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# Climate Change and Karst Aquifers – Methodologies Review

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Abstract

Groundwater resources in many regions are not immune to climate change. More attention is being paid to the role of groundwater in maintaining ecological flows in rivers during a drought due to decreased precipitation and snowmelt under climate change. Karst aquifers are vulnerable to the increasing occurrence of climate extremes events. This abstract will give an overview of some modern approaches which are used in the assessment of the climate change impact on the karst groundwater. Methods include GIS implementation and remote sensing tools which can contribute to local, regional, and global scale research. Combining the modern research tools with traditional, in-situ obtained data, can lead to more reliable results and more sustainable water management in the future.

**Keywords:** climate change, GIS, karst, aquifer, remote sensing.

## 1. INTRODUCTION

Karst aquifers cover 15.2% of the global ice-free continental land (Goldscheider et al. 2020; World Karst Aquifer Map (WoKAM)). The largest percentage of them can be found in Europe (21.8%), while the largest absolute area all around the world is in Asia (8.35 million km²) (Stevanović et al. 2021). Karst aquifers around the world act as a partial source providing drinking

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water for almost a quarter of the world's population (Ford and Williams 2007). Karst aquifers store considerable amount of water because it is composed of high-porosity carbonate rocks, which are usually more reactive on frequency of flooding and droughts resulting from climate change. Therefore, to quantify and mitigate the influence of changing, it is important to understand the aquifer characterisation and geological properties and assess aquifers' intrinsic features. In that way it is possible to develop a relevant approach in solving problems related to the aquifers' variable recharge, reservoirs, and drainage dynamics. It is the heterogeneity of the karst aquifers which leads to their different hydraulic behaviour during recharge periods. Karst aquifers might be a fast responder to rainfalls, but also can act as a "sponge" which can absorb a huge amount of water and only then start to drain it slowly.

Anticipating changes in climate and assessing their impact on karst aquifers is one of the most important tasks in securing safe water supply in the future. Therefore, much research in the past two decades was focused on the impact of climate changes on groundwater in different types of aquifers (Taniguchi and Holman 2010; Treidel et al. 2012; Stevanović et al. 2012). Hereby, the overview of some valuable methods for assessing of the climate change impact on karst aquifers will be presented. The aim of this extended abstract is to discuss the advantages of modern approaches in assessing the impact of climate change in the karst environment. In the following chapter, the Geological Information System (GIS) methods including Climate Changes Permeability and Storativity (CC PESTO), GALDIT, and Gravity Recovery and Climate Experiment (GRACE) approaches will be presented.

## 2. OVERVIEW OF THE GIS BASED METHODOLOGIES

### 2.1 CC PESTO method

One of the more recent methods, which was designed directly in the function of assessing the sensitivity of aquifers to climate change, is the CC PESTO method (Climate Changes – CC, PErmeability and STOrativity; Stevanović et al. 2021). This method aims to assess and map the vulnerability of karst aquifers to climate change. CC PESTO was tested on a karst aquifer due to the global importance of these waters, but also the complexity that karst terrains bring with them (Stevanović et al. 2021). This method evaluates intrinsic vulnerabilities without considering the human intervention. To achieve this, the aquifer conductivity, storage capacity and discharge regime are considered, as well as the slope of the terrain. This method requires the digitization of existing geological and hydrogeological maps, preparation of each parameter separately in the form of digital base maps. To achieve this, the conductivity, storage capacity and discharge regime are considered, as well as the slope of the terrain, where the slope is obtained via Digital Elevation Model (DEM). According to a specially defined algorithm, the weighting factors of all mentioned parameters are combined and as a result, the intrinsic vulnerability of the aquifer is visually presented.

This method provides valuable karst aquifer management information on protecting the aquifer from extreme climate events and contributes to the karst aquifer water management plan. Stevanović et al. (2021) emphasize that CC PESTO is flexible and applicable to all forms of karst landscape, but that it is necessary to determine the weighting factors for each parameter depending on the local conditions of the terrain on which it is applied.

### 2.2 GALDIT method

The sensitivity of groundwater to seawater intrusion can be defined as the sensitivity of groundwater quality to artificial extraction, or to sea level rise, or both when it comes to coastal areas. This sensitivity is determined by the characteristics of the aquifer. Seawater intrusion is one of the most common mechanisms of salinization that affect the quality of coastal aquifers. It is an active process that leads to the disruption of the hydrodynamic equilibrium between fresh and sea water. One of the reasons for the occurrence of salinization is over pumping due to the constantly growing population in coastal areas, but also due to natural changes in feeding or raising the level of the world sea (Kouz et al. 2018). The GALDIT method for assessing the vulnerability of groundwaters to climate change was developed specifically for coastal areas and the assessment of seawater intrusion.

Principles of applying the GALDIT approach according to Kouz et al. (2018) is based on a classification system and is a qualitative method based on six parameters:

(G – Groundwater Occurrence) Occurrence of groundwater, and as part of that, vulnerability to marine intrusion is considered in relation to the type of aquifer, which can be closed, semi-closed and open, where the open aquifers will be the most exposed to seawater intrusion;

(A – Aquifer Hydraulic Conductivity) For the same pumping capacity (or natural flow), the acceleration of the contact of fresh and salt water is closely related to the hydraulic conductivity;

(L – Height of Groundwater Level below Sea Level) This parameter determines the hydraulic pressure that allows pushing the contact of fresh and salt water. Groundwater level in correlation to mean sea level is a very important factor in controlling the progress of saltwater intrusion and assessing marine intrusion into the coastal aquifer;

(D – Distance from the Shore) The distance from the shore is measured perpendicular to the shore. The impact of saltwater intrusion decreases with distance from the coast;

(I – Impact of existing status of seawater intrusion in the area) Parameter is represented in the spatial variation of the ratio – Cl−/HCO3− + CO3. Chloride is the dominant anion in seawater, while it is very little present in fresh water;

(T – Thickness of the aquifer) The greater the volume of the aquifer is, the greater is the importance of the extension of saltwater intrusion.

By combining all maps obtained (for each described factor), using the appropriate algorithms, the final vulnerability map will be produced. Overlapping of parameter maps (basemaps) is similar procedure as it was for CC PESTO method. This approach is commonly known for the GIS based groundwater vulnerability mapping.

## 3. GRACE SATELITES DATA APPROACH

Special attention should be given to satellite technology and the launch of the GRACE (Gravity Recovery and Climate Experiment) satellite in 2002. The main difference between the previous uses of satellite research and remote sensing in general and GRACE tools is that other satellite analyses of water resources are based on radiometric measurements of the Earth’s surface, while GRACE provides data based on changes in gravity (Swenson and Famiglietti 2012). Hydrological resolution of GRACE is debated, depending on the required accuracy of estimate and it is coarse in general. These changes in time occur mainly due to the redistribution of mass within the Earth’s fluid layer, on a daily to decadal scale. The cause can be found in tectonic movements or glacial isostatic signals, but also in changes in surface concentrations in the atmosphere, oceans and continental water bodies (Leblanc et al. 2012). From its launch until today, the GRACE satellite has been used to assess changes in terrestrial water reserves, with increasing use in assessing changes in groundwater reserves.

## 4. DISCUSSION AND CONCLUSION

The underlying principle of discussed GIS based methods are similar. These methods require digitization, vectorization and rasterization of data in GIS, apply algorithms proposed and obtain the final vulnerability map. Vulnerability classes are also similarly ranked in the final vulnerability maps. Difference in each method is observed in the number of parameters that are included in the final algorithm for obtaining the vulnerability map. Furthermore, GALDIT method includes the observed intrinsic vulnerability to seawater intrusion, which indirectly introduces a qualitative parameter as one of the participants in the groundwater vulnerability assessment, while CC PESTO method is oriented towards the quantitative sensitivities of karst groundwater. When it comes to GRACE satellite data it is concluded that its application is the most successful when it comes to global and regional assessments of the groundwater reservoir change. For applying this method on local scales, the special data downscaling shall be done. It is recommended that, whenever possible, results obtained by this method are calibrated by the traditional, field work based approaches and calculations.

Ultimately, it is obvious that these methods might be a powerful tool in assessing climate change impact on karst aquifers if handled carefully by groundwater experts.

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