from 0 to 123. A comparison of the sinkhole density map, which shows areas of different karstification intensities, with the geological map shows a relation between different lithological units and karstification intensity. The areas where sinkhole density is more than 25 sinkholes per km^2 are related directly with the karstified Upper Cretaceous and Paleogene limestones with numerous and well developed morphological karst forms in the underground.

CONCLUSION

The sinkhole density is an important factor in determination of areas prone to development of sinkholes. It is known that the areas with larger number of registered sinkholes have higher number of unstable cavities in the underground, and probably a well developed system of caverns. The Istria County area stands our for higher karstification intensity of Upper Cretaceous and Paleogene limestones which are more prone to development of different karst forms, unlike Jurassic and Lower Cretaceous limestones. Therefore, it could be concluded that the areas with high number of sinkholes have similar geological and topographic characteristics, and the areas with high density of sinkholes per surface area intensify erosion processes and stimulate further generation of new sinkholes increasing in that way the geological hazard. Generation of new sinkholes is a slow natural process which cannot be stopped, but can be accelerated by in impact of human activities, such as overpumping of groundwater and phreatic line drawdown, boring and excavations, creation of reservoirs, etc.

Further, since the sinkholes are a direct link between the surface and the underground, they are potentially very dangerous points for propagation of accident-related contamination directly into the underground causing contamination of the groundwater. The groundwater in karst aquifers generally streams through underground karst conduits, its flow rates are much higher than in other aquifers, thus any ingress of contaminant into the underground water bearing system could result in contaminant transportation to large distances in a very short period of time. This makes them exceptionally vulnerable and endangered systems.

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