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Protect a desert scenery by restoring the natural wind flow field

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SUMMARY: (10 pt)
The Singing Sand Mountain and Crescent Spring scenic spot in Dunhuang, Northwest China is a world-renowned desert attraction. This area underwent a 30-year transformation from a severe sand risk with the spring water facing sand bury due to dune deformation to the restoration of the original sand flow field and the mitigation of the sand problem. The current paper summarizes the research works on the intensive monitoring of the dynamic change of a star dune, the observation of wind and sand flow, and then the resounding of dumbed singing sand. The existing and potential impacts of anthropogenic and natural forces on the deformation of the sand mountain are described, followed by the mitigating measures implemented and their ameliorating effects. Contract to common sand control practices that may desire to reduce wind speed and stop blown sands, the mitigation measures here consisted of removing excessive vegetation and newly added buildings to recover the original wind flow field and sand transport activity. These research and mitigation efforts ensure the scientific protection and restoration of the special desert landform and contribute to the mutual enhancement of the conservation and exploitation of this representative desert scenic spot.

Keywords: Singing Sand Mountain; Crescent Spring; wind-blown sand problem

1. INTRODUCTION

The Crescent Spring scenic spot in Dunhuang City, Gansu Province, is located at the western end of the Hexi Corridor and the center of the ancient Silk Road. In recent decades, the wind-blown sand activity has posed a threat to this precious scenic spot as the dunes at the north and south tend to migrate toward each other, resulting in a shrink of the spring area and a fatal buried future. These threats posed by wind-blown sand, which may lead to the disappearance of spring, have garnered widespread attention (Zhang et al., 2019).

Since 2008, aeolian researchers and the management departments have collaborated to establish multiple observation sites and to study regional air circulations, local airflow characteristics, blown sand activities, sand dune morphologies and changes using a variety of scientific techniques. The scientific causes of the dangers posed by wind-blown sand were identified, along with related mitigation strategies. Then, a number of engineering control measures were implemented, effectively mitigating the threat posed by the sand problems to the spring. These works are acknowledged by every segment of society.

2. RESEARCH ON DUNE MORPHOLOGY

2.1. Long-term monitoring

Using photographs from a century ago and interviews with local staff and residents, it has been demonstrated that the geometry of the north and south sand dunes has obviously changed, and that they tend to move closer together and bury the spring. Multiple monitoring sections were constructed using multi-period remote sensing images of 1963, 1985, 2004 and 2009 for dynamic monitoring analysis. It was discovered that the slopes of the two dunes in the north and south, which are both over 100 m in height, were relatively stable, whereas the slopes facing the spring had significantly increased in height and their ridge lines had moved closer over the past several decades. The formerly smooth south face of the north dune rose more than 20 m in height, resulting in an obvious bump toward the spring (Figure 1 c), whereas the north face of the south dune rose approximately 15 m (Pang et al., 2014b; Zhang et al., 2013).

2.2. Short period monitoring

Since 2014, annual 3D scanning of the dunes has been performed in order to construct digital models, extract morphology changes, and calculate erosion and accumulation rates at various locations throughout the entire dune surface. It was proved that the ridge line of star dunes and the low-lying linear dunes in the perimeter undergo considerable changes over the course of a year, and the impacts of the three principal wind directions on the seasonal morphological changes of dunes were investigated in depth (An *et al.*, 2018; Zhang *et al.*, 2019). The multiphase data indicate that the northward movement of the south dune has been limited, whereas the southerly surface bumping of the north dune has recovered in 2018-2019.

3. RESEARCH WORKS ON WIND FLOW FIELD

3.1. Background winds

Monitoring work indicates that the dynamic equilibrium of sediment transport under the three principal wind directions is the primary reason for the long-term persistence of huge dunes and the Crescent Spring. The northeast wind and northwest wind are mainly influenced by regional circulation, whereas the southerly wind is the valley wind created by the complex terrain of sand mountain and the difference in heat capacity between sand dune and the spring (Zhang *et al.*, 2013). Due to the influence of newly constructed buildings and trees over the past years, the east wind that reaches the spring has been diminished, and the original sand transport condition has become unbalanced (Zhang et al., 2012). In contract, the south wind was stable and relatively stronger than before, leading to the northward movement of south dune and burying the ancient buildings near the spring (Pang et al., 2014).

3.2. Surface airflow

Multiple locations on the surface of surrounding dunes are equipped with 2D and 3D wind speed and direction observation devices to record both short-term and long-term surface airflow changes. It is proved that the star dune on the north side of spring generates a high vertical climbing flow and a strong backflow area on the leeward side under northeast wind conditions, similar to a transverse dune. Under a northwest wind, the dune modifies the airflow like a longitudinal dune, and the wind speed on the windward side increases significantly with the dune height (Zhang et al., 2016). The morphological changes of star dunes are controlled by the activities of wind and sand, indicating that the original air flow field in this area must be restored to recover the shape of sand mountain (Zhang *et al.*, 2019).

4. THE INFLUENCE OF ANTHROPOLOGICAL FACTORS

4.1. Urban development in the upwind direction

we determined the impact of new city construction on the spring and the feasibility of the construction activity. Wind observation control sites were established at the open Gobi area in the upwind, the construction site, and northeast of the spring. On the construction site, 5 mobile wind masts were set up to create an observation section (O1-5) to evaluate the impact of construction work on the wind that flows approaching the spring. Mthe newly constructed structures can reduce downwind speed by more than 40%.

Then, numerical simulations based on actual terrain and encompassing the entire proposed construction area and the northeast Gobi is conducted to examine the variation of the air flow field under various future construction scenarios (Liu *et al.*, 2014). It was determined that the current planning and design of the new city may reduce the northeast wind speed and wind energy reaching the spring by about approximately 10% and 20%.

4.2. Surrounding vegetations

The area of woodland and orchard at the edge of the oasis on the north side of Crescent Spring has been expanding steadily expanding over the past 30 years, coinciding with the considerable shift in dune morphology. We established high-precision scale wind tunnel experiments using a 3D-printed solid model in which the spatial position and percentage of surrounding ground items are all mirrored, and streamwise wind speeds were measured directly at the model surface by multiple pitot tubes (i.e., Figure 9 of Liu *et al.*, 2021). The impact of dunes, building, spring water, grass land, and trees are also simulated in meter-level numerical models in equal proportion (i.e., Figure 8 of Liu *et al.*, 2021).

4.3. The artificial removal of a dune arm

For the convenience of tourists, the southeast arm of the north star dune was removed artificially in the 1990s, which was also consistent with the considerable morphological change of dunes. The effect of the removal of SE dune arm was studied using high-precision 3D wind tunnel tests and numerical simulations. With and without the arm, the wind fields at several points of the dune were compared. The arm was printed as a part of the solid model in the wind tunnel or visually constructed in the numerical simulation. Although the removed portion represented only 0.07% of the overall volume of the dune (about 1×104 m^3), it had a significant impact on the extent and severity of the backflow zone on the south leeward area under northeast wind (Liu *et al.*, 2021).

5. THE APPLIED MITIGATION MEASURES AND THEIR EFFECTS

5.1. Mitigation activities

Based on these research works, short-, medium- and long-term sand control recommendations were proposed. Among them, the impact of tourists' tramping is visible, because a considerable quantity of sand has slid down the slopes of the two dunes facing the spring, which surpasses the ability of the air flow to transport sands upward. It can be resolved by restricting the climbing area and regulating the tourist population (short term measure). In 2012, mitigating practices were initiated. In the northeast direction, 0.5 km^2 of waste landfill site, mining and excavation of sand pits, and some unauthorized plant building on the gravel flat surface were removed (Figure 7a). About 1722 fruit trees and 10047 wood trees that planted in recent years on the edge of oasis

and at the north foot of the dunes were removed. On the east side of the spring, the original administration office with 2000 m^2 buildings has been removed. The ancient building group adjacent to the spring has taken measures including opening or demolishing walls to minimize their influence on wind flow and restore the natural flow field.

5.2. Effect of mitigation measures

All kinds of mitigation measures have direct impact on restoring the original air field and sand dune morphology surrounding the spring. In-situ observations indicate that the sand drift potential of the NW wind at the top of the north dune has about doubled compared to what it was before to the implementation of the measures, and that the average wind speed close to the spring has increased by more than 10%. As a result, the bump "belly" on the south slope of the north dune tends to disappear, the accumulated 1.2-meters-high sand that once buried the corridor near the south wall of the ancient buildings was naturally removed by wind, and the sand deposit on the east side of spring decreased significantly.

6. CONCLUSIONS

The Crescent Spring is a rare natural desert scenery, but many disturbances on the wind flow field, including extra buildings, vegetations, and tourist tramples, have caused the deformation of surrounding dunes, the loss of spring space, and the silence of singing sands. The aeolian sand disaster has been mitigated and aeolian geomorphology has advanced over the past decade as a result of mitigation efforts based on extensive research on the dune shape dynamic, wind flow, and their impacting elements.

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