Available online at http://www.journalijdr.com

IJDR

International Journal of
DEVELOPMENT RESEARCH

ISSN: 2230-9926

International Journal of Development Research
Vol. 06, Issue, 09, pp.9551-9555, September, 2016

Full Length Research Article

RAINWATER HARVESTING TO COMBAT ROCK DESERTIFICATION IN KARST AREAS

[1,*]Kwong Fai Andrew Lo, [2]Guanghui Jiang and [1]Thomas Chao-Chun Huang

[1]Graduate Institute of Earth Science, College of Science, Chinese Culture University, Taipei 11114, Taiwan
[2]Key Laboratory of Karst dynamics, Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin 541004, P.R. China

ARTICLE INFO

Article History:
Received 20th June, 2016
Received in revised form
28th July, 2016
Accepted 30th August, 2016
Published online 30th September, 2016

Key Words:

Water runoff, Fragile karst ecosystem, Pond siting, Design and construction, Operation and maintenance.

ABSTRACT

Rock desertification has become the most serious ecological disaster in southwest China. Area of rock desertification is expanding at an alarming rate and is restricting social and economic development in southwest China. The objective of this study is, therefore, to assess the impact of rock desertification in southwest China and to suggest means to alleviate intensification of rock desertification problem with rainwater harvesting using natural ground catchment and open water reservoir. Besides providing direct water use, natural ground catchment and open ponds can recharge ground water and near-by ponds also. However, the negative effects of ponds may include siltation, high evaporation, seepage, construction and maintenance. The stagnant water may breed vectors and cause degraded microbiological and chemical water quality. Proper siting, design, construction, operation and maintenance are therefore essential in ensuring success in combating rock desertification problem in southwest China.

INTRODUCTION

Rock desertification is a soil erosion process leading to the exposure of bedrock, and is often caused by both natural and anthropogenic factors. It is one of the most serious land degradation problems in karst areas. It is also regarded as an obstacle to local sustainable development. In geological time, this process is dominated by the natural processes, whereas during historical and modern times, anthropogenic processes have superseded these natural processes. Human activities have accelerated and exacerbated rock desertification. However, the effects of climate change also aggravate rock desertification in karst areas due to temperature and precipitation increase. Under normal conditions, the natural forces generally cause erosion and solution of surface soil and carbonates, and human activities have relatively little effect on these processes. Under prolonged running water and solution actions, the surface materials are destroyed by erosion and soil loss. This is followed by the formation of small-scale rock sculpting, solution channels and caves. Karst landforms develop naturally under normal condition, and natural erosion of soils creates rock desertification land.

Corresponding author: Kwong Fai Andrew Lo,
Graduate Institute of Earth Science, College of Science, Chinese Culture University, Taipei 11114, Taiwan.

Rapid population growth and government policies are the main anthropogenic factors affecting rock desertification. To obtain adequate food supply for the rapidly increasing population, farmers have to use inefficient slash-and-burn methods and over-cultivation of steep slope land to increase crop yield. Due to a shortage of coal and electric power, especially in the karst region, large areas of forest vegetation have been destroyed for fuel wood supply. Overgrazing and animal trampling with goat, cow and pig husbandry in mountainous regions to provide food source and additional income, often results in plant root system damages, destruction of above ground vegetation cover, and severe topsoil erosion. Intensification of these human activities often leads to unsustainable land use, low production potential, high natural soil erosion rate, and accelerating rock desertification. The state and local government policies have great influence on rock desertification through deforestation, overgrazing and over-cultivation. Farmers are encouraged to reclaim land, cut down trees, and increase cultivated land. Grain and meat production increase, particularly in mountainous and karst regions, leads to large scale reclamation of slope land and uncontrolled removal of forests and grasslands. The objective of this study is, therefore, to assess the impact of rock desertification in southwest China and to suggest means to alleviate intensification of rock desertification problem with rainwater harvesting using natural ground catchment and open water reservoir.

ROCK DESERTIFICATION IN SOUTHWEST CHINA

Scientists have warned that rock desertification has become the most serious ecological disaster in southwest China. Area of rock desertification is expanding at an alarming rate (2,500 km^2/yr) and is restricting social and economic development in southwest China. Bedrock emerges due to severe vegetation destruction and soil erosion (Yuan, 1997). Currently, area of rock desertification in 284 counties in Yunnan, Guizhou, Sichuan, Chongqing, Guangxi and western Hunan exceeds more than 100,000 km^2 with significant annual economic loss (Jiang *et al*., 2014). According to the definition of desertification accepted by the United Nation Convention to Combat Desertification, and based on the results of field investigations, Li and Wang (2007) have defined rock desertification as land degradation that occurs in humid and sub-humid climates with karst topography as a result of human activities and climate changes, leading to vegetation degradation, soil erosion, surface water loss, bedrock exposure, and the development of a rocky desert landscape. Rock desertification caused vegetation communities to change towards xerophytic and lithophytic organisms with a simplified community structure and reduced diversity and vegetation cover.

This vegetation succession occurred in response to anthropogenic influences and natural factors. By the end of this process, only some mosses, lichens and dwarf herbs were able to survive in the rocky desert (Figure 1) (Li *et al*., 2009). The forest cover in southwest China areas drops to less than 15%. The waterfalls in Huangguoshu in Guizhou has extended its annual dry season from two months in the 1980s to five months now and sometimes even dries up (Jiang *et al*., 2011). Rock desertification affects 80-90% of the forest land (3,000 km^2) in Mashan, Guizhou where forest coverage used to be 60-80%. More than 100,000 people's livelihood has been disrupted and has to be re-settled. Rock desertification has brought a loss of 2.8 billion yuan (US $338 million) to 77 counties in Guizhou. Of the 48 poverty-stricken counties, 39 are in rock desertification-stricken areas. There are more than three million poverty-stricken people and the poverty rate is ever increasing. Rock desertification also causes serious loss of soil and water, endangering the navigational safety in the Pearl and the Yangtze River (Yuan, 1993). In Guizhou, where rock desertification is the most serious, land area of about 80,000 km^2 suffers severe loss of soil and water. About 270 million m^3 of sand is delivered annually to both Pearl and Yangtze River, posing serious dangers to the electric power stations downstream. Sediment in the last 5 years at the Wujiangdu Power Station on the Wujiang River, a major tributary of the Yangtze River, is 10 times higher than the designed amount. Sediment from rock desertification are now also posing serious danger to Longtan and Dahua Power Stations on the Hongshui River, a tributary of the Pearl River. Operations of these Power Stations have direct impact on electricity transmission as well as ecological safety, economic and social stability in Guangzi, Guangdong, Hong Kong and Macao. Substantial efforts have been made in studying the nature and origin of rock desertification and possible countermeasures in the karst region of southern China (Yang, 1993; Zhu and Cui, 1996; Tu, 1996; Yuan, 1997: Yuan, 2002; Wang, 2002; Wang *et al*., 2003; Cao *et al*., 2004; Han, 2006). Scientists have suggested that governments and scientific communities have to combine efforts to establish a comprehensive plan to control rock desertification using biological, engineering and management integrated approach. One attempt is to help peasants get rid of poverty and encourage them to give up crop farming and return to bamboo, grass or orchard farming, along with aforestation. Other attempts suggest agriculture and grazing prohibition in vulnerable areas. In addition, alternatives should be promoted to provide local residents to earn a living and to reduce poverty (Fan and Gao, 2000). Measures such as vegetation protection, reforestation, grassland improvement, soil conservation, biogas and electricity use are encouraged to enhance good ground cover in rock desertification areas. However, most remedial proposals need adequate supply of quality water and application. As such, means to increase good quality surface water supply is the key to alleviate rock desertification problem in southwest China.

NATURAL GROUND CATCHMENT AND OPEN WATER RESERVOIR

Large open water ponds are useful in storing rainwater. Natural depressions also hold rainwater in a similar way but are not modified or designed. Ponds include those that are either excavated or which might make use of the natural topography, and which in most cases involve an embankment around part of the pond to retain water (the material may have come from excavation works) (Figure 2). These reservoirs can also be formed in existing seasonal water courses or valleys, in which case they may also be called valley dams or check dams. They can have limited to high aquifer recharge capacity – for ponds purposely built to increase groundwater recharge (Figure 3). Ponds are excellent in storing surface water for various uses (e.g. irrigation, livestock), although they may also recharge groundwater. Ponds can be lined as well as unlined (Figure 4).

Suitable Siting

The advantages and disadvantages of natural ground catchment and open water reservoir are listed in Table 1. Besides providing direct water use, ponds can recharge ground water and near-by ponds also. However, the negative effects of ponds may include siltation, high evaporation, seepage, construction and maintenance. The stagnant water may breed vectors and cause degraded microbiological and chemical water quality. The most ideal locations for constructing ponds are areas with high rainfall intensity leading to high runoff and minimum infiltration into the soil. Building small reservoirs (5-10 ha) in large watersheds (> 400 ha), a good spillway is necessary to avoid problem with siltation. Siting is best determined in proximity of village and road access. With larger reservoirs (> 15 ha), hydrology plays an important role in the design. However, reservoir size less than 10,000 m^3 is not recommended for watershed larger than 400 ha. The amount of overflow is often too excessive and creates spillway wash-out. In pasture land areas, ponds are recommended in areas where traditional pasture may flourish with the first rain. This can make direct good use of rainwater to establish ground cover and minimize seepage and evaporation. So that later on much water may be collected by dams with more surface runoff.

Table 1. Advantages and disadvantages of natural ground catchment and open water reservoir

Advantages	Disadvantages
1. Can be used for direct water use. 2. Ponds may recharge into surrounding ground and near-by wells so there is continued water even after pond dries up.	3. Silt up easily due to lost vegetation cover and leads to soil erosion under intense rainfall and high runoff volumes. De-silting takes time and money. 4. Maintaining dams requires communal effort and communal institutions might not be strong enough. 5. High combination of evaporation and seepage rates means that water in ponds does not last very long. 6. Vectors can breed in open water. 7. Microbiological and chemical water quality is not acceptable for direct consumption. 8. High cost of construction.

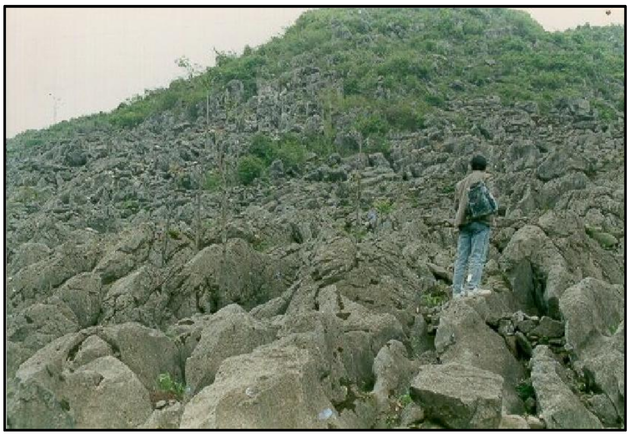

Figure 1. Typical landscape of a rocky desert in southwest China (Yuan, 1997)

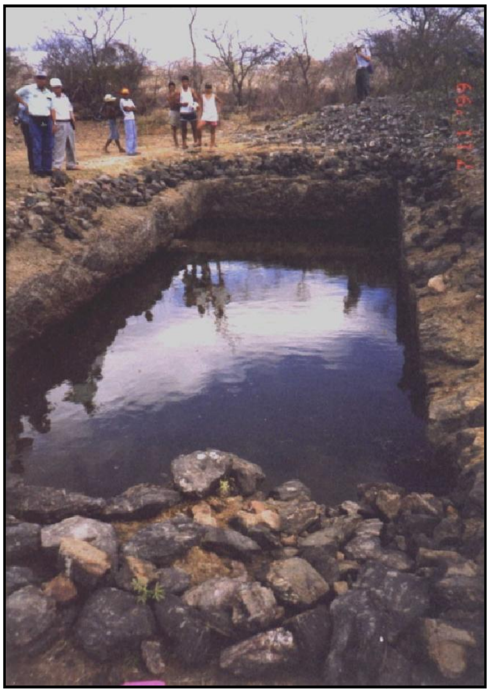

Figure 2. Excavation work to construct a rock catchment in Brazil

Figure 3. Earth embankment to retain rainwater for groundwater recharge in Iran

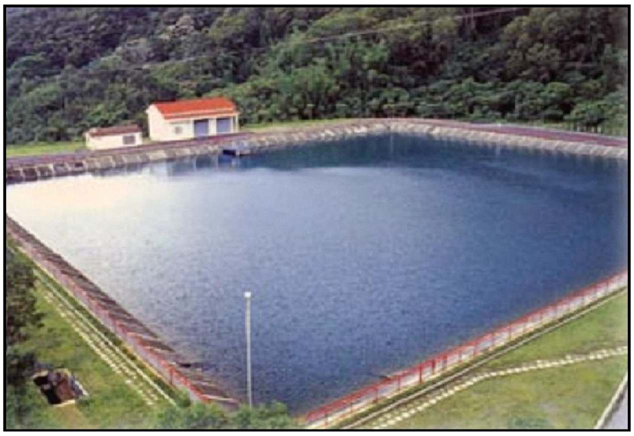

Figure 4. A lined open water pond in Taitung, Taiwan

Design

Pond size (or dam height) can be decided according to water demand, evaporation and seepage losses, length of critical period and average stream flow according to the following:

$$S = (R + A \times E - Q) \times T \qquad [1]$$

where,
S = effective storage requirement (L)
R = water demand (L/day)
A = area of pond (m^2)
E = evaporation and seepage losses (mm/day)
Q = average stream inflow during critical period (L/day)
T = length of critical period during which stream flow is less than water requirement (days)

Site should then be surveyed to estimate area A (m^2) of pond/reservoir for different values of normal water level. The water level that gives reservoir capacity greater than storage requirement S is the optimum height of the dam D (m). To allow for flood level and safety margin, D plus 1 m is the best recommended dam height.

Construction

Land ownership issues should be solved prior to construction of new dams. Small dams owned privately might have more chance of success in terms of construction and maintenance.

However, small dams tend to fail much more frequently than larger dams. This is often due to poor siting, lack of design, poor construction techniques and lack of maintenance. Proper design, construction and maintenance are therefore important. The following are guidelines used for hillside dams less than 3 m high, where water is retained by an embankment. For heights over 3 m, other guidelines are available.

1. Material used for the dam wall should be impermeable. It should have a high clay content (55% minimum), to avoid cracks that induce piping and leakage. The following materials are not recommended: organic material in topsoil with roots/stones, decomposing material, material with high mica content, cracking clays, calcitic clays, fine silts, sodic soils (high sodium concentration), schists and shales. Piping is often a major reason for structural failure of dams and can be recognized by increased seepage rates, discolored seepage water, sinkholes on or near the embankments and whirlpools in the water.
2. The dam should have a cut-off (minimum 2.5 m wide) which locks into the subsoil foundation.
3. Strip topsoil away from dam foundation since it contains organic matter.
4. Dam material layers in 100-200 mm depth and compacted (with roller or vehicles/animals) at optimum moisture content.
5. An additional 10% material is necessary to allow for settlement after construction.
6. Upstream slope should be 1 : 3. Downstream slope should be 1 : 2.5.
7. To prevent overtopping of dam crest, water level should be 1 m less than the dam crest. For a 3 m high dam, normal water level should be 2 m high, leaving 0.5 m for floodwater level (height of spillway) and at least another 0.5 m as a safety margin for water rise due to wind/wave action and wear and tear on the dam crest.
8. The dam crest should be 10% higher at the center (convex shape) so that in case of catastrophic overtopping, water will escape from the edges which will require less repair work.
9. Crest width should be 3 m minimum. For dams over 3 m, width needs to be greater (4 m minimum). The crest needs to have a slope of 1 : 50 from downstream to upstream side of the crest.
10. Dam embankment needs to be protected both upstream and downstream. This can be done by covering with topsoil and planting with low spreading grasses (e.g. Kikuyu grass) to protect against erosion. In arid and semi-arid areas where grasses may not easily grow without irrigation, graded rocks (riprap) with maximum size of 600 mm is recommended to cover the embankment.
11. A floating timber beam secured 2 m from the dam is suggested to protect the upstream slope and needs to be replaced every 10 years. Stone or brush mattress and with maximum size of 600 mm may reduce erosion and protect the upstream slope.
12. A rock-toe drain may be used to collect seepage water (which is inevitable with all earth dams). This is built up to one third the dam height with a graded sand/gravel layer separating the dam material from the rock-toe (to stop clay particles being washed out).
13. The spillway outlet needs to be made robust enough to resist erosion. Concrete can be used. But a cheaper way is a grass spillway. If grass cannot grow well, riprap may be used instead. Velocity should not exceed 2.5 m/s. Spillway inlet widths vary according to the floodwater flow, but a minimum width of 5.5 m is recommended. The spillway needs to be kept clear from debris to avoid overtopping.
14. The spillway channel should not allow erosion of the dam structure, and ideally should be lined with walls to channel the water in the right direction. Grass again may be used (e.g. Kikuyu grass), planted in contour lines with 30 cm spacing may resist erosion. Alternatively, low stone masonry walls at 2 m spacing may act as a staircase to slow down floodwater. The end of a lined spillway channel needs to have a cut-off down to solid ground or rock in order to prevent undercutting of the channel. Spillway slope should be 1 : 33.

A large number of small reservoirs designed to hold water have high seepage rates (up to 24 mm/day). Seepage can be reduced by:

1. Covering the pond base with clay soil and compacting it with vehicles or animals. Lining may become more robust with addition of powdered lime.
2. Large open reservoirs have been lined in the past with natural or artificial liners, but it is expensive and the lining material is prone to damage by animals, ultraviolet light, and the desilting process.

Operation

For open water catchments that utilize rock surfaces or water stored behind earth dams, direct abstraction (using pumps or pipes) works well. Abstraction method should minimize disturbance of the settled water, thus reducing treatment requirements later. Even with preventive methods to reduce turbidity (silt trap, extraction method), the water is still turbid and contaminated and may require treatment. Choice of household water treatment technology should be based on efficiency of removing contaminants present in the water. Open waters are subject to cyanobacteria, due to many nutrients in the water. The start of the rainy season is the most likely time for cyanobacterial proliferation. Cyanobacteria can be harmful to human health and can cause minor disorders such as headaches or lethal deterioration of hepatic functions and promotion of liver cancer. For open waters that may be prone to cyanobacterial blooms, a concrete biosand filter is a good choice due to its ability to remove cyanobacterial toxins. For reservoirs near urban environments or where the runoff area has intensive agriculture practice in its vicinity, diversification of water resources is a good idea to provide alternatives for direct drinking purposes. Strengthening controls and restrictions on use of illegal substances will also help. Microbiological and chemical water quality is likely to not be acceptable for direct consumption. Water is often contaminated by urban runoff, as well as communal access to the water by humans and animals. Where runoff is from agricultural areas, there is a possibility of pesticides and fertilizers entering the pond water and sediments. Some may have harmful effects for the aquatic environment and human health. There are many ways to reduce risks by reducing nutrient loads entering the reservoir. This includes rehabilitating vegetation in the runoff zone to use up some of the nutrient enriched water before it enters the reservoir.

Maintenance

Siltation is probably the greatest risk of failure with ponds and dams. The idea is to keep silt out in order to reduce the need for subsequent desilting, and to have desilting mechanisms and institutional arrangements that actually work. Keeping a good cover of indigenous grasses in the runoff area may prevent silt build-up. Contour lines with trees or grasses in the runoff area also work. If the inflow channel is defined, silt traps can be used to reduce silt load. Stones laid across the channel form mini dams and perennial vegetation can be grown between these mini dams to reduce flow velocity of water, thereby encouraging silt deposition. Desilting will most probably need to be carried out at some stage. There may be more sustainable ways of doing this compared to the usual approach of hiring commercial help and often paid for by the public sectors. For effective desilting, incentive schemes are commonly needed to entice communities to improve their own ponds. New and innovative ways to engender ownership and management of facilities are most critical. An institutionally-resilient way to desilt ponds may be to promote ponds on private land, where one landowner has a vested interest to maintain and desilt the pond, thus reducing the need for public intervention in the longer run.

Other considerations

High evaporation rates are common with open water in certain areas, depending on the climate. Water lost to evaporation can be considerable. Some ways to reduce this may include:

1. Digging deeper to have a larger volume to surface area ratio.
2. Planting trees around the pond will act as a windbreak, thereby reducing evaporation.

Fish can be introduced to eat mosquito larvae, while at the same time providing a source of nutrition. Mudfish are a good option as they can survive dry periods in the silt at the base of ponds. Experience from many under-developed countries indicates that access to finance seems to be important in allowing farmers to implement ponds.

CONCLUSION

Substantial efforts have been made in studying the nature and origin of rock desertification and possible countermeasures in the karst region of southern China. Remedial measures such as vegetation protection, reforestation, grassland improvement, soil conservation, biogas and electricity use are encouraged to enhance good ground cover in rock desertification areas. However, most proposals need adequate supply of quality water and application. As such, means to increase good quality surface water supply is the key to alleviate rock desertification problem in southwest China. Large natural ground catchment and open water ponds are useful in storing rainwater. Besides providing direct water use, ponds can recharge ground water and near-by ponds also. However, the negative effects of ponds may include siltation, high evaporation, seepage, construction and maintenance. The stagnant water may breed vectors and cause degraded microbiological and chemical water quality. Proper siting, design, construction, operation and maintenance are therefore essential in ensuring success in alleviating rock desertification problem in southwest China.

Acknowledgements

This paper was supported by Project No. 14-A-03-01, Key Laboratory of Karst Dynamics, Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin, 541004, P.R. China.

REFERENCES

Cao, J.H., Yuan, D.X., Zhang, C. 2004. Karst ecosystem constrained by geological conditions in southwest China. Earth and Environment, 32 (1): 1–8.

Fan, S.Y., Gao, X.C. 2000. Innovations in the model for bringing desertification under control in China an Institutional Creation. Social Sciences in China, (6): 37–44.

Han, Z.Q. 2006. Exploitation of Guizhou Province during the Yongzheng reign period and its effect on the rocky desertification in this area. *Fudan Journal (Social Sciences)*, 23(6): 657–666.

Jiang, Z.C., Li, X.K., Hu, B.Q. 2011. Rocky Desertification in Karst Mountainous Areas in Guangxi and Its Comprehensive Treatment. Science Publishing House, Beijing, China.

Jiang, Z.C., Lian, Y.Q., Qin, X.Q. 2014. Rocky desertification in Southwest China: Impacts, causes, and restoration. Earth Science Reviews, 132: 1-12.

Li, S., Dong, Y.X., Wang, J.H. 2007. To discuss the concept and classification of rocky desertification again. Carsologica Sinica, 26(4): 270-284.

Tu, Y.L. 1996. Analysis on actuality and cause of rocky desertification of Guizhou. In: Li, Q. (Ed.), Exploiture and Future of Calcareous Rocky Area. People's Press of Guizhou, Guiyang, China.

Wang, S.J. 2002. Concept deduction and its connotation of karst rocky desertification. Carsologica Sinica, 21(2): 101–105.

Wang, S.J., Li, Y.B., Li, R.L. 2003. Karst rocky desertification: formation background, evolution and comprehensive taming. Quaternary Sciences, 23(6): 657–666.

Yang, J.C. 1993. Features and Evolution Landforms in China. Ocean Press, Beijing.

Yuan, D.X. 1993. Environmental change and human impact on karst in south China. In: Williams, P. (Ed.), Karst terrains: environmental change and human impact. Catena Suppl., 25: 104.

Yuan, D.X. 1997. Rock desertification in the subtropical karst of south China. *J. Geomorphol*., 108: 81–90.

Yuan, D.X. 2002. Karst Ecological System of China. Geology Press, Beijing.

Zhu, Z.D., Cui, S.H. 1996. The problem of desertification in south China. *Journal of Desert Research*, 16(4): 331–337.

****