Agricultural Water Management 159 (2015) 55–65

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Major problems and solutions on surface water resource utilisation in karst mountainous areas

Luoyi Qin[a,b,d], Xiaoyong Bai[a,d], Shijie Wang[a,d,*], Dequan Zhou[b], Yue Li[a,d], Tao Peng[a,d], Yichao Tian[a,c,d], Guangjie Luo[a,c,d]

[a] State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China
[b] School of Geography and Environmental Sciences, Guizhou Normal University, Guiyang 550001, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Puding Karst Ecosystem Observation and Research Station, Chinese Academy of Sciences, Anshun 561000, China

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 22 May 2015
Accepted 25 May 2015

Keywords:
Surface water
Lithological character
Karst
Surface rainfall collection
Rain harvesting

ABSTRACT

Water shortage in karst mountainous areas is a difficult problem faced worldwide. Serious surface water leakage, which is a karst characteristic, has puzzled global scientists for a long time. Local climate and hydrology play important roles in water resources occurrence and behaviour, which in turn affects surface and groundwater management. The objectives of this study were as follows: to conduct in-depth analysis of the major problems in the current utilisation on the surface water resources in karst areas; to reveal the differences in surface hydrogeological structures that grew and formed under the control of different lithological characters, surface water occurrence conditions and its cyclical rules; to propose strategies for development and effective utilisation of water resources. A series of technologies for karst surface water resource use on the basis of karst hydrogeological features and development law is proposed. These technologies include gully section runoff confluence water harvesting technology, surface karst spring directional diversion technology, sunken geomorphology ecotype cistern design technology, road rainwater-harvesting and effective utilisation technology, effective comprehensive and utilisation of rooftop rainwater harvesting technology and other surface water resource optimal allocation technologies. Thus, this study offers research-driven technological solutions to ease water shortage, facilitate modern agriculture and regional economic development in karst mountainous areas.

1. Introduction

Water is an irreplaceable resources for human survival and development. It is important for economic and social development, agricultural production, and ecological restoration (Keshavarzi et al., 2006; Hannu and Bjørn, 2010; Johan et al., 2010; Vialle et al., 2011). In karst mountainous territories, Due to the extensive development of underground fissures, pipeline, caves and underground streams causes surface water scarcity, with water rapidly infiltrating underground through the network of karst fissures and conduits in the rock mass (White, 1988; Ford and Williams, 2007; Williams, 2008; Lopez et al., 2009; Brinkmann and Parise, 2012; Bai et al., 2013; Dubois et al., 2014). The shortage of surface water is a major bottleneck in ecological restoration and sustainable development of economy and society (Aley, 2000; Parise and Sammarco, 2014). Changes in the global climate have exacerbated this problem. Utilisation of water resources in karst territories include centralised water supplies by large-scale water conservancy facilities, shallow groundwater exploitation and surface rainfall collection. Large-scale water conservancy facilities aim at solving the water demand of cities, large-scale industrial and mining enterprises or contiguous farmlands. Shallow groundwater exploitation is applied to plains or highlands, where groundwater is relatively shallow. These two utilisation methods of water resources are proficiency and yield good results (Goel and Kumar, 2005; Hatibu et al., 2006; Dafny et al., 2010; Pachpute, 2010; Khaldi et al., 2011).

Analysed part of the Chinese karst area is generally mountainous (Bai and Wang, 1998). A typical bare karst mountainous area is rugged with scattered arable lands, settlements and sloping lands. Therefore, a karst area is beyond the reach of the centralised water supply of large-scale water conservancy facilities. Groundwater in such areas is also generally deep; therefore, the cost of

* Corresponding author at: Institute of Geochemistry, Chinese Academy of Sciences, 99# Lincheng West Road, Guiyang, Guizhou 550002, China. Tel.: +86 851 5895338.
E-mail address: wangshijie@vip.gyig.ac.cn (S. Wang).

http://dx.doi.org/10.1016/j.agwat.2015.05.024
0378-3774/

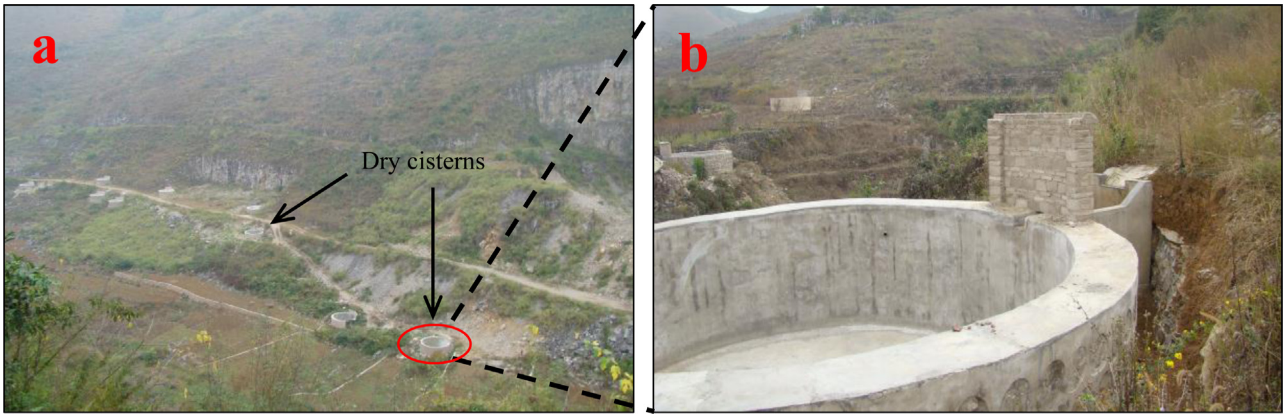

Fig. 1. Rainwater was unable to accumulate in many catchment facilities without rainwater harvesting surface.

exploitation is high. As a result, the centralised water supply by large-scale water conservancy facilities and shallow groundwater exploitation cannot solve water shortages in karst mountainous areas.

In karst areas with abundant rainfall, precipitation and water formed at the surface can be considered valuable resources for supporting regional ecological restoration and social development (Sazakli et al., 2007; Gikas and Angelakis, 2009; Gikas and Tsihrintzis, 2012). In exploring technologies of water sources utilisation in karst areas, local people have started to consider utilising surface water, Many examples of such abilities are distributed throughout the Mediterranean area and in the Middle East (Wilson 2001; Mays et al., 2007; Angelakis 2009; Bonacci et al., 2012; Voudouris et al., 2013; Parise and Sammarco, 2014). And in karst mountainous areas of south China, local government construct some catchment facilities for the sake of agricultural production (Fig. 1a), however, given that such people lack the scientific understanding of the migration and transformation of surface water resources, as well as the hydrology and water chemistry properties of karst areas, many catchment facilities are out of operation and unable to accumulate rainwater (Fig. 1b). The water shortage in karst mountainous areas caused by the geological structure of the special environment has attracted considerable attention from government regulators and international scholars. And many relevant research papers were published, the papers proposed several measures and modes to solve water shortages in karst territories (Shi et al., 2005). However, these studies without fully understanding the lithology of karst mountainous areas and the particularity and complexity of hydrogeological structures, the proposed development and utilisation modes of surface water resources have not fully solved the problem of water shortage in this area.

Therefore, this study proposes a series of surface water resource-utilisation technologies for karst hydrogeological characteristics and development law through in-depth analysis of existing problems about water resource use in karst areas. This study also establishes scientific and rational technology system of surface water resources utilisation in karst areas (Fig. 2), in order to contribute to regional ecological restoration and socio-economic development.

2. Differences in surface water resource utilisation among the karst areas

2.1. Obvious differences in hydrogeological structures formed under different lithologies

Carbonate is extensively developed in karst mountainous areas (Ni, 2013). Significant difference exists in geomorphological and hydrogeological structures developed under a combination of different lithologies (Fig. 3a–d). Cracks and channels extensively develop on mountainous slopes formed by limestone (Fig. 3e), surface water leakage is high, and runoff coefficient is low. Rocks on slopes formed by dolomite as the substrate are weathered wholly, and rock and soil are evenly distributed (Fig. 3f). The surface runoff coefficient is higher on limestone slopes, however, the soil on dolomite slopes was shallow and has a large proportion of stones in it, contribute to high soil permeability and poor water retention. Thus, rainwater leaks or losses occur along slope gullies once rainfall reaches the ground surface. Therefore, karst slopes resulting from different lithology developments have different surface water and surface runoff coefficients in karst mountainous areas of south China, so in these areas the limestone or dolomite slopes should adopt the corresponding water resource development and utilisation methods. However, existing water resource utilisation modes do not fully consider the different slope hydrogeological structures and runoff coefficient. Thus, the established rainwater harvesting facilities are ineffective and do not play a role in fighting drought and ensuring harvests.

2.2. Low runoff coefficient on the surface of karst areas

Subject to particular double-layer and three-dimensional hydrogeological structures, there are ground and underground double hydrogeological systems, in addition to stereoscopic structure of horizontal and vertical direction, surface and sub-surface rock pores, cracks and pipelines in karst mountainous areas are prosperous (Wang and Zhang, 2004; Williams, 2004). Hence, the runoff coefficient on the slope surface is lower than that on non-karst areas (Yan et al., 2000; Dong et al., 2009; Li et al., 2011; Chen et al., 2012; Peng and Wang, 2012)(Table 1). So rainfall rapidly infiltrates into the bedrock through the systems of discontinuities in the soluble rock mass (Fig. 4), and creates the underground network of conduits and caves which is the most typical feature of karst environments (White 1988; Ford and Williams 2007; Parise and Sammarco, 2014). Therefore, the rainwater is difficult to save on the surface without available geological and morphological conditions (Lopez et al., 2009), The established small pools or cisterns were isolated and in short of the rainwater harvesting surfaces, thus, the catchment facilities are difficult to collect rainfall, and causing surface water shortages.

2.3. Large runoff of gully after secondary rainfall

Rocks on slopes of dolomite as the bedrock are highly weathered wholly. With uniform, uninterrupted, shallow soil cover and poor water holding capacity, there are many small gutterways or gullies