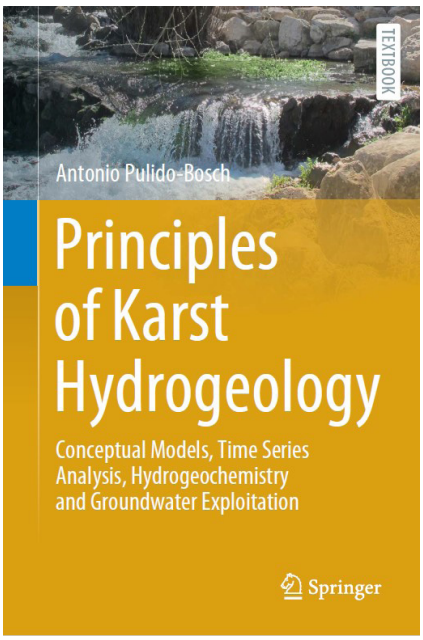
sciendo

Geologos 29, 1 (2023): 61–64
https://doi.org/10.14746/logos.2023.29.1.06

GEOLOGOS

Principles of karst hydrogeology – conceptual models, time series analysis, hydrogeochemistry and groundwater exploitation, by Antonio Pulido-Bosch, 2021. Springer International Publishing, 369 pages. eBook price: 50,28 EUR, ISBN 978-3-030-55370-8.



Karst aquifers are considered to pose the biggest challenge to hydrogeologists because of the extreme heterogeneity and anisotropy of the internal hydraulic structure. For these reasons, calculation methods, including numerical ones, in such systems are often unreliable, especially when they concern local practical problems. Antonio Pulido-Bosch, who is one of the most eminent experts in karst hydrogeology, has now decided to summarise in the present volume his > 40-year-long research in karst areas, mainly in Spain, but also in other countries. The book also profitted from rich sources of knowledge assembled since the days of the fathers of karst hydrogeology, Cvijic and Martel, up to the present. From a wide range of karst hydrogeology, the author has chosen the issues included in the subtitle of the book, namely: Conceptual models of karst aquifers, time series analysis in karst springs, hydrogeochemistry of karst waters and problems related to groundwater exploitation in karst areas.

The structure of the book is quite original in that the author has divided it into eight chapters, each of them beginning with a basic term glossary and a general discussion of the problem. Afterwards, relevant case studies are described in the form of separate boxes. Moreover, the recommended general literature list (further reading), short questions, personal work and a list of literature referenced in each chapter are presented. In this, the present tome takes the form of a lecture series, which resembles an academic textbook, which is added value. The book also makes an important item in the scientific literature in the field of hydrogeology, in particular karst hydrogeology.

In the introduction, the author briefly recalls the beginnings of karstology and karst hydrogeology, the establishment of related scientific organisations, cyclical scientific events and specialised journals, but also lists also titels of theses of his graduate students, doctoral students and projects related to this book.

The first chapter starts with general information on karst rocks and their occurrence around the Mediterranean Sea and in Spain and continues almost entirely on the porosity and permeability of carbonate rocks. This is a highly valuable part of the book since the author recognises the importance of hydrogeological properties of matrix in carbonate rocks in the karstification process; these are usually ignored in texts on karst hydrogeology. Here we find examples of five karst aquifers, including two cases based on results of the hydrogeological properties of matrix research, and three cases based on results of the geometry of fracture research. Amongst these cases, the unique karst massif Torcal de Antequera and the impressive Sorbas gypsum in south-east Spain, in the Almería area, are described.

From the microscale (matrix, fissures) the author moves onto the karstic rocks massif scale. He begins this part of the book by discussing the main karst processes: dissolution, corrosion and erosion, and the role of insoluble substance (residue) in these processes. The types of surface forms resulting from these processes are also briefly described. The simple scheme shown in Figure 2.1 provides an excellent synthesis of this issue. Examples of karst form diversity are described in detail in four cases:

the previously mentioned gypsum karst of Sorbas, that of Vallada (Valencia), pseudokarst forms on the southern edge of Sierra del Maimón (Almería) and gypsum of Pinoso Karst (Alicante).

In the Sorbas gypsum massif, apart from caves and springs associated with the karst system, there are also rare unusual surface forms, the so-called tumuli which form a kind of „bursting blisters"on the terrain surface. These interesting forms are extensively described here, inclusive of results of comprehensive morphometric studies and statistical analyses. The Vallada area is described as a classic karst massif with characteristic surface forms (e.g., sinkholes, uwalas), caves and karst springs. It appears that the example of pseudokarst surface forms in the alluvial fan of the carbonate rocks massif (dolomites and limestones) foreground, resembling uvala and even polja, should not be described here, amongst gypsum karst aquifers. However, this is a highly instructive piece of evidence that different processes can lead to similar geometric forms found in karst areas.

An interesting example is the gypsum cap on the Triassic salt diapir in the region of Pinoso (Alicante), where salt has been mined using the borehole method since 1980. Salt exploitation, despite the applied protections, additionally contributes to the formation of surface karst forms, such as doline, uvala, sinkhols or collaps doline. Within the gypsum cap, there are also springs of various hydrochemical types: sulphate and chloride. The author explains this case by different water circulation systems in the diapir, where the shallower one covers only the gypsum cap (sulphate waters), and the deeper one covers the cap and salt rocks (chloride waters).

Examples of conceptual models of karst aquifer are presented in the next chapter. In general, the conceptual model that underpins research in life sciences is a quantitative description of a system and its representation (e.g., geometry, parameters, initial and boundary conditions) relevant to the intended use of the model. Here there is an individual creation of the author's imagination, his own simplifying synthesis, and therefore the same system can be presented differently. The author discussed the conceptual models of karstic aquifers from the first, simplest Martel model in the form of underground rivers, to the more complex ones (e.g., of Kiraly or Mangin), in which the hierarchy of groundwater flow system geometry was taken into account. In this part of the present volume, two topics are discussed in more detail: data necessary to build a conceptual model and the typology of aquifers in carbonate rocks. The former includes the results of pumping tests, performed in the carbonate aquifers (limestone and dolomite) of the Spanish Levant, which are of a great economic interest, and their synthetic elaboration. This issue is accompanied by one of the previously shown conceptual models of karst aquifers. The second topic includes a short case study concerning the typology of karst aquifers from Bayó and also Quinlan et al., with an added element of vulnerability.

An extensive part of the present book (two chapters) concerns the analysis of spring hydrographs in terms of groundwater reservoir volume from which they are supplied, and an impact of the amount of precipitation on changes in the spring efficiency. In the first chapter deterministic methods are presented using mathematical formulas by various authors, starting with the simplest, classic Maillet formula. The author has taken into account the most important formulas known from the literature, and presented examples of practical application of some of them. The second chapter of this part constitutes an example of the use of methods based on time series analysis, which enables separation of three components in the spring hydrograph, i.e., secular, seasonal and random. These are advanced statistical methods that allow for a good approximation of the hydrological system structure and operation. Examples of these methods use have been presented on specific spring cases.

The chapter entitled „Mathematical models" presents methods of modelling of karst aquifers. The first group includes the „black box" methods, in which it is assumed that an input function (rainfall) is transformed by karstic aquifer (black box) into an output function (spring's flow). Four computational models, with varying degrees of complexity, are discussed. More complex univariate models are based on the analysis of stochastic structure of time series to forecast complete data in the short term, or to generate a synthetic series preserving the main statistics, especially the temporal correlation (autocorrelation function) of the underlying process in the original series. The use of these models requires frequent measurements of source efficiency, preferably using continuous logging devices.

The author has also included classic numerical modelling into the group of mathematical models, and for specific examples of two karstic aquifers (Torcal de Antequera and Sierra Grossa) he has presented the modelling results, and also pointed out that in this case the karstic aquifer was treated as a porous aquifer, i.e., homogeneous and isotropic. It is believed that the model corresponds to real-life conditions when the assumed compatibility of the hydrodynamic field in model and reality is achieved, with the assumed values of transmissivi-

ty and storage coefficient in individual elements of the grid and boundary conditions (recharge, discharge). Here we approach the problem of scale, which is particularly important in the case of karstic and fissure aquifers with two flow components: diffuse and conduit. Diffuse flow can be assumed throughout karstic or fissure aquifer on a regional scale, but on a local one (e.g., spring or mine galleries) the conduit flow component should be included. Solving the scale problem by developing some unitary mathematical model of karst aquifer is a challenge for the future.

An extensive chapter of the book is devoted to the issues of hydrogeochemistry and water quality in karstic aquifers. It kicks off with a general introduction to the chemical composition of water in limestones and dolomites, the origin of the main ions and the basic processes shaping this composition.The author has briefly discussed selected methods of presenting hydrochemical data and pointed to the commonly used computer programs (software) WATEQ and PHREEQC, which are helpful in calculating saturation indexes for individual mineral phases. Examples of the author's own hydrochemical research results, carried out for many years in various karst aquifers in Spain, are atypical for classic karst areas (mountains and uplands), thus they expand the scope of knowledge in this field. Moreover, they make a very valuable addition, both in terms of research and teaching.

The first of such examples considers the saline springs of Sierra de Mustalla (province of Valencia) with various mineralisations, including chlorides (from 200 to 8500 mg/L) and elevated temperatures from 18 to 29^{o}C, flowing from the limestone massif. This is a spectacular example of deep groundwater circulation, with chemical composition not consistent with the host rock. Another example involves the Campo de Dalías, or vast alluvial fans, formed on the Mediterranean coast at the foot of the Sierra de Gádor mountain range (Almería). It is a large area covered by vegetable crops cultivated in foil tunnels. The cultures are irrigated with underground water from deep wells, into which sea water began to flow over time. It is an excellent example of the mixing of fresh waters flowing from the Sierra de Gádor mountains with sea water intrusions. Comprehensive results of many years of research into this process, both in chemical and isotopic aspects, together with their interpretation illustrate the complexity of this process.

A similar case is the Crevillente aquifer, situated within Jurassic limestone (Liassic), from which drinking water is pumped. As a result of excessive exploitation, the level of underground water in the limestones has systematically decreased, which has triggered ascension of mineralised waters from the Triassic bedrock composed of clays, gypsum and marls, and deteriorated water quality in the intakes. Short case studies on the hydrogeochemistry of Sorbas gypsum and Vallada area (Valencia) complete this part of the book. However, it seems that concentration values of individual ions, presented in Table 7.10 (p. 283), are given not in mg/l, but in other units (meq/l or mmol/l?). The conductivity values of several thousand μS/cm quoted in the text (p. 282) indicate that the TDS is much higher than what would have resulted from the sum of ion concentrations given in the table mentioned above.

Specialists dealing with hydrogeochemical modelling should be interested in the example of hydrogeochemical modelling, to determine the processes and identify possible flow systems and potential pathways in salt evaporites of the Fuente Camacho presented in this part of the book. This area constitutes a variety of diapiroid of Triassic evaporites (Keuper facies) containing a series of superficial karst forms, including flooded dolinas and a brine spring that supplies salt. Therefore, there are underground waters with a highly diverse mineralisation, from mineral ones, typical of gypsum, to brines. The PARQUIMIC program was used for hydrogeochemical modelling to obtain results similar to WATEQ, WATSPEC and GEOCHEM, but with a simplification of phases present in this medium. The chapter on hydrogeochemistry and water quality ends with a discussion of issues related to hazard in karst groundwater. The impact of human activities on groundwater, control measures, protection procedures , as well as risk analysis related to the development of karst areas, are generally discussed.

The last part of the present tome is devoted to problems of exploration and exploitation of groundwater from karst aquifers. In the part devoted to exploration, the author briefly discusses the methods and gives examples of the use for some of them. Considered by the author as a good exploration tool, but treated marginally in the environment of hydrogeologists, is morpho-structural analysis, which can provide a lot of information about the underground groundwater circulation system in karst areas. The example of the use of thermal and hydrochemical methods in the exploration of groundwater is also worth noting. Simple temperature and electrical conductivity (EC) measurements can help identify the components of deep groundwater circulation without the use of complex and costly isotopic methods. The author briefly mentions well-known geophysical and hydrodynamic

methods such as pumping tests, injections, changes of water level and piezometers or spring flows. One of the more advanced methods of exploration of groundwater is undoubtedly the tracer test, often used in karstic aquifers. The course of such an experiment and its results carried out in the Dobrich area (north-east Bulgaria) are described in detail, the experiment demonstrating the complexity of the karst groundwater circulation system at the mesoscale. Finally, the author mentions simulation models as a method of groundwater exploration.

In the section on exploitation, various methods of water intake from karst aquifers are discussed, and synthetically presented in a very impressive diagram (Figure 8.20). The diagram includes methods to capture sources, as well as galleries and boreholes. To the latter, drilled in galleries, the author devotes more space, giving practical tips and also describing how to improve the efficiency of the hole by acidification. This chapter also discusses the karst spring intakes on sea coasts, which require original technical solutions. At the end of the book, the author discusses in general the direct and indirect impacts of karst water exploitation, and this part of the tome is supported by examples. Regarding direct impacts, the results of lowering of natural groundwater levels, affecting springs, surface watercourses, wetlands, wells etc., are presented, while for indirect influences, secondary effects of lowering the mirror are discussed. Moreover, the negative impact on water quality caused by changes in flow direction, including ascension, or deformations of land surface, could be caused by e.g., suffosion. On a larger scale, a progressive desertification in semi-arid regions is also discussed.

The present volume constitutes a very good academic textbook, and is also a valuable source of knowledge for hydrogeologists, in particular those who deal with karst aquifers.

Jacek Motyka and Kajetan d'Obyrn
AGH University of Science and Technology
Kraków, Poland
e-mails: motyka@agh.edu.pl and dobyrn@agh.edu.pl