Acta Ecologica Sinica 34 (2014) 116–122

Contents lists available at ScienceDirect

Acta Ecologica Sinica

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

Determination and analysis of phreatic water evaporation in extra-arid dune region

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ARTICLE INFO

Article history:
Received 28 September 2012
Revised 9 April 2013
Accepted 5 June 2013

Keywords:
Desert
Extra-arid region
Phreatic water evaporation

ABSTRACT

Extra-arid desert is a terminal of biological geochemistry circulation system. It has important value in scientific research and huge new discoveries, which is very useful in many regions, such as energy resources, mineral, water resources, ecology, biodiversity, tourism and characteristic agriculture. Meanwhile, extra-arid area's desertification is a serious threat to the ecological safety of earth. Aeolian desertification is one of style of desertification caused by water shortage. Once desert has formed, it is very difficult to management or recovery. One of most effective methods for desert control is using integrated ecosystem management based on considering water and the soil. Therefore, it is very important to find a new available water resource, and authors' research is in this field. In this paper, we select a Gobi on Dunhuang Mogao Grottoes of Kumtag desert fringe, where the buried depth of phreatic water is over 200 m. Using an arched shed-air conditioning system, where covered drift sand thickness of 2.0 m, the phreatic evaporation was measured for the first time. In order to analyze influence factors, the evaporation of phreatic water on Gobi was measured and compared. The temperature of soil and air, the humidity inside and outside of the arched shed were also monitored. It is found that the phreatic water under sand can go through sand layer and get to surface, which forms evaporation. The amount of evaporation changes along with solar radiation and temperature fluctuations in the day. It also changes periodically in the year. During five months from June to October, the sunshine time is longer and temperature is higher, and the evaporation is higher too, and the mean daily evaporation is 3.6 g/(m^2 d). In other periods, the amount of evaporation of phreatic water is extremely weak. It is difficult to monitor by the arched shed-air conditioning system. Compared with Gobi region, the amount of evaporation of phreatic water on dune is very low, which is only 15.0% evaporation on Gobi. The key reason is the difference of salts in soil. The crystal water could be decomposed from salts or combined again. This reversible process plays a key role in transferring phreatic water of dune and Gobi. The amount of phreatic evaporation is proportional to the salts content in shallow soil. The salts content in dune is only 0.7% of salts content in Gobi, and water content in dune is 3.2% of the Gobi soil. According to results of monitoring, the water content is low in sand. The crystal water in shifting sand could be completely decomposed from salts with temperature rising. It causes relative humidity (RH) decreasing, which is inversely in the sand compared to in Gobi soil. In depth of 10 cm sand, the daily fluctuation is about 10%, which is significantly higher than that of in Gobi soil (3%). As the crystalline salt is a kind of typical water carrier, decreasing the content of crystalline salt results to reduce water transporting because carrying capacity of water is significantly reduced. After condensing and collecting 168 days, 9808 g of water was outputted from sand. However, the water content in sand was still obviously higher than original content. That means the underground vapor migrates upward, and the phreatic water moves to surface. From the evaporation comparison of dune and Gobi, we can conclude that the amount of evaporation could be controlled by changing the soil property in interface, this points out the direction for utilization of phreatic water evaporation.

1. Introduction

The lack of water is the main cause of desertification, it seriously influences the human production and living environment [1]. In recent decades, the study of land desertification is gradually paid high attention by governments and scientists from the world, and involves multiple disciplines such as plant ecology, geological geomorphology, climatology, hydrology and soil science [2]. However, just as the world famous desert scientist Петров said, in currently the arid desert research on the whole was still relatively weak [3]. The extra-arid desert is the terminal of biogeochemical cycle system, and has great value in scientific research and huge

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1872-2032/$ - see front matter
http://dx.doi.org/10.1016/j.chnaes.2013.06.004

potential new discoveries. The extra-arid desert in China, accounting for 36.9% of arid regions, is a new frontier of national economic development, also has an important significance for energy, minerals, water resource, ecology, biodiversity, tourism, characteristic agriculture, etc. [4]. But meanwhile, the extra-arid desertification is a major factor in threatening global ecological security, among which the aeolian desertification is one of the most important form. Once aeolian desert has formed, it is very difficult to management [1–4]. The most effective means of controlling desertification scientifically is a comprehensive biological–ecological management with water as the center, the soil as the foundation, and biology as the leading [4]. From the long-term perspective, if vegetation coverage on the dune areas reaches to a certain degree, it would guarantee the sand surface against wind erosion, and desert could be controlled permanently [5]. In the phreatic water shallow-buried areas, using the groundwater to construct the ecological windbreak belt has made a significant progress [6], and the windbreak plays an important role in combating desertification [7].

In the extra-arid region where phreatic water is deep-buried and the buried depth is over than capillary functions. On the one hand, some researchers concern on phreatic water study, such as phreatic water evaporation [8], the role of phreatic water in ecosystem [9] and the influence of buried depth itself on vegetation [10], on the other hand, the more researchers focus on overground water, for example, the rainfall [11], dew [12] and atmospheric water effects on soil moisture in the shallow layer [13], as well as ecological response [14]. The laws of water activities in dune [14–16], rainfall infiltration [17] and water sources [18] have been the hotspot of research. For a long time, most studies consider that soil moisture in the extra-arid regions is the remains of precipitation [19], when buried-depth reaches to a certain degree there will be no more evaporation, because there are a zero flux plane and a maximum depth [20]. Moreover, by soil weight method it is found that soil water in the shallow layer in the extra-arid area has violent daily fluctuations, many scholars think that the atmospheric water can form condensation water in soil [21], in some areas the accumulated quantity of condensation water is over the local precipitation [22,23] and even greatly complements the phreatic water [24], but other studies consider that the condensation water mainly comes from groundwater, and phreatic water has great feedback and supplement to soil water in the shallow layer [25,26], the condensation water and precipitation are unable to supplement the phreatic water in the extra-arid region [27,28].

Therefore, the authors have systematically studied moisture in the extra-arid region from Groundwater–Soil–Plant–Atmosphere Continuum (GSPAC) movement aspect and consider that there exists a mechanism and the conditions for phreatic water moving up even in Mogao Grottoes where the buried depth exceeds 200 m [29]. In Mogao Grottoes the monitoring of soil weight showed that soil moisture fluctuates violently, as same as the other extra-arid areas, the amount of diurnal variation is up to 9.3 mm in 0–60 cm soil, but monitoring of soil humidity showed that relative humidity (RH) generally remains below 61% and there is no water condensation event happening in 0–20 cm soil, where the water change is most violent [30,31]. The authors conducted a qualitative analysis of soil moisture sources in Gobi [32] and Dune [33] by the arched shed; the results showed that phreatic water is the main source of deep soil moisture in the extra-arid region. Soil water fluctuations in the extra-arid region are the result of moisture adsorption and decomposition under the effect of temperature; it is an important process of GSPAC movement and form of phreatic water evaporation [29,30].

The new finding of phreatic water source has brought a new hope for controlling the extra-arid desert, therefore, to determine the quantity and characteristics of phreatic evaporation, as well as GSPAC movement mechanism are crucial to exploitation and utilization of phreatic water. The preliminary results from natural condensation of arched shed (greenhouse) showed that there is 2.1 g/(m^2 d) phreatic evaporation in Gobi [32] and only 1.3 g/(m^2 d) in dune [33], the amount was so small that its utilization value was in doubt, but analysis revealed that it was the greenhouse effect that seriously restrained the phreatic evaporation. In 2009, an air conditioner was installed in the shed through air conditioner's refrigeration and condensation dehumidification to control temperature and humidity inside the shed and by the amount of air conditioner condensation water to measure the phreatic water evaporation in Gobi surface. The results showed that there exists at least 21.9 g/(m^2 d) phreatic water evaporation in Gobi soil [34]. If this water can be made full use by plants, it is enough to support a certain degree of vegetation coverage, thus achieving the aim of ecological control of the Gobi desert. Therefore, determining the amount of phreatic water evaporation and influential factors in the sandy desert are very critical for biological sand-control and managing sandy desert, and these also are issues that need to be solved urgently.

At the same time, the land degradation in the extra-arid desert, the global climate warming and the increasingly fierce human disturbance are causing serious damages to natural history of desert, and its cultural heritage is in danger of unprecedented loss too [4]. The Mogao Grottoes in Dunhuang is a cultural treasure in the extra-arid desert, also faces severe challenges. However, moisture is the main factor which makes precious wall paintings deterioration, such as mildew, disruption, plaster detachment and flaking. The drift sand activities on the top of grottoes are extensive and probably have a significant impact on phreatic evaporation, as well as directly affect the caves' water migration under ground. Therefore, the measurement and study of phreatic evaporation on dune in the Mogao Grottoes area have a great practical significance to scientific conservation of the precious cultural relics.

2. Description of experimental areas

The location for the dune-shed-air conditioner condensation experiments is located on the top of the Mogao Grottoes (40°02′14″N, 94°47′38″E) and is about 1 km from the group of caves (Fig. 1).

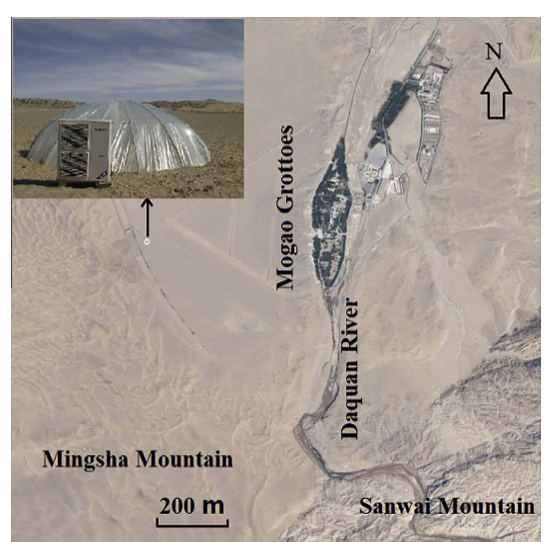

Fig. 1. Site of experiment and control of shed-air condition system.