



Dr. Pooja Panchariya, is a State Forest Services Officer, in Rajasthan, presently undergoing SFS induction training (2022-2024) at Central Academy for State Forest Services, Coimbatore. Dr. Pooja has been awarded doctorate degree in Chemistry from Jai Narain Vyas University, Jodhpur. She has published more than 15 scientific research papers in reputed National and International Journals and Conferences in the field of chemistry. She has qualified CSIR NET JRF, SET and GATE examinations. She has served as Lecturer before joining Rajasthan Forest Services. Her vision is to play a pivotal role in conserving wildlife and managing natural resources, implementing sustainable forestry practices to foster environmental resilience and fight climate change.

Sand Dune Stabilization in Thar Desert of India: Challenges and Practices

Pooja Panchariya

Sand Dune Stabilization in Thar Desert of India: Challenges and Practices



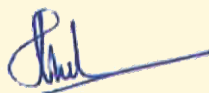
**CENTRAL ACADEMY FOR STATE FOREST SERVICE
COIMBATORE**

2024

◆ Foreword ◆

Dr. Pooja Panchariya, State Forest Service (SFS) Officer Trainee of 2022-24 batch from Rajasthan state has written a Field guide on Sand Dune Stabilization in the Thar Desert of India based on her experience in her On-Job-Training. It is a useful guide to the practicing foresters in desert areas. I compliment Dr. Pooja Panchariya, State Forest Service (SFS) Officer Trainee of 2022-24 batch for bringing forth this useful guide. It will also serve as a bench mark guide to plantation in desert areas, as they have further scope of developing as per their requirements. I also wish her to keep the enthusiasm in documenting useful management practices for the benefit of forest managers.

Best Wishes.



V. Thirunavukarasu, IFS
APCCF &Principal, CASFOS, Coimbatore

Preface

The western part of Rajasthan, the Thar Desert, a vast expanse of arid land, is a symbol of resilience and adaptation. Sand dunes cover a large part of it. The relentless winds and shifting sands pose a constant threat to the fragile ecosystems and communities that reside in and around these sand dunes. Bikaner, a city nestled within this desert landscape, has grappled with the challenges of sand dune stabilization for generations.

This field guide delves into the intricate relation between man and nature, exploring the various strategies employed to combat the encroaching dunes and protect precious resources. From traditional methods passed down through generations to innovative technological solutions, we will examine the multifaceted efforts to create a sustainable future in the heart of the Thar Desert.

Dr. Pooja Panchariya,
Officer Trainee, SFS 2022-24
Batch-II, CASFOS Coimbatore

◆ Acknowledgement ◆

With great regards, I would like to express my deepest gratitude to our respected Principal CASFOS Coimbatore, Shri V. Thirunavukarasu, IFS for triggering the interest and providing the necessary platform to come up with this publication.

I extend my sincere thanks to respected former Course Director, 29thSFS Batch 2022-24, Dr. K Anandh, IFS and our Course Director Sh. Anisha Kalkoor, M, IFS for their guidance, persistent encouragement and valuable inputs throughout the training.

My sincere gratitude to the esteemed faculty members: Dr. V. S. Senthilkumar, IFS, Dr. C. Vidhyasagar, IFS and Dr. Ramkrishnan R., Scientist C, for their technical guidance and the mentorship they have provided.

I am highly indebted to Sh. Hanumana Ram, CCF, Bikaner, Sh. Madan Singh Charan, DFO, IGNP stage II, Bikaner for giving me the opportunity and required space to study the Sand Dune Stabilization works of the division during on job training and compile this work.

I am especially grateful to members of the Editorial Committee Dr. Ramkrishnan R, Shri. K. Muniyasamy, PT&GI and Dr. B. Md. Rafi Hussain, Library Information Assistant for their valuable time and inputs related to the layout and design of this publication.

My gratitude extends to my friends and family members for their unwavering support and encouragement.

Lastly, I would like to express my grateful thanks to my fellow Officer Trainees of SFS Batch 2022-24 for their constant encouragement and for providing the cordial atmosphere to come up with this work.

with heartfelt appreciation

Dr. Pooja Panchariya

Contents

Topic	Page No.
Foreword	
Preface	
Acknowledgement	
1. Introduction	1
2. Characteristics of Thar Sand Dunes	6
3. Objectives	9
4. Case study of Sand dune stabilization	12
5. Materials and Methods	21
6. Results and Discussions	27
7. Discussions	30
8. Annexure I	35

1. Introduction

A sand dune is a hill or ridge of sand accumulated by wind action, commonly found in deserts, coastal regions and other arid or semi-arid areas. Sand dunes are formed through the process of wind erosion and deposition, where wind-blown sand particles are transported and deposited in areas where the wind's velocity decreases. The shape and size of sand dunes can vary widely, ranging from small mounds to large, extensive dune fields. The formation and movement of sand dunes are influenced by several factors, including wind direction and strength, the availability of sand and the presence of vegetation, which can stabilize the dunes and reduce their mobility.

Sand dunes, commonly found in deserts and coastal regions, are formed through wind action and vary widely in shape and size. Their stabilization is critical for ecological, environmental, and socio-economic reasons.

This field guide investigates various sand stabilization methods implemented in Bikaner, Rajasthan, India, and other global regions. Key objectives include monitoring dune movement, preventing siltation, enhancing biodiversity, improving soil fertility, and conducting long-term research. Temporary sand control methods, such as sand shielding with stone mulch and water or brine wetting, and the construction of sand fences (checkerboard and fore dune fences), provide immediate but short-term stabilization. Permanent

stabilization through afforestation, although challenging due to desert conditions, offers a sustainable solution.

Essential factors for successful afforestation include effective water management, selecting appropriate plant species, and ensuring site maintenance. The results demonstrate that temporary methods effectively reduce wind erosion and sand movement, creating favourable conditions for permanent solutions.



Fig. 1: Image of sand dunes encroaching residential area taken from high altitude drone

Afforestation significantly improves soil conditions, enhances biodiversity, and provides socio-economic benefits by protecting infrastructure and creating recreational areas. Regular monitoring and maintenance are crucial for sustaining these measures. Sand dune stabilization is significant for several ecological, environmental and socio-economic reasons.

- A. **Erosion Control:** Stabilized sand dunes help prevent soil erosion by wind and water, protecting inland areas from desertification and loss of fertile soil.
- B. **Habitat Creation:** Stabilization promotes the development of diverse plant and animal habitats. As dunes stabilize, they accumulate organic matter and nutrients, supporting a variety of plant species, which in turn provide habitat and food for animals.
- C. **Biodiversity Conservation:** Stabilized dunes support a wider range of species compared to active dunes. This increased biodiversity includes various plants, insects, birds and other wildlife that rely on stable dunes for survival.
- D. **Climate Regulation:** Vegetation on stabilized dunes can act as a carbon sink, absorbing carbon dioxide from the atmosphere and contributing to climate change mitigation.
- E. **Water Retention:** Vegetated dunes enhance the infiltration and retention of water, which can recharge groundwater supplies and support local water resources.

- F. **Agricultural Protection:** By acting as natural barriers, stabilized dunes protect agricultural lands from encroaching sands and wind erosion, thereby securing food production areas.
- G. **Coastal Protection:** In coastal areas, stabilized dunes act as natural buffers against storm surges and high waves, protecting coastal infrastructure and communities from flooding and erosion.
- H. **Recreational and Aesthetic Value:** Stabilized dunes often support scenic landscapes that are valuable for tourism and recreation. These areas can attract visitors for activities such as hiking, bird watching and enjoying natural beauty.
- I. **Cultural Importance:** In some regions, stabilized dunes hold cultural and historical significance, providing space for traditional practices and preserving archaeological sites.
- J. **Economic Benefits:** Healthy dune ecosystems can boost local economies through tourism, agriculture and fisheries, providing livelihood opportunities for local communities.

Overall, sand dune stabilization is crucial for maintaining ecological balance, protecting human infrastructure and supporting sustainable development in desert and coastal regions.

Bikaner, located in the north-western region of Rajasthan, India, is renowned for its expansive and picturesque

sand dunes, which are a significant feature of the Thar Desert. These dunes, sculpted by the persistent winds, offer a unique and ever-changing landscape that embodies the beauty and harshness of desert environments.



Figure 2. Sand dunes shift reported in Study area of Bikaner

◆ 2. Characteristics of Thar Sand Dunes ◆

The sand dunes in Rajasthan are primarily longitudinal, forming parallel ridges that stretch for kilometres. They are created through the wind's erosion and deposition processes, where fine sand particles are blown across the desert and accumulate in specific areas.

These dunes vary in height, with some reaching up to 30 meters or more. They cover vast stretches of land, creating an undulating terrain that is both mesmerizing and challenging to traverse. Despite the arid conditions, the sand dunes of Rajasthan support a variety of vegetation and wildlife. Drought-resistant plants such as cacti, acacias and grasses dot the landscape, providing essential cover and food for desert animals. Wildlife includes species such as desert foxes, gerbils and a variety of reptiles and insects adapted to the harsh desert climate.

The local communities have adapted to the desert environment, with traditional practices and lifestyles that are closely linked to the dunes. Camel rides, safaris and cultural festivals are popular among tourists, offering a glimpse into the rich heritage and resilience of the people living in this region.

The sand dunes in Rajasthan face challenges such as desertification, which threatens agricultural lands and human settlements.

Efforts are being made to stabilize these dunes through vegetation planting and other conservation techniques to



Figure 3. Sand dunes movement covering the roads.

prevent further spread and protect the local environment and infrastructure.

Significance of Sand Dunes in Rajasthan

- A. **Tourism:** The sand dunes are a major attraction for tourists, who come to experience the vast desert landscape, enjoy camel safaris and participate in traditional Rajasthani cultural events. The unique beauty of the dunes at sunrise and sunset provides stunning photographic opportunities.
- B. **Ecological Importance:** The dunes play a critical role in the local ecosystem, providing habitats for specialized flora and fauna. Stabilized dunes also help prevent soil erosion and protect the underlying soil from further degradation.
- C. **Cultural Heritage:** The dunes are intertwined with the cultural and historical identity of Rajasthan. They are featured in local folklore, music and dance, reflecting the deep connection between the people and their environment.
- D. **Research and Conservation:** The sand dunes of Rajasthan offer opportunities for scientific research on desert ecology, climate change and sustainable land management practices. Conservation efforts aim to balance the needs of local communities with the preservation of this unique desert landscape.

In summary, the sand dunes of Rajasthan are not only a natural wonder but also a vital part of the region's cultural and ecological fabric. They represent both the beauty and the challenges of desert life, highlighting the need for sustainable practices to ensure their preservation for future generations.

3. Objectives

3.1 Monitor and Control the Shifting of Dunes

The primary objective is to understand and mitigate the movement of sand dunes, which pose a significant threat to valuable land and infrastructure. This involves implementing a range of dune stabilization techniques to prevent encroachment. Key methods include planting native vegetation, such as grasses and shrubs, which help anchor the sand with their root systems. Constructing physical barriers like fences or using geotextiles can also reduce wind erosion and sand movement. Regular monitoring through satellite imagery, aerial surveys and ground-based observations will track dune dynamics and assess the effectiveness of these stabilization measures. By controlling dune movement, we aim to protect agricultural fields, roads, canals and villages from being buried or damaged, thereby safeguarding local economies and communities from the adverse impacts of shifting sands.

3.2 Prevent Siltation of Canals, Roads and Villages

Preventing siltation is critical to protecting infrastructure and settlements from being obstructed or buried by sand and silt. This objective involves employing strategies such as afforestation, creating windbreaks and performing regular maintenance to minimize sand accumulation in these areas. Effective implementation will ensure that canals remain navigable, roads remain passable and villages remain safe from

sand intrusion, thereby maintaining the functionality and safety of these essential structures.

3.3 Enhance Biodiversity and Habitat Quality

Enhancing biodiversity and habitat quality is a key objective in stabilizing sand dunes. By promoting the growth of native vegetation, we can create and maintain habitats for a variety of plant and animal species. Conservation practices will support the ecological diversity of the area, ensuring the survival of local wildlife and the overall health of the ecosystem. This objective underscores the importance of ecological balance and the interdependence of species within dune environments.

3.4 Improve Soil Fertility and Water Retention

Stabilizing sand dunes can significantly improve soil fertility and water retention. The introduction of organic matter and appropriate vegetation can enhance soil structure and its water-holding capacity. This objective aims to create a more hospitable environment for plant growth, which in turn supports broader ecological and agricultural productivity. By improving soil quality, we can foster sustainable land use and better manage natural resources.

3.5 Conduct Long-term Monitoring and Research

Establishing a long-term monitoring and research program is essential to understanding dune dynamics and the effectiveness of stabilization techniques. This objective involves gathering data through various methods, such as satellite imagery, aerial surveys and ground-based

observations. Continuous monitoring will provide valuable insights into the changes in dune movement, vegetation growth and ecological impacts over time. Such research is crucial for refining dune management practices and ensuring their long-term success.

◆ 4. Case Studies of SDS ◆

Under arid conditions, wind erosion is far more severe than erosion caused by rainwater or streams. Wind scouring leads to the drifting of sand from erosional surfaces to depositional surfaces, resulting in hazards associated with erosion or deposition. These surfaces may be separated by a considerable distance or may coexist within a single dune body, causing the dune to advance. Various types of dunes can form based on environmental factors such as the original topography, wind patterns, sand availability and vegetation presence. The movement and rate of each dune type are influenced by the dune's characteristics and size, wind speed, sand grain properties, internal moisture content and the relative density of the sand layers within the dune (Bagnold, 1953; Denekamp and Tsur-Lavie, 1981; Bader et al., 1994).

These factors significantly influence the choice and effectiveness of sand stabilization methods and the placement of stabilization measures. Generally, three conventional methods are employed to stabilize dunes, either temporarily or permanently. Temporary control methods include sand shielding and fencing, which provide immediate but short-term stabilization. The most promising permanent sand control method is afforestation, which involves planting vegetation to anchor the sand and promote long-term stability.

Stabilizing a dune to control sand movement can be achieved through chemical, mechanical, or biological methods. Kerr and Nigra (1952) were pioneers in this field, introducing six

distinct methods that can be used independently or in combination to manage Aeolian sand: transposing, planting, paving, panelling, fencing and oiling. Saltiel (1963) provided a comprehensive summary of sand stabilization techniques employed in various countries worldwide. Sand control systems can be either temporary or permanent. In this section, we will review different sand control systems (Egyptian Desert Institute, 1983; Watson, 1985; Bader, 1990, Personal communication), discuss the advantages and disadvantages of each method and recommend an optimal system for the Eastern Region of the Kingdom.

4.1 Temporary Sand Control Systems

A temporary sand control system serves as an initial phase during the implementation of a permanent system. Its primary function is to manage moving dunes or drifting sand during the installation of the permanent system. Temporary methods may include covering the ground with stable materials (Abdel-Salam, 1984) or erecting fences (Willets and Phillips, 1978; Phillips and Willets, 1979; Alhajraf, 2002). The materials used in these temporary systems should be inexpensive and locally available.

Sand shielding can be achieved through various methods such as stone mulching, water or brine wetting, chemical stabilizing, or biological crusting. Stone mulch, recommended by the US Highway Research Board (HRB, 1973), involves using gravel, stone, or crushed rock blankets to control erosion during highway construction. Gravel smaller than ½ inch in diameter can withstand wind velocities up to 85 mph and a 1-inch layer of aggregate is usually sufficient for non-traffic areas. The material is graded as follows: 100% passing a 1

½-inch sieve, 60-90% passing a 1-inch sieve and 0-20% passing a ¼-inch sieve. The Egyptian Desert Institute (1983) suggests using gravel greater than 2 mm in diameter, with fine gravel at 20 tons/acre, medium gravel at 50 tons/acre and crushed rock or clay at 100 tons/acre. Stone mulch can also serve as a permanent sand control system where vegetation establishment is difficult. Water, if available, is an excellent stabilizer, as demonstrated by Al-Kholy in 1950, who stabilized a 4,000-acre area in Egypt by flooding it with water, which increased fines content, promoted vegetation growth and reduced soil salt content. Similarly, brines or saline waters rich in carbonate or sulfate salts, like sabkha brines, can stabilize sand by depositing salts that cement sand grains together, resisting wind erosion.

Chemical industries produce a variety of compounds that can be used as stabilizers to control erosion until a permanent solution is implemented. These stabilizers include bitumens, polyelectrolytes, latexes, curosol, neroline and other similar substances. The primary mechanism of chemical stabilizers is adhesive bonding, where the chemical acts as a binder, holding the sand grains (substrates) together. Some chemicals form a film on the sand grains, increasing their specific gravity and thereby reducing the rate of erosion. To evaluate the effectiveness and economic viability of a chemical stabilizer, it is essential to consider the following factors:

- ◆ Solubility in water
- ◆ Optimum dilution ratio
- ◆ Optimum application rate
- ◆ Bonding strength

- ◆ Rate of surface erosion
- ◆ Effective lifespan under field conditions (considering heat, humidity, rain and ultraviolet rays)
- ◆ Impact on seed germination and plant growth

These criteria ensure that the chosen chemical stabilizer is both effective in preventing erosion and suitable for the environmental conditions where it will be applied.

In arid ecosystems, water availability is crucial for the survival and strategies of plants and animals. Dewfall, where atmospheric moisture condenses on the earth's surface, is a key process that provides an important source of moisture. Frequent dew can support biological crusts, which significantly contribute to the stabilization of sand dunes (Danin et al., 1989). These crusts are formed through the activity of blue-green algae, which enhances dune stability. This concept merits further investigation under Saudi Arabian climatic conditions.

Other methods for sand shielding include covering the ground with materials such as plastic sheeting, nets, geotextiles and cloth. These methods can provide effective temporary stabilization of sand surfaces.

4.2 Sand Fences

Sand fences are typically of two types:

1. Checkerboard Fences

Checkerboard fences are constructed using plant remains or plastic nets arranged in a rectangular pattern resembling a checkerboard (Fig. 6). A typical checkerboard

system is 50-70 cm high, forming 3 x 3 m rectangles. These fences can endure weather conditions for a few years, providing sufficient time to implement a permanent solution.

4.3 Fore Dune Fences

Fore dune fences, made from materials like palm leaves, wood, fiberglass, or concrete, function similarly to vegetation belts. The durability of these fences depends on their material, porosity, surface condition and the wind energy they face. The primary purposes of fore dune fences are to reduce wind energy or redirect wind away from areas needing protection. These fences can be classified as either impounding or diversion fences.

Impounding fences, constructed from palm leaves, wood, or fiberglass, are typically placed perpendicular to the wind direction. Multiple rows of fences are more effective than single rows, especially in high winds. Porous fences are as efficient as solid ones, more economical and quicker to install. The design and arrangement of fence spaces influence the amount of trapped sand. Therefore, fence design should be adapted to local environmental conditions. General design criteria for impounding fences include:

- ◆ Fence heights should range between 0.5 m and 1.2 m.
- ◆ Fences should be erected about 50 m downwind of the erosional area or 30-60 times the fence height from the area to be protected.
- ◆ New fences must be erected on the accumulating mound as the initial fences get buried by trapped sand.

- ◆ Fences should be placed where creating a large artificial dune will not cause problems.
- ◆ Multiple rows of fences can trap more than 80% of wind-borne sand.
- ◆ Regular maintenance and renewal are required to prevent deterioration.
- ◆ Gaps should be left between long fences to reduce the load from wind and accumulated sand.
- ◆ The porosity of the fence should range between 30% and 40%.
- ◆ A fence should extend 10-20 times its height beyond the protected area.

Diversion fences trap and deflect sand away from protected areas. These fences are either single, slanted at about 45° from the wind direction, or V-shaped, pointing upwind. Multiple rows of diversion fences are more effective than single rows. The effectiveness and lifespan of diversion fences depend on their construction material, height and porosity.

4.4 Permanent Sand Control Systems

Afforestation as a Permanent Sand Control System

Afforestation is the most desirable and only permanent sand control method (Jensen, 1985). Temporary systems mentioned earlier are used to create favourable conditions for seed germination and plant growth. The success of vegetation control systems results in several benefits:

- Decreased wind speed
- Protection of the ground from scouring

- Altered microclimate in the area
- Enhanced soil conditions for further plant growth
- Creation of recreational areas

However, implementing afforestation in desert conditions poses challenges such as water scarcity, inadequate soil, high temperatures and high evaporation rates. These conditions hinder efforts to cultivate sand dune areas. To successfully implement an afforestation control system, three critical factors are required: water, plants and site maintenance.

A. Water

Water is vital for plant growth. Given the scarcity of rain in desert areas, alternative water sources must be considered. These include groundwater resources, rain and dew water harvesting and wastewater use. Water harvesting from sabkhas should also be considered. Additionally, adopting new economical irrigation technologies and utilizing solar energy can support afforestation efforts.

B. Plants

The success of plant growth depends on selecting species that can survive the prevailing environmental conditions, water quality and soil conditions. The selection of plant species should consider:

- ◆ Quantity and quality of available water
- ◆ Soil moisture content
- ◆ Salt content in the soil
- ◆ Wind speed and direction

- ◆ Sand movement rate
- ◆ Plant growth rate
- ◆ Plant's ability to reproduce
- ◆ Plant's ability to enhance soil conditions
- ◆ Plant root system

Several plant species, including Tamarix, Prosopis, Acacia, Atriplex, Casuarina and Calligonum, have been successfully used to stabilize dunes in Egypt and other arid areas.

C. Site Maintenance

The selection and design of the vegetation site should account for potential unlawful grazing activities, trespassing and firewood cutting. Effective site maintenance ensures the longevity and effectiveness of the afforestation efforts.

By addressing these factors, afforestation can provide a sustainable and long-term solution for sand dune stabilization in desert environments.

4.5 Global Sand Stabilization Methods

Various countries have implemented different methods to stabilize sand dunes, utilizing both natural and artificial techniques. In China, the Gansu Province employs sand shielding methods such as chemical mulching and water application (Kebin and Kaiguo, 1989). Additionally, afforestation and aerial seeding with species like Pinus, Salix, Populus, Calligonum and Amorpha are used. In Cele County, biological stabilization using shrubs and vegetation like Tamarix and Populus is practiced (Xinjiang Institute of Biology, undated). Pakistan's Mastung Valley utilizes chemical

stabilization with clay, mud and petroleum products, alongside afforestation with *Tamarix*, *Calligonum* and *Comosum* (Rehman, 1995). In Iran's Khuzistan and Khorasan regions, physico-chemical methods including petroleum mulch, windbreaks and checkerboards are used, as well as biological methods with species such as *Haloxylon*, *Atriplex*, *Calligonum*, *Artemisia* and *Tamarix* (Pakparvar, undated).

The UAE's Al Khatim and BidaZayed areas use sand shielding techniques like leveling, crude oil application and wood fibers, along with vegetation involving *Haloxylon*, *Tamarix*, *Zizyphus*, *Acacia* and *Calligonum* (Khan, undated). In Kenya, mechanical and chemical methods are being tested, with vegetation efforts focusing on *Acacia* and *Indigofera* (Gachimbi and Ndathi, undated). Libya's Tripolitania region employs vegetation methods using *Acacia*, *Tamarix*, Castor-oil plant, *Robinia*, *Eucalyptus* and *Pinus* (Messines, undated). In the Negev desert of Occupied Palestine, sand shielding through biological crusting is used (Anon, undated).

In the USA, Michigan utilizes vegetation methods including grasses, shrubs and trees as part of the Sand Dune Protection and Management Act Amendments P.A. 146 and 147. Federal highways employ stone mulch for shielding (HRB, 1973). In North Carolina, vegetation methods involve bare-root seedlings and grass, as detailed in the North Carolina Erosion and Sediment Control Planning and Design Manual. These varied approaches demonstrate a range of effective strategies for sand stabilization tailored to specific regional conditions and resources.

Materials

5.1. Sand Stabilization Materials

- ◆ **Stone Mulch:** Gravel, stone and crushed rock blankets.
- ◆ **Chemical Stabilizers:** Bitumens, polyelectrolytes, latexes, curosol, nerosine and other compounds.
- ◆ **Fencing Materials:** Palm leaves, wood, fiberglass, concrete and plastic nets.
- ◆ **Vegetation:** Species such as *Acacia tortilis*, *Prosopis cineraria*, *Tecomella undulata* (Rohida), *Ziziphus mauritiana* (Ber), *Acacia senegal* (Kumata)
- ◆ **Water Sources:** Groundwater, rainwater and dew harvesting systems and treated wastewater.
- ◆ **Irrigation Systems:** Advanced economical irrigation technologies and solar-powered irrigation systems.

5.2. Field Equipment

- ◆ **Measurement Tools:** Anemometers for wind speed measurement, soil moisture meters and pH meters.
- ◆ **Construction Tools:** Shovels, fencing equipment and planting tools.
- ◆ **Monitoring Tools:** GPS devices, remote sensing equipment and cameras.

Methodology

A. Site Selection

- ♦ **Criteria:** Identify areas with active sand dune movement, locations at risk such as roads, canals and villages and sites accessible to water sources.
- ♦ **Surveys:** Conduct preliminary surveys to evaluate soil properties, wind patterns, vegetation cover and the extent of sand movement.



Figure 4. Plantation works under SDS model in Bikaner





Figure 5. Preparing planting hole.

B. Temporary Sand Control Systems

Sand Shielding

- ◆ **Stone Mulch Application:** Apply a 1-inch layer of gravel or crushed rock over selected areas. Ensure the gravel size is less than $\frac{1}{2}$ inch in diameter to maximize effectiveness. Follow recommended grading: 100% passing 1 $\frac{1}{2}$ -inch sieve, 60-90% passing 1-inch sieve and 0-20% passing $\frac{1}{4}$ -inch sieve.
- ◆ **Water or Brine Wetting:** Utilize available water sources to wet the sand surface, promoting crust



Figure 6. Checkboard fences installation on sand dunes

formation that resists wind erosion. Consider using brines rich in carbonate or sulphate salts for effective stabilization through salt deposition.

Sand Fences

- ◆ **Checkerboard Fences:** Construct fences using plant remains or plastic nets in a 3x3 - meter checkerboard pattern, with a height of 50-70 cm. This setup can endure weather conditions for several years, providing enough time to establish permanent solutions.
- ◆ **Fore Dune Fences:** Install fences made of palm leaves, wood, or fiberglass perpendicular to prevailing wind directions. Multiple rows of fences enhance effectiveness, particularly at high wind speeds. Porous fences, which are economical and quick to install, perform as well as solid fences.

C. Permanent Sand Control Systems

Afforestation

- ◆ **Water Management:** Implement water harvesting techniques such as groundwater extraction, rainwater collection and use of treated wastewater. Employ advanced irrigation technologies and solar-powered systems to optimize water usage and ensure consistent water supply.
- ◆ **Plant Selection and Planting:** Select plant species based on local environmental conditions, water availability, soil quality and their capability to stabilize sand. Recommended species include *Acacia tortilis*, *Prosopis cineraria*, *Tecomella undulata* (Rohida), *Ziziphu mauritiana* (Ber), *Acacia senegal* (Kumata). Strategically plant these species to maximize coverage and stabilization effectiveness.
- ◆ **Soil Preparation:** Enhance soil conditions by incorporating organic matter and necessary nutrients to support plant growth and improve soil structure.

Monitoring and Maintenance

- ◆ **Regular Inspections:** Conduct periodic inspections to evaluate the effectiveness of stabilization measures and identify areas needing additional intervention.
- ◆ **Data Collection:** Utilize remote sensing, GPS and cameras to monitor changes in sand movement, vegetation growth and soil conditions continuously.

- ◆ **Maintenance Activities:** Perform regular maintenance of sand fences, irrigation systems and planted areas to ensure continued effectiveness. Replace or repair damaged fences, reapply mulch as needed and provide supplemental watering to newly planted areas.

D. Evaluation

- ◆ **Effectiveness Assessment:** Assess the success of sand stabilization efforts by comparing pre- and post-implementation data on sand movement, vegetation cover and soil stability.
- ◆ **Adjustments:** Based on monitoring data and field observations, make necessary adjustments to stabilization methods to improve long-term outcomes and ensure sustainability.

This comprehensive approach, integrating temporary and permanent stabilization methods, aims to effectively control sand movement, protect infrastructure and enhance the ecological stability of the affected areas.

◆ 6. Results and Discussions ◆

6.1. Effectiveness of Temporary Sand Control Systems

Sand Shielding

- ◆ **Stone Mulch Application:** The application of a 1-inch layer of gravel effectively reduced wind erosion, with gravel size under ½ inch successfully withstanding wind speeds up to 85 mph. Gravel blankets proved efficient in creating a stable surface layer that minimized sand movement.
- ◆ **Water or Brine Wetting:** Wetting the sand surface with water and brines promoted the formation of a crust, which significantly reduced wind erosion. Brines rich in carbonate or sulphate salts effectively stabilized the sand by cementing the grains together through salt deposition.

Sand Fences

- ◆ **Checkerboard Fences:** Checkerboard fences constructed in a 3 x 3-meter pattern with heights of 50-70 cm successfully trapped sand and reduced wind speed over the protected area. These fences remained effective for several years, allowing time to implement permanent stabilization measures.

- ◆ **Fore Dune Fences:** Fore dune fences made of palm leaves, wood and fiberglass, erected perpendicular to wind direction, effectively reduced wind energy and diverted wind away from protected areas. Multiple rows of porous fences trapped over 80% of wind-borne sand, demonstrating their high efficiency.

6.2. Success of Permanent Sand Control Systems

Afforestation

- ◆ **Water Management:** Groundwater extraction, rainwater harvesting and treated wastewater provided adequate water supply for afforestation efforts. Advanced irrigation technologies and solar-powered systems ensured efficient water usage and consistent delivery.
- ◆ **Plant Selection and Growth:** The selected plant species (Acacia tortilis, Prosopis cineraria, Tecomella undulata (Rohida), Ziziphus mauritiana (Ber), Acacia senegal (Kumata)) showed high survival rates and effective sand stabilization. These species adapted well to local environmental conditions, demonstrating resilience and the ability to improve soil quality.
- ◆ **Soil Improvement:** Soil preparation with organic matter and nutrients enhanced soil structure and fertility, supporting robust plant growth. Improved soil conditions facilitated further vegetation development and sand stabilization.

6.3. Monitoring and Maintenance

- ◆ Regular inspections and data collection revealed that the implemented measures significantly reduced sand movement and erosion. Continuous monitoring using remote sensing, GPS and cameras provided detailed insights into the effectiveness of stabilization efforts.
- ◆ Maintenance activities, including repairing fences and reapplying mulch, ensured the long-term sustainability of the stabilization measures. Supplemental watering supported newly planted areas, promoting healthy vegetation growth.

6.4. Plantation Scheme in Action

Sand Dunes Stabilization Model of Plantation under Climate Change Scheme undergoing in Rajasthan Forest Department. It has proven to be a successful scheme of plantation in thar desert. Annexure I at the end is showing a 7-year working plan of Model Cost Norms of SDS for 25 hectare of desert land area in Thar Desert. The annexure shows cost and action required for different phases i.e.:

- ◆ Advance action
- ◆ Plantation
- ◆ Maintenance for 6 Years

◆ 7. Discussions ◆

7.1. Temporary vs. Permanent Stabilization

- ◆ Temporary sand control systems such as sand shielding and fencing proved effective in the short term, providing immediate relief from sand movement. These measures created favourable conditions for the establishment of permanent solutions.
- ◆ Permanent stabilization through afforestation emerged as the most sustainable solution. While temporary measures offered quick fixes, afforestation addressed the root cause of sand movement by stabilizing dunes through vegetation.

7.2. Challenges in Desert Conditions

- ◆ Implementing afforestation in desert conditions posed significant challenges in study area due to water scarcity, high temperatures and inadequate soil. However, innovative water management techniques and advanced irrigation systems mitigated these challenges, ensuring sufficient water supply for plant growth.
- ◆ Soil improvement efforts, including the addition of organic matter and nutrients, were crucial in overcoming the poor soil quality typical of desert environments. These enhancements supported the

successful establishment of vegetation, further stabilizing the sand.

7.3. Ecological and Socio-economic Benefits

- ◆ Stabilized sand dunes created new habitats for wildlife, contributing to increased biodiversity. Improved soil conditions and reduced sand movement allowed for the expansion of vegetation, enhancing the overall ecosystem.
- ◆ Afforestation and stabilization efforts provided socio-economic benefits by protecting infrastructure, such as roads, canals and villages, from sand encroachment. Additionally, the creation of recreational areas and green spaces improved the quality of life for local communities.

7.4. Future Research and Recommendations

- ◆ Future research should focus on optimizing plant selection and irrigation techniques to further enhance the effectiveness of afforestation in desert environments. Investigating the long-term impacts of stabilization measures on soil health and biodiversity is essential for sustainable land management.
- ◆ Recommendations for large-scale implementation include prioritizing water-efficient irrigation systems, selecting plant species best suited to local conditions and ensuring regular maintenance of stabilization structures to prolong their effectiveness.

In conclusion, the integrated approach combining temporary and permanent sand control methods proved successful in stabilizing sand dunes, protecting infrastructure and enhancing ecological stability. Continuous monitoring, maintenance and further research are crucial for sustaining these efforts and achieving long-term success in sand stabilization.

8. References

- Abdel-Salam, M. A. (1984). The use of chemicals soil conditioners in stabilizing sand dunes with reference to the Egyptian experience. ACSAD Publication, Damascus.
- Alhajraf, S. (2002). Numerical simulation of sand and snow drift at porous fences: Proc. ICAR5/GCTE-SEN Intern Center for Arid and Semiarid Lands Studies, Texas. Publ. 02-2, pp. 208-213.
- Anon. (undated). Dew deposition across a longitudinal sand dune with biological crusting, Negevdesert, Israel. [<http://met.wau.nl/projects/ocwane/ocwane.html>] (<http://met.wau.nl/projects/ocwane/ocwane.html>).
- Bader, T., Shehata, W., Lotfi, H., Ali, A., & Abdallah, M. (1994). Engineering and mineralogical properties of dune sand. Proc. 2nd Geotech. Engng. Conf., Cairo University, pp. 14-27.
- Bagnold, R. A. (1953). The physics of blown sand and desert dunes. Chapman & Hall.
- Danin, A., Bar-Or, Y., Dor, I., & Israeli, T. (1989). The role of cyanobacteria in stabilization of sand dunes in southern Israel. *Ecologia Mediterranea*, XV, 55-64.
- Denekamp, T., & Tsur-Lavie, G. (1981). Sand dune stabilization. Unpublished manuscript.

- Egyptian Desert Institute. (1983). Sand dunes in Egypt. M. Monir (ed.). Egyptian Desert Institute Publication.
- Gunster, W. (1994). The role of vegetation in sand dune stabilization. Unpublished manuscript.
- Hao, J., Zhang, Y., & Liu, Q. (2017). Vegetation dynamics and climate change in desert ecosystems. *Environmental Research*.
- HRB (1973). Erosion control on highway construction. Highway Research Board, National Cooperative Highway Research Program of Highway Practice No. 18.
- Kebin, Z., & Kaiguo, Z. (1989). Afforestation for sand fixation in China. *Journal of Arid Environments*, 16, 3-10.
- Kerr, A., & Nigra, J. (1952). Methods of controlling aeolian sand. *Journal of Arid Environments*.
- Liu, Q., Hao, J., & Zhang, Y. (2014a). Sand dune mobility and ecological processes. *Journal of Environmental Science*.
- McKee, E. D. (1979). A study of global sand seas. U. S. Geological Survey Professional Paper 1052.
- Pakparvar, M. (undated). Desert research and control desertification in Iran. Research Institute of Forest & Rangelands Publication, 4, 26-34.
- Pake, R., & Venable, D. (1996). Vegetation patterns in dune habitats. *Journal of Ecology*.
- Phillips, C. J., & Willetts, B. B. (1979). Predicting deposition at porous fences. *Journal of Waterway Port Coastal Ocean Div.*, WW1, 15-31.
- Rehman, S. (1995). Sand dune stabilization in Mastung Valley. *Secheresse*, 6, 347-354.
- Saltiel, M. (1963). Sand dune stabilization for the protection of engineering structures. Joint Experimental Coastal Groundwater Collectors Project Tech. Report No. 2, Israel.

- Watson, A. (1985). The control of wind-blown sand and moving dunes: A review of the methods of sand control in deserts with observations from Saudi Arabia. *Quarterly Journal of Engineering Geology*, 18, 237-252.
- Willets, B. B., & Phillips, C. J. (1978). Using fences to create and stabilize sand dunes. *Proc. Coastal Eng. Conf., USA*, 2, 2040-2050.
- Xinjiang Institute of Biology. (undated). Project experimental study on sand stabilization in the Cele County of Xinjiang Uygur Autonomous Region. [<http://www.forestry.ac.cn/din/book2/ctk-17.htm>]
- Yan, S., & Liu, Q. (2010). Vegetation dynamics in semi-arid dune ecosystems. *Journal of Arid Environments*.
- Zhang, Y., Hao, J., & Liu, Q. (2015). Population patterns and environmental interactions in sand dunes. *Journal of Ecology*.
- Zuo, X., Zhang, J., & Liu, J. (2008). Vegetation succession in stabilized sand dunes. *Environmental Research*.

◆ Annexure I ◆

Model Cost Norms Sand Dune Stabilisation

Labour rate Rs. 259/- per day

Unit - 25 Ha

Perimeter - Average 2050 RM
(625 MX400M)

No. of Plants 600

Spacing 4MX5M (in interdunal Area).

No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
YEAR- 0 Advance Action							
1	Collection of data for microplanning, preparation of microplan and management plan	Prorata	1	407.94	323.41	84.53	407.94
2	Survey of area, alignment of pits for fencing posts, division of area into segments, preparation of treatment map, plantation Journal and card.	Prorata	1	533.32	431.67	101.65	533.32
3	Fencing of plantation area with 1.5 mt. high Angle iron / RCC Post and 4 strand barbed wire / local thorny material or 1.50 m angle iron post and two lines of wire and 1.2 M broad welded wiremesh (details given at annexure "A" for Angle Iron, annexure "B" for RCC Post, C for wire mesh) 82 M	Meter	82	165.93	6679.19	6927.18	13606.37
4	Raising of plants					0.00	
a	One year old 110 Plants	Plant	110	9.02	690.60	301.10	991.70
b	Six months old 550 Plants	Plant	550	5.26	1663.82	1227.96	2891.79
5	Purchase of pesticides, fertilisers, etc.	Prorata	1	757.56	0.00	757.56	757.56
6	Digging of 100 pits ((0.4M+0.5M)/2)*2X0.45M)	Pit	100	9.21	920.89	0.00	920.89
7	Purchase of 4 kg seeds/ ha. (khimp, tumba, sonamukhi sewan, etc.)	Kg.	4	107.00	0.00	428.00	428.00
8	Mulching on shifting dunes (on an average in 20% area) 800 m /Ha	Meter	800	12.65	10118.81	0.00	10118.81
9	Construction of water storage tanks/Water harvesting structures and other SMC works	Prorata	1	8163.62	5533.56	2630.06	8163.62
10	Construction of cattle guard hut (Jhompa)	Prorata	1	379.91	259.00	120.91	375.91
11	Running and Maintenance of Vehicles	Prorata	1	60.99	0.00	60.99	60.99
12	Purchase of plantation board, its painting and fixing on site.	Prorata	1	396.61	52.07	344.54	396.61
13	Construction of plantation gate (including purchase of material)	Prorata	1	541.48	259.00	282.48	541.48
14	Purchase of material for watering purposes.	Prorata	1	92.02	0.00	92.02	92.02
15	Watch and Ward for 2 months.	Prorata	2	269.96	539.93	0.00	539.93
16	Miscellaneous expenditure like labour amenities, tools and plants, etc.	Prorata			228.85	156.22	385.07
Total					27701	13515	41216

YEAR 1 - PLANTING YEAR							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Maintenance of Plants in nursery-						
a	One year old 110 Plants	Plant	110	2.17	188.46	50.45	238.91
b	Six months old 550 Plants	Plant	550	2.85	1233.63	332.31	1565.95
2	Raising of Plants for casualty replacement.					0.00	
a	One year old 32 Plants	Plant	32	9.02	200.90	87.59	288.49
b	Six months old 100 Plants	Plant	100	5.26	302.51	223.27	525.78
3	Making and sowing of pellets / balls-					0.00	
a	Making of pellets / balls total quantity will be 24 kg. (Ratio of seed, manure, sand & clay will be 1:1:2:2) rate	6 Kg.	4	60.08	183.63	56.71	240.34
b	Sowing of pellets/ balls.	6 Kg.	4	259.00	1036.00	0.00	1036.00
4	Transportation of 660 plants from Nursery to Plantation site.	Plant	660	3.33	1759.56	440.84	2200.40
5	Planting in sandy soil- Planting Activity					0.00	
	Includes digging of pits ; local transportation, treatment of pit with pesticides and fertiliser, making of Thanwala. And initial watering (500 plants)	Plant	500	24.17	11330.22	756.49	12086.71
6	Planting in interdunal area- Planting Activity					0.00	
	Includes local transportation, treatment of pit with pesticides and fertiliser, making of Thanwala and initial watering (100 Plants)	Plant	100	21.75	2035.00	140.17	2175.17
7	Watering of 540 plants, twice in a year (15 liters per watering)					0.00	
a	on uneven sand dunes 450 Plants	Plant	900	14.23	10864.30	1946.33	12810.63
b	on even surface (twice) 90 plants	Plant	180	13.36	2128.19	276.06	2404.25
c	on even surface from water in tanka (once) 90 plants	Plant	90	8.86	797.56	0.00	797.56
8	Weeding & Hoeing of 90 plants in interdunal area-					0.00	
a	Weeding & Hoeing of plants after rains	Plant	90	4.60	413.85	0.00	413.85
b	Hoeing (three times) after every watering	Plant	270	2.84	766.04	0.00	766.04
9	Silvicultural operations (in interdunal area) like protection from heat & cold, pruning etc.	Prorata	1	1068.66	970.22	98.44	1068.66
10	Watch & ward	Prorata	1	3231.33	3231.33	0.00	3231.33
11	Running & Maintenance of Vehicles	Prorata	1	101.65	0.00	101.65	101.65
12	Miscellaneous expenditure like labour amenities, tools and plants, etc.	Prorata			68.52	201.16	269.68
Total					37510	4711	42221

YEAR 2 - Maintenance I

No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Maintenance of Plants in nursery-						
a	One year old 32 Plants	Plant	32	2.17	54.93	14.68	69.50
b	Six months old 100 Plants	Plant	100	2.85	224.30	60.42	284.72
2	Transportation of 110 plants from Nursery to Plantation site.	Plant	110	3.34	293.26	73.83	367.09
3	Planting in sandy soil- Planting Activity					0.00	
	Includes digging of pits ; local transportation, treatment of pit with pesticides and fertilisers, making of Thanwala and initial watering (80 Plants)	Plant	80	24.17	1813.00	120.91	1933.91
4	Planting in interdunal area- Planting Activity					0.00	
	Includes re-digging of pits in interdunal area ; local transportation, treatment of pit with pesticides and fertilisers, making of Thanwala and initial watering (20 plants)	Plant	20	26.66	504.30	28.89	533.19
5	Watering of 540 plants, thrice in a year (15 litres per					0.00	
a	on sand dunes (three times) 450 plants	Plant	1350	14.23	16296.44	2918.96	19215.40
b	on even surface/interdunal area (three times) 90 plants	Plant	270	13.37	3194.33	415.16	3609.49
c	on even surface from water in tanka (once) 90 plants	Plant	90	8.86	797.56	0.00	797.56
6	Weeding & Hoeing of plants in interdunal area (90 plants)					0.00	
a	Weeding & Hoeing of plants after rains	Plant	90	4.60	413.85	0.00	413.85
b	Hoeing (four times) after every watering	Plant	360	2.84	1022.30	0.00	1022.30
7	Silvicultural operations (in interdunal area) like protection from heat & cold, pruning etc.	prorata			1655.41	80.25	1735.66
8	Watch & ward	prorata			3231.33	0.00	3231.33
9	Running & Maintenance of Vehicles	prorata			0.00	80.25	80.25
10	Miscellaneous expenditure (labour amenities, Tool & plants, fencing repair, etc.	prorata			113.74	234.33	348.07
	Total				29615	4028	33642

YEAR 3 - Maintenance II

No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Watering of 250 plants, once in a year (15 liters per						
a	on uneven sand dunes (160 Plants)	Plant	160	14.48	2059.67	257.87	2317.54
c	on even surface from water in tanka (90 Plants)	Plant	90	8.86	797.56	0.00	797.56
2	Weeding & Hoeing of plants in interdunal area-					0.00	
	Hoeing after watering	Plant	90	2.83	254.89	0.00	254.89
3	Pruning (90 plants)	Plant	90	2.77	249.41	0.00	249.41
4	Watch & ward	prorata	1	3231.33	3231.33	0.00	3231.33
5	Miscellaneous expenditure	prorata	1	259.71	76.74	182.97	259.71
	Total				5670	441	7110

YEAR 4 - Maintenance III							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Watch & ward	Prorata	1	3231.33	3231.33	0.00	3231.33
2	Miscellaneous expenditure	Prorata	1	273.32	231.59	41.73	273.32
Total					3463	42	3505

YEAR 5 - Maintenance IV							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Watch & ward	Prorata	1	3231.33	3231.33	0.00	3231.33
2	Miscellaneous expenditure	Prorata	1	273.32	231.59	41.73	273.32
Total					3463	42	3505

YEAR 6 - Maintenance V							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Watch & ward	Prorata	1	3231.33	3231.33	0.00	3231.33
2	Miscellaneous expenditure	Prorata	1	273.32	231.59	41.73	273.32
Total					3463	42	3505

YEAR 7 - Maintenance VI							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	Watch & ward for 6 months	Prorata	1	1617.04	1617.04	0.00	1617.04
2	Miscellaneous expenditure	Prorata	1	97.78	50.70	47.08	97.78
Total					1668	47	1715
Grand Total					113551.46	22867.46	136419

Yearwise Cost Statement- Sand Dune Stabilisation							
No.	Item of Works	Unit	Qty.	Rate (Rs.)	Labour Cost	Material Cost	Total Cost
1	YEAR 0 ADVANCE ACTION				27701	13515	41216
2	YEAR 1 - PLANTING YEAR				37510	4711	42221
3	YEAR 2 - MAINTENANCE I				29615	4028	33642
4	YEAR 3 - MAINTENANCE II				6670	441	7110
5	YEAR - 4 MAINTENANCE III				3463	42	3505
6	YEAR - 5 MAINTENANCE IV				3463	42	3505
7	YEAR - 6 MAINTENANCE V				3463	42	3505
8	YEAR - 7 MAINTENANCE VI				1668	47	1715
Grand Total					113551	22867	136419

नोट :- मॉडल कार्यस्थल विशेष पर कार्य सम्पादित कराने के लिये प्राक्कलन नहीं है वरन केवल मार्गदर्शक है। कार्यस्थल पर कार्य सम्पादित कराने के लिए कार्य स्थल की विशेषताओं/ परिस्थितियों के अनुसार प्राक्कलन के आधार पर कार्य कराये जायें।