Abstract

In NW Vietnam, karst areas cover nearly 18% of the land surface and have substantial socio-economic importance as groundwater resources, as well as zones for forestry, agriculture and tourism. In many areas, however, both the karst landforms and the groundwater resources have recently come under pressure in response to urbanisation, economic development and increase of population. Karst aquifers are particularly vulnerable to contamination resulting from human activities. Karst groundwater consequently requires special protection. A sound knowledge of the hydrogeological system is a precondition for any protection strategy. Such understanding, however, is presently lacking in Vietnam.

This work aims at better understanding the hydrogeological characteristics of the tropical karst regions in Vietnam and providing a scientific basis for groundwater protection. The study focuses on two major mountainous areas that belong to the NW karst belt: Son La and Tam Duong, which mainly consist of thick Middle Triassic carbonate-rock formations. An investigation methodology has been applied and adapted to the conditions of the remote areas, for which little information is available. The employed methods included tracer tests, hydrodynamic, hydrochemical and microbiological spring monitoring, as well as stable isotope and rare earth elements studies.

Tracer tests proved underground connections between several swallow holes and springs in the two test site areas. The NW-SE and SW-NE faults have a great influence on the underground drainage patterns. The flow paths run either across the folds along the NW-SE faults or follow the SW-NE faults; these flow paths coincide with the preferential directions of cave development.

Groundwater mixing effects can be observed in both areas. Hydrochemical data from Son La show a significant difference in the Ca and Mg contents between a swallow hole and a connected spring, which can be explained by mixing effects. Stable isotope results further support this observation. The high stability of $\delta^{18}O$ of karst springs in the Nam La valley (Son La) compared with meteoric water also indicates that this karst system contains well-mixed groundwater. The hydrochemical results from the Tam Duong area show a difference in Ca and Mg content between a swallow hole and a connected spring, which also can be explained by the mixing effect. The little variation in chemical content along the flow path compared to the Son La area may reflect the water–rock interaction in this karst system.
Large karst springs are observed in Son La, while smaller karst springs occur in Tam Duong. The results obtained from this study suggest that concentrated recharge prevails in the Tam Duong area, while the recharge processes and groundwater flow in the Son La area appear to be more complicated. There is evidence for point recharge and conduit flow on one hand, but also for significant diffuse recharge and flow through small joints and fractures on the other hand.

Tracer tests in the Son La area gave groundwater flow velocities ranging from 75 to 166 m/h. These are typical values for karst aquifers and indicate low-resistance flow paths. The flow velocities in the Tam Duong area are up to 700 m/h, which is one of the highest values recorded in the literature. The two investigated springs near Tam Duong show a different hydrological and physical-chemical response on precipitation events. A dilution effect was observed at one karst spring, while the other spring displayed a piston effect.

The physical-chemical parameters of all sampled karst water in both areas meet the WHO standards for drinking water. The REE concentration levels found in spring water from Tam Duong are higher than those from other karst areas reported in the literature but still safe for the health of the consumers. In contrast, the microbial investigation revealed that all karst water contain high levels of thermotolerant coliforms (TTC). The contamination shows high temporal fluctuations and mainly results from untreated domestic wastewaters, agriculture and other human activities.

In order to protect the valuable groundwater resources in Vietnamese karst areas, a simplified methodology for mapping groundwater vulnerability and contamination risk was developed and first applied in the test sites. It is based on a conceptual framework proposed by the European COST Action 620. The vulnerability map takes into account the overlying layers (O) and the flow concentration (C). The risk map is obtained by a combination of the vulnerability map and a simplified hazard assessment. The maps provide a basis for land-use planning and groundwater protection zoning. Groundwater protection should be a priority in vulnerable zones such as swallow holes and along sinking streams.

The work gives details and an insight into the understanding of karst hydrogeological characterization in the Son La and Tam Duong areas. The methods applied in this work constitute useful tools for the hydrogeological investigation of remote and mountainous tropical karst areas in Vietnam and made it possible to provide a scientific basis for sustainable groundwater management.