Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.14, No.5, 2022 www.iiste.org

# Impact of Sand Drifts on Jordanian Railway Infrastructures: Alternatives and Mitigation Measures

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**Abstract**
Railways play a critical role in connecting urban and rural regions, thereby promoting the economic sectors of a country. Nevertheless, railway tracks may suffer from several infrastructural problems and deficiencies including sand drifts, particularly in arid and semi-arid regions. This research aims to provide an analytical review of sand-laden drifts and winds, and the measures that can alleviate their impacts on the Aqaba railway tracks, Jordan. It also studies the influence of phosphate deposition as a result of trucks' passage on the railway tracks. General and practical recommendations from a socio-geographical context are also highlighted in view of proposing tactical solutions and identifying prospects for upcoming research to advance the technical and economical efficiency of the Jordanian railway network.
**Keywords:** Sand drifts, wind, railway network, railway infrastructures, mitigation measures.
**DOI:** 10.7176/CER/14-5-01
**Publication date:**August 31st 2022

## 1. Introduction

The Jordanian railway system consists of two major lines. The first line, comprising of 293.7 km, falls under the jurisdiction and management of the Aqaba Railway Corporation, which is devoted to the transportation of phosphate minerals from mining sites to the port of Aqaba. The second line (327.8 km) is the Jordanian Hijaz Railway, which extends from the Jordanian-Syrian border in the north through Zarqa, Amman, and Ma'an to the Saudi border in the south (Fig.1). The Jordanian Hijaz Railways supports limited passenger services and freight services between Amman and Damascus (Almasri and Al-Waked 2016, Rjoub and Al-Shawabkeh 2018).

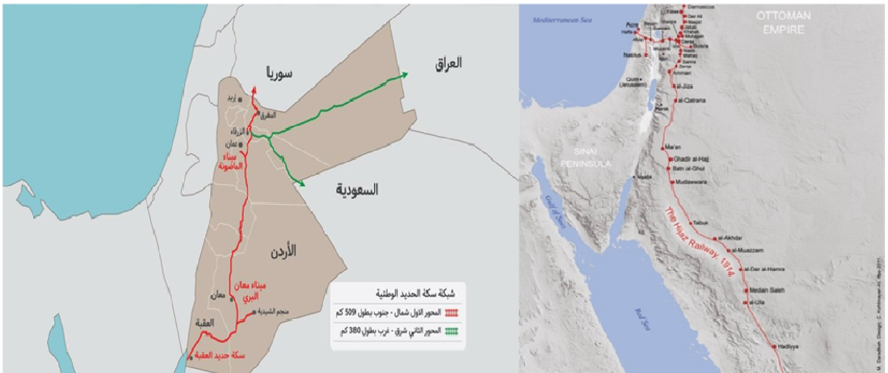



Figure 1. Map of the main Jordanian railways: red colour represents the first line (Aqaba Railway), and green colour displays the second line (Jordanian Hijaz Railway)

The Aqaba Railway line is exposed to two syncretistic phenomena. One of them is a human-induced phenomenon caused by the fall of phosphate from the wagons onto the railways (Fig.2). When phosphate material falls on the railway body (ballast), phosphate penetrates between the spaces in the ballast, which causes alterations in the work of the railway body from an elastic state to a rigid state. Subsequently, this leads to cracks in the rails and corrosion of the train's wheels. The second is a natural phenomenon that results in the accumulation of air-laden sand on the railways when the wind blows over the deserts (Fig.3). In addition, the seasonal temperature variations influence the railways (i.e., expansion, contraction, cracks…etc). The higher/lower temperatures could lead to traffic disruptions and lead to damage to the track railways. Heavy rainfall can cause flooding and temporary closure, which can result in the requirement to re-route sections of the track. Rainfall also leads to rusting of railways.

Figure 2. Use of special tools to remove phosphate materials falling from trucks on Aqaba railways

Figure 3. Sand encroachment on the Aqaba railway line

Sand drift is an important criterion in the design of railways in arid and semi-arid sandy deserts (Mehdipour and Baniamerian 2019, Lagum and Elektorowicz 2022). The amount of creeping sand depends on the wind speed and direction, land topography, size and density of sand grains, time of wind blowing, and presence of natural and artificial obstacles in the area, which are factors that can impact the geometric shapes of the railway tracks (Bruno et al. 2018, Raffaele and Bruno 2018). Extensive studies have been carried out on different types and sizes of sandy and creeping dunes (Al-Awadhi et al. 2005, Raffaele and Bruno 2020, Horvat et al. 2021). It was found that they take several geometric shapes including wavy-sand layers, rectangular dunes, around dunes, isolated dunes, longitudinal dunes, transverse dunes, sword dunes, star dunes, isolated crescent-shaped dunes, and paired crescent dunes (the paired crescent dunes are an advanced stage of crescent dunes) (Zhang et al. 2010, Rahdari and Rodríguez-Seijo 2021, Sampath et al. 2022). Isolated crescent-shaped dunes are the most widespread sandy and creeping dunes in the area of study.

The formation of the dome, ellipticalor crescent-shaped dunes along the railroad bed of Aqaba is caused by the movement of sand with the direction of the wind. The rate of dune formation depends essentially on wind energy, where the most crescent dunes formation range between 10-15 m/year (Hamdan et al. 2016). The formation of elliptical and semicircular dunes, on the other hand, ranges between 8-12 m/year. Fluctuating seasonal winds accentuate the dune formation along the Aqaba railway line, as the path of the dunes across the railway line, which is located between Haswa station located at 22+705 km to Amran station located at 88+901 km (Fig.1). In the Aqaba region, the sand movement is the most dangerous phenomenon on the railway.

The encroachment of sand on railway lines can cause numerous problems including obstruction of traffic and delay in scheduled routes (Behbahani 2015, Middleton et al. 2019). The accumulation of sand is usually irregular, leading to one of the bars being submerged in a thick layer of sand and the other free of sand (Fig.3). This creates a difference in the coefficient of friction between the surface of the rails and the wheel rims and exposes the trains to non-parallel slips.

The impact of sand particles on the train wheels increases as they rotate over the sections that are exposed to the accumulation of sand. It was found that the wheels in these areas are subjected to rolling flows that project outside the normal track of the wheels which may lead to slips. The difference is apparent between the wheels that run on bars covered by sand and those running on the lines free of sand (Fig.4).

Practical experiments have been conducted to study the corrosion of the wheels and rails on one and two sides of the rails. We did also experiments on locomotive rotation and these experiments changed the direction of wear for the rails. It was proven that sand drift is a major issue in railway design in arid sandy deserts. Given the increasing volume of new railway constructions and train speeds, it is important to adopt the necessary measures to ensure the safety of railway construction and to coordinate the movement of trains, in addition to performing frequent maintenance of the rail network. The practical experimental results will be presented in a future publication.

Figure 4. Special mechanisms of displacing sand and keeping it away from Aqaba railways


Figure 5. The effect of sand on the movement and corrosion of wheels and rails

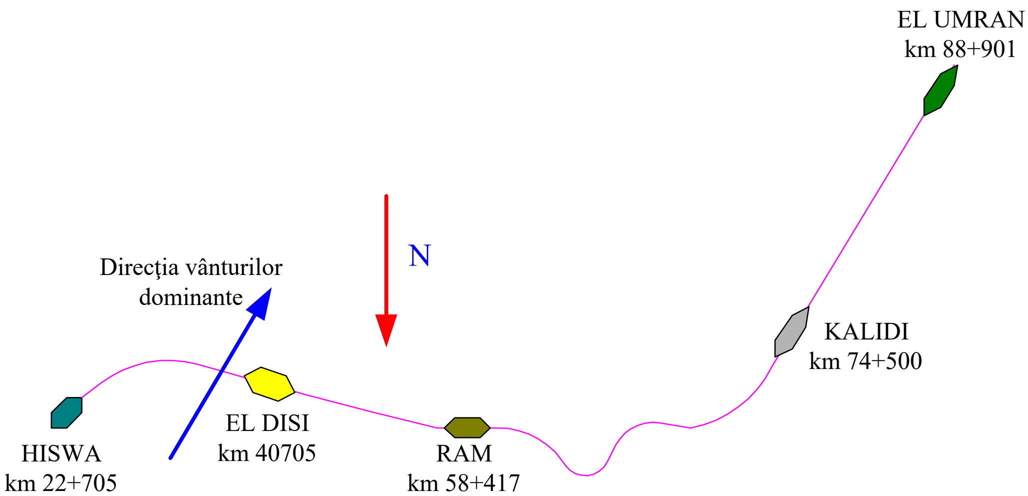



Figure 6. The path of the dunes is perpendicular to the Aqaba railway lines

## 2. Approaches for Solving Sand Encroachment

*2.1 The Following Highlights are Specific Strategies to Remedy Sand Encroachment on Aqaba Railway:*

1. Identification of areas that are highly prone to sand encroachment to ensure their protection.
2. Assessment of the climatic conditions and suitability of the sandy-area to the plant environment.
3. Evaluation of side slopes of the railway bridge to prevent sand from leaking and accumulating on the

bridges (railway flats).
4. Establishment of field stations equipped with instruments for sand observations and climate monitoring.
5. Implementation of adaption strategies, as well as application of lessons learnt when designing new railway lines.
6. Establishment of geomorphological maps displaying geological and topographical characteristics of exposed areas to sand encroachment.
7. Promoting vegetation covers and plant breeding in the area to capture and hold land.

*2.2 Mechanical, Chemical and Biological Strategies:*

*2.2.1 Mechanical Processing:*

The mechanical solution involves:
1. Isolating or removing the sand manually or by automated means from the railway lines (Fig.4).
2. Correcting the slopes of the line's path bridges and roughening them.
3. Introducing clay, steel, or wooden barriers on both sides of the line as fenders to protect against sand encroachment and prevent its accumulation on the railways (Fig.7 and Fig.8).

Although mechanical treatment provides temporary protection for the railway, it is a necessary measure to ensure the safety of trains and is highly recommended prior to implementing the first stage of biological treatment.

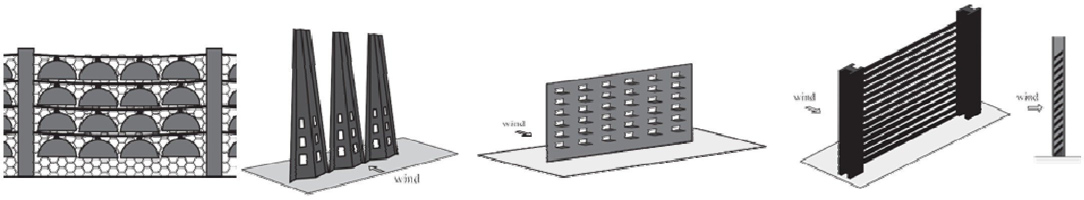


Figure 7. Examples of steel barriers (Bruno et al. 2018)

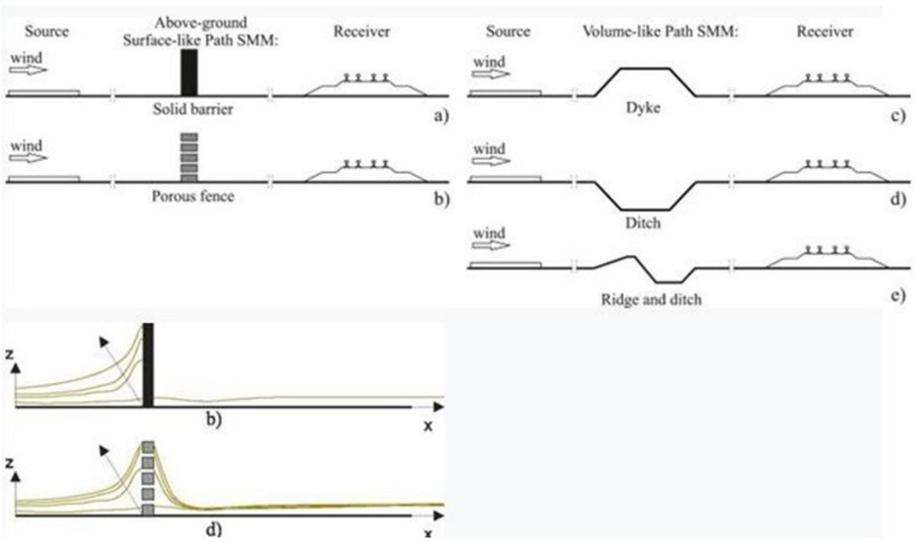



Figure 8. Barriers in the form of flat fences: (a) solid (b) permeable (c); shafts (d), ditches, and (e) ditches (Bruno et al. 2018)

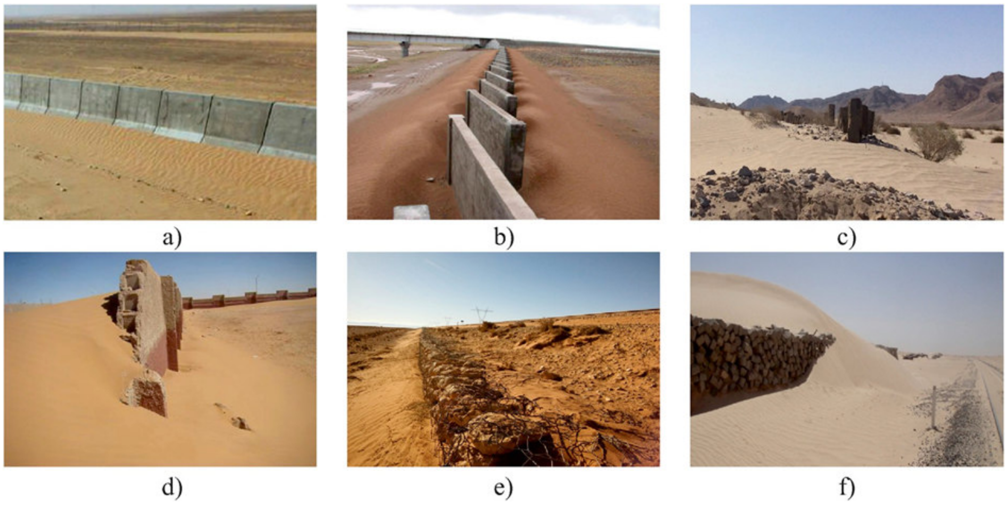



Figure 9. Some common installed concrete barriers to decrease sand deposition on the railway tracks. Straight vertical walls examples: a) precast r. c. modules (R. Mendez, Mendez, 2016 from Bruno et al. (2018); b) slanted, overlapped modules Zhang et al. (2010); c) alignment of vertical sleepers (curtsey of Astaldi). Straight vertical wall sedimentation patterns: d) free-standing concrete wall (Boulghobra 2015); ); e) gabion wall adjacent to the toe of the railway embankment (curtsey of Astaldi); and f) horizontally stacked sleepers (Boulghobra et al. 2016)

*2.2.2 Chemical Processing:*

This solution involves spraying adhesives such as oils or oil derivatives over the sandy soil to stabilize and limit the movement of sand particles.

Although chemical treatment may provide satisfactory results, there is almost unanimity in rejecting this method because it is not permanent and requires spraying adhesives that may have harmful repercussions on the environment, particularly on surrounding vegetation.

*2.2.3 Biological Treatment:*

Biological protection measures aim at cultivating sand-friendly plants (i.e., *psammophytic*) on the most durable quicksand. Examples of psammophytic plants include sea sandwort and saltwort, marram grass, creeping buttercup, creeping willow, and festuca rubra. However, this essential and environmentally-friendly measure takes a long time due to various reasons affecting its possibility and effectiveness, and it is not always possible to implement, particularly for seasonal plants.


Figure 10. Psammophyitic plants

Several researchers recognize the need to use technical engineering measures as support to increase the effectiveness of agroforestry measures such as physical and chemical methods to enhance the structure and mechanical properties of soils (Cherubin et al. 2019, Feng et al. 2019, Li et al. 2019). Sand erosion (creep) and, measures to mitigate its impact on the railway track (the layer line) create favourable conditions for seed germination and protect seedlings and cuttings from being blown by the wind.

The formation of dunes is reinforced along the bottom of the Alagba railway, in which the wind carries sand to the unprotected path. It is enshrined in railway design standards in conditions of sandy deserts, as well as in the rules for the protection of railways. Rules for the protection of railways from unfavourable phenomena have to be clearly identified. Also, the strengthening of the sandy areas adjacent to the roadbed should be considered by regular planting of trees, shrubs, and weeding of native species, as well as integrating the biological methods with technical procedures proven by the Green Belt System.

The experiments carried out by the Aqaba Railway Corporation indicated that the biological solution was the best, optimal and permanent measure. Biological treatment has multiple advantages in addition to its primary task in securing the protection of vital installations including railways. The performed studies were conducted to reduce the cost of this treatment, which was significant in the past. However, the results showed that cost is still an obstacle to adopting this solution, making it optional when necessary. Progress in biological treatment led experts to germinate crops, suitable and adapted to desert conditions, that are cheap and do not require continuous watering. Researchers also identified another solution for this treatment that depends on dry watering for germination, in which replaces continuous watering of crops and achieves the desired goal of this treatment at the lowest costs.

The so-called mechanical stabilization of technical measures is also used to prevent the source of shrinkage and intercept sand deposition from the stream, which achieves a quick result in sand stabilization with sand and preventing sand erosion. The mechanical method is performed by installing on the surface of solid barriers, porous fences, ditches, dams, hills and ditches, as well as chessboard devices (Fig. 11 and Fig. 12).

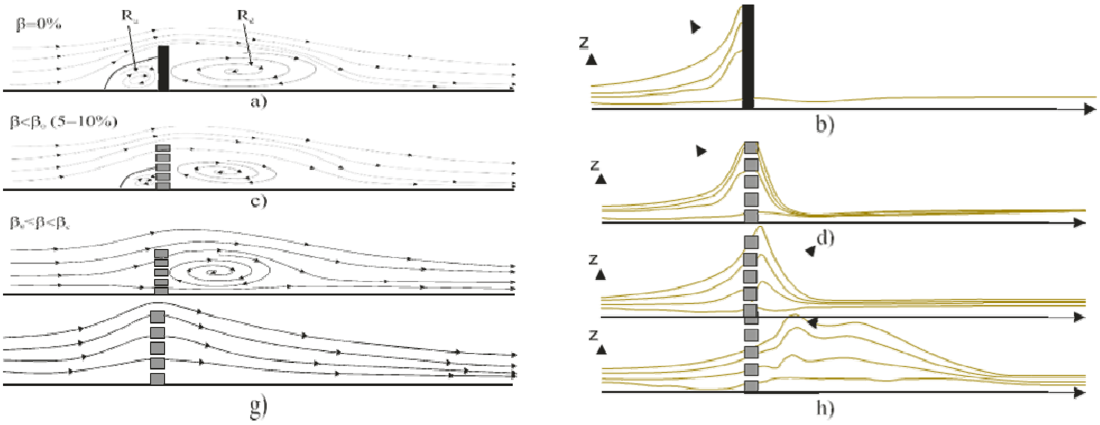



Figure 11. Wind flow mean streamlines and related sedimentation levels around: (a, b) solid , (c, d) very low porosity fences (β < β0), (e, f) low porosity fences (β0 < β < βc ), (g, h) high porosity fences (β > βc ). Sand sedimentation levels scale: Dz ¼ 5Dx (Bruno et al. 2018)

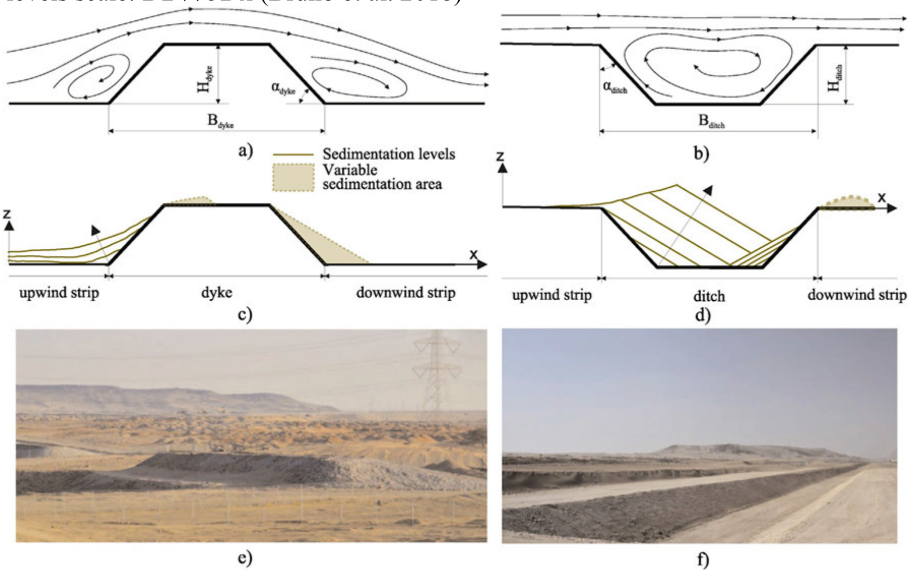



Figure 12. Volume-like SMMs. Wind flow means streamlines around a) a dyke, and b) a ditch. Sand sedimentation levels around c) a dyke, d) a ditch, e) a dyke, and f) a ditch

### *2.3 Basic Measures and Strategies to Mitigate the Impact of Wind and Sand Flow on the Infrastructure in Sandy Deserts:*

#### *2.3.1 Technical Protection*

Technical approaches include chemical improvement, mechanical protection, and change of track superstructure design among others. Organizational and economic approaches include reducing livestock grazing and fence installation. These classifications are very general and do not reveal the interaction and mutual influence of different sets of techniques and methods, nor specify the scope of each of them, or differentiate the degree of drifts.

The analysis of empirically-tested technological solutions is considered as an attempt to classify measures of protection against drifts and shrinkage. This is depending on the purposes, methods and means used: (i) preventive, (ii) vegetative coagulation, (iii) engineering coagulation and (iv) complex coagulation. The classifications of sand mitigation measures on railways are grouped based on the intended objectives. This solution depends on the existing vegetation cover and planting trees suitable for the climate and the dry desert nature (Li et al. 2004, Zakeri 2012, Pearlmutter et al. 2020).

Fences and shields can be used based on simulations and experimental testing of aerodynamic (Fig. 13). Raffaele and Bruno (2018) proposed a probabilistic model to evaluate the windblown sand sedimented around railways by analogy with environmental actions (i.e., wind, windblown snow, and wind-induced ice accretion). They found that the upper part of the vertical barriers must be curved in the direction of the wind and form a deflection as the use of snow-blown fences and shields as effective protection measures. Nonetheless, this approach requires intensive technical resources such as labour, material and equipment. Therefore, this approach may not be technologically and economically viable, except in the cases when it is used in combination with other measures in the context of creating a forest belt.

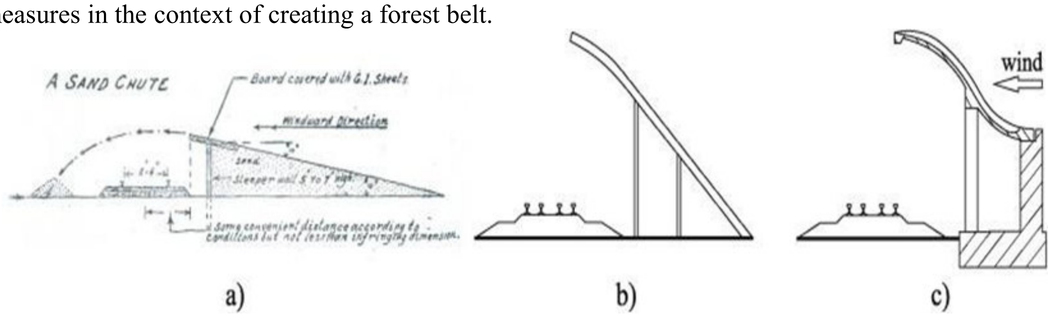



Figure 13. Construction of sand-transfer barriers: (a) Rahim (1945); (b) Guangyong and Peng (2012); and (c) (Sato and Ono 1990)

*2.3.2 Volumetric Protection*

The Arabian Peninsula has widespread use of different fence and shield types as volumetric protection. Trenches, columns, and trenches have three dimensions: length, height, and width. By contrast, fences and shields have only two dimensions: length and height. Volume baffles also include low baffles made of reeds, straw, palm branches, and other plant-based materials, in addition to synthetic woven and non-woven materials in the form of cells called a chessboard device. This is because they have three dimensions: the size of the cage in the scheme (length and width) and height.

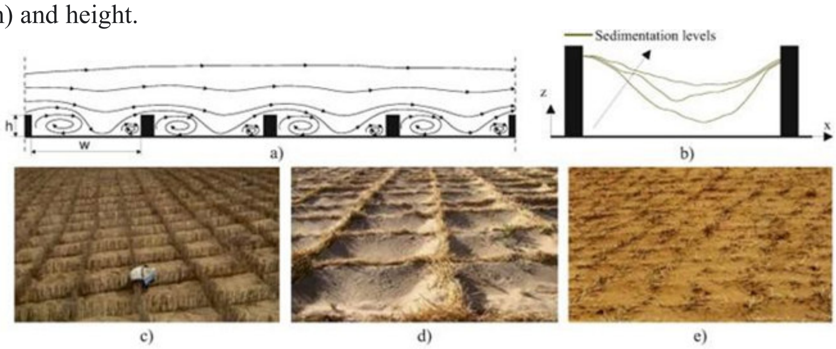



Figure 14. Cell protection from reeds: (a) placement of standing rows of reeds and (b) sand deposits; cell states: (c) initial, (d) in the process of filling with sand and (e) filled with sand (Raffaele and Bruno 2019)

*2.3.3 Physical and Chemical Measurements*

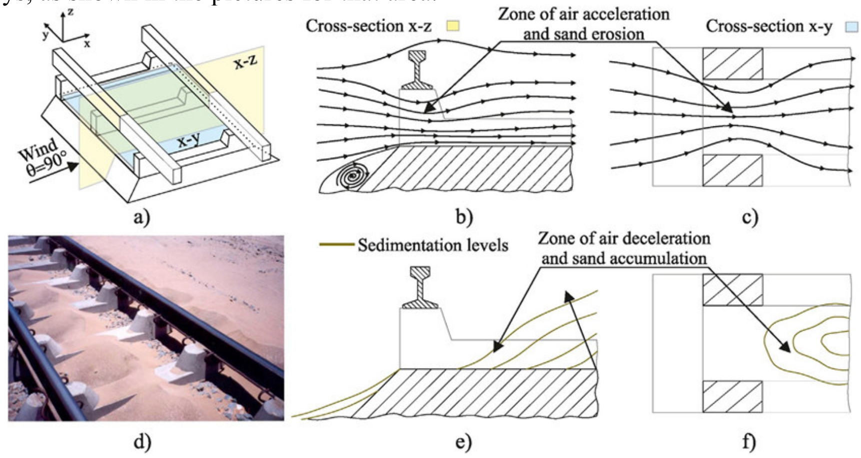
Several researchers have experimentally tested various binders to develop the theoretical and practical foundations of the physicochemical methods for the fixation of mobile dunes (Stipho 1992, Dong et al. 2004, Bruno et al. 2018, Raffaele and Bruno 2020). Kuldasheva et al. (2015) examined a number of polymers through which a list of physicochemical methods were provided, classifying these methods following the structure of molecules, molecular weight, and the criterion of the used materials. Another study reported that there was no obvious pattern for the influence of molecular weight on the impregnation process and the formation of the structure layer of the rigid sand (Mirakhmedovich et al. 2021). Unquestionably, the classification relating to the sort of bonds framed between the sand particles is significant. Muzaffarova and Mirakhmedov (2021) have made a significant contribution to the advancement of methods, proving the role of physical and mechanical characteristics of materials as well as the parameters of protective layers resistant on the reduction of wind-sand flow impacts.

Another promising technique is the cultivation of biological biomass on the sand using cyanobacteria and other types of algae (Román et al. 2020). Such technique is biological and environmentally-friendly, and is considered as the most promising measure, resulting in the obstructive of shrinkage source and works as a protective shell.

This method of reflective mats was used, where the steam current rising from the ground to the atmosphere through the desert sands is the cause of its destruction. It is also possible that this method is the cause of its greening. To lock it up and intensify it and return it to water for desert watering, and to benefit from it in its cultivation, and the task of the reflective mats is to increase the fishing area to intensify the water to the extent that is sufficient for watering sandy-plants.

**3. Major Problems Facing the Jordanian Railway Network**

1. Phosphate falling from trucks while passing on the Aqaba railway.
2. Sand encroachment on the Aqaba railways.
3. The presence of parts of the railway that is not higher than the level of the natural ground, which helps in the accumulation of transported sand with the air inside the path.
4. The presence of apparent gradients in the railways, which are confined to areas of sand encroachment on the railways, as shown in the pictures for that area.




5.

Figure 15. Ventilation holes at the bottom of the two rails that allow the wind-carrying sand particles to pass through. Venturi effect-based: a) humped sleepers scheme. Streamlines in the section: x-z (b), x-y (c). d) humped sleepers. Qualitative sand accumulation levels in the section: x-z (e), x-y (f) (figures reprinted from: Bruno et al. (2018)

**4. Recommended Applications to Mitigate Sand-Drift Impacts on the Jordanian Railway Network**

1. A promising measure to eliminate sources of shrinkage is the cultivation of cyanobacterial biomass. This approach is considered as a friendly measure to combat sand erosion.
2. Increase the ventilation holes at the bottom of the two rails that allow the wind-carrying sand particles to pass through.
3. Placing obstacles made of ballast material in the direction from which the wind blows.
4. Use and spray oils on both sides of the railway bridge.
5. Increase the number of sand barriers.
6. Adjusting the slopes of the side bridges and making them more streamlined to allow the passage of wind without any obstruction or stopping.
7. Adoption of the sand tenders that are made of wood, iron, or concrete sheets to prevent sand and phosphate from penetrating the ballast, as they have proven to be effective in protecting railways from accumulating quicksand.
8. The use of reflective mats for sunlight in large areas, as this experiment was successful in desert places, particularly areas of sand encroachment on railways.
9. Covering the dunes with a mixture of cement and sand or a mixture of gravel and clay, which is less expensive than other methods.
10. Using planes to scatter the seeds of grain that can grow and flourish to help stabilize the dunes.
11. Phosphate is a non-renewable resource with a limited reserve on the ground (Adam and Elektorowicz 2017, Adam; and Elektorowicz; 2018, Lagum 2021), thereby phosphate recovery methods from the railway line should be considered.

The above recommendations are specific to desert environmental conditions. Nevertheless, some of them can be implemented to maintain sustainable infrastructure in the cold regions by referring to actual, specific project constraints, economic, and environmental scenarios for each construction (i.e., railway lines, water systems …etc.) (Di Bernardino et al. 2015, Elektorowicz et al. 2016, Adam and Elektorowicz 2017).
Future studies should focus on the impact of Aqaba railway infrastructure on the surrounding environment and

tracking the fate of phosphate materials since it causes environmental contamination, particularly for surface and groundwater resources (Adam and Elektorowicz 2017). The majority of environmental effects within Aqaba railway system are caused by rails, ballast, sub-ballast, and civil engineering constructions. With nearly 50%, production of rail steel is the tremendous source for greenhouse gases (GHG) emissions within a high-speed railway track construction (Landgraf et al. 2022).

## 5. Concluding Remarks

This research contributes to increase knowledge about the influence of sand-laden winds and their flow on the Jordanian railway trails. The Aqaba city railway system appeared to suffer from combined damage by wind-blown sand and phosphate deposition as a consequence of wagons'passage on the railway lines. With the climate changing and human activities increasing (i.e., mines, phosphate transportation…etc.), sand damage along the railroad track will increase in the future. Albeit numerous sand-control measures were taken on, the damage of wind-blown sand is still severe in the Aqaba railroad track. As indicated by other studies on sandy-desert regions, the application of fences and blown snow shields as measures to protect railway lines from sand drifts is acceptable only by their use in integration with other measures in order to establish a forest belt. It is strongly recommended that the cultivation of cyanobacteria biomass on the sand, which is a beneficial measure for eradicating sources of deflation. The cultivation of cyanobacteria biomass creates a defensive layer, to act as an example of an astringent-sand defensive crust. Furthermore, it is suggested that more investigations should be conducted on sand encroachment assessment by modelling future climate change.

## 6. Acknowledgment

The authors express their gratitude to the Isra University (Amman, Jordan) for their support in carrying out this study.

## 7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 8. References

Adam, A. and M. Elektorowicz (2017), "Enhanced Electrochemical and Biological Phosphorus Removal in A Sole Reactor". *Canadian Society for Civil Engineering (CSCE): Leadership in Sustainable Infrastructure*. Vancouver, British Columbia, Canada, Canadian Society for Civil Engineering (CSCE) 437-481.

Adam, A. and M. Elektorowicz (2017), "Investigation of Fouling Mitigation under Low-Temperature Conditions Using Electro–Bioreactor". *International Symposium on Electrokinetic Remediation (EREM)*. Montreal, Quebec, Canada: 21-29.

Adam, A. and M. Elektorowicz (2017), "Low-Temperature Treatment of Municipal Wastewater in Bio-Electrochemical Reactor". *International Symposium on Electrokinetic Remediation (EREM)*. Montreal, Quebec, Canada, EREM 2017: 30-39.

Adam, A. and M. Elektorowicz; (2018), "Innovative Anammox Electro–Bioreactor Treating Municipal Wastewater at Low Temperature". *The 5th International Conference on Innovation in Science and Technology*. Barcelona, Spain, Diamond Scientific Publishing: 22-23.

Al-Awadhi, J., A. Al-Helal and A. Al-Enezi (2005), "Sand Drift Potential in the Desert of Kuwait". *Journal of Arid Environments* 63 (2): 425-438.

Almasri, A. H. and Q. F. Al-Waked (2016), "Inspection and Numerical Analysis of an Ottoman Railway Bridge in Jordan". *Advances in Materials Science and Engineering* 1 (2): 412-419

Behbahani, A. M. (2015), "Hazard and Risk Assessment of Wind Erosion and Dust Emissions in Denmark-A Simulation and Modelling Approach", *University of Basel*.

Boulghobra, N. (2015), "Sand Encroachment in The Saharan Algeria; the Not Declared Disaster-Case Study: In-Salah Region in The Tidikelt." *Planet Risk* 3 (1): 72-76.

Boulghobra, N., N. Koull and T. Benzaoui (2016), "Four Decades Period of Climatic Data for Assessing the Aeolian Hazard in The Region of Touggourt (Low Algerian Sahara) ". *Geographia Technica* 11 (1).

Bruno, L., M. Horvat and L. Raffaele (2018), "Windblown Sand Along Railway Infrastructures: A Review of Challenges and Mitigation Measures". *Journal of Wind Engineering and Industrial Aerodynamics* 177: 340-365.

Cherubin, M. R., J. P. Chavarro-Bermeo and A. M. Silva-Olaya (2019), "Agroforestry Systems Improve Soil Physical Quality in Northwestern Colombian Amazon". *Agroforestry Systems* 93 (5): 1741-1753.

Di Bernardino, A., P. Monti, G. Leuzzi and G. Querzoli (2015), "Water-Channel Study of Flow and Turbulence Past A Two-Dimensional Array Of Obstacles". *Boundary-Layer Meteorology* 155 (1): 73-85.

Dong, Z., G. Chen, X. He, Z. Han and X. Wang (2004), "Controlling Blown Sand Along the Highway Crossing the Taklimakan Desert". Journal of Arid Environments 57(3): 329-344.

Elektorowicz, M., S. Ibeid, Z. Arian and A. Adam (2016), "Wastewater Treatment and Water Recovery in Cold Regions Using Electro-Bioreactor". *Arctic Technology Center, ARTEK Event* 2016: 57-58.

Feng, Y., J. Wang, Z. Bai, and L. Reading (2019), "Effects of Surface Coal Mining and Land Reclamation on Soil Properties: A Review". *Earth-Science Reviews* 191: 12-25.

Guangyong, L. and M. Peng (2012), "Wind-Preventing Sand-Throwing Wall", *CN Patent*.

Hamdan, M., A. Refaat and M. A. Wahed (2016), "Morphologic Characteristics and Migration Rate Assessment of Barchan Dunes in The Southeastern Western Desert of Egypt". *Geomorphology* 257: 57-74.

Horvat, M., L. Bruno and S. Khris (2021), "CWE Study of Wind Flow Around Railways: Effects of Embankment and Track System on Sand Sedimentation". *Journal of Wind Engineering and Industrial Aerodynamics 208*: 104476.

Kuldasheva, S., B. Jumabaev, A. Agzamkhodjayev, L. Aymirzaeva and K. Shomurodov (2015), "Stabilization of The Moving Sands of The Drained and Dried Aral Sea Bed". *Journal of Chemical Technology & Metallurgy* 50 (3).

Lagum, A. A. (2021), "Integrating Electrochemical and Biological Phosphorus Removal Processes Via Electrokinetic-Based Technology". *Journal of Environmental Chemical Engineering* 9 (6): 106609.

Lagum, A. A. and M. Elektorowicz (2022), "Modification of Nitrifying Microbial Community via DC Electrical Field Application". *Journal of Environmental Chemical Engineering*: 107743.

Li, R., Q. Wu, J. Zhang, Y. Wen and Q. Li (2019), "Effects of Land Use Change of Sloping Farmland on Characteristic of Soil Erosion Resistance in Typical Karst Mountainous Areas of Southwestern China". *Polish Journal of Environmental Studies* 28 (4): 2707-2716.

Li, X. R., H. L. Xiao, J. G. Zhang and X. P. Wang (2004), "Long-Term Ecosystem Effects of Sand-Binding Vegetation in The Tengger Desert, Northern China". *Restoration Ecology* 12 (3): 376-390.

Mehdipour, R. and Z. Baniamerian (2019), "A New Approach in Reducing Sand Deposition on Railway Tracks to Improve Transportation". *Aeolian Research* 41: 100537.

Middleton, N., P. Tozer and B. Tozer (2019), "Sand and Dust Storms: Underrated Natural Hazards". *Disasters* 43 (2): 390-409.

Mirakhmedovich, Mirakhmedov and Makhamad (2021), "Sand Drift and Measures to Mitigate Its Impact on The Railway Track." *Turkish Journal of Computer and Mathematics Education* 12 (3): 3156-3161.

Muzaffarova, M. and M. Mirakhmedov (2021), "Physicochemical Method of Fixing Mobile Sands with Local Materials". *E3S Web of Conferences, EDP Sciences*.

Pearlmutter, D., D. Theochari, T. Nehls, P. Pinho, P. Piro, A. Korolova, S. Papaefthimiou, M. C. G. Mateo, C. Calheiros and I. Zluwa (2020), "Enhancing the Circular Economy with Nature-Based Solutions in the Built Urban Environment: Green Building Materials, Systems and Sites". *Blue-Green Systems* 2 (1): 46-72.

Raffaele, L. and L. Bruno (2018), "Probabilistic Assessment of Windblown Sand Accumulation around Railways". *Conference of the Italian Association for Wind Engineering, Springer*.

Raffaele, L. and L. Bruno (2019), "Windblown Sand Action on Civil Structures: Definition and Probabilistic Modelling". *Engineering Structures* 178: 88-101.

Raffaele, L. and L. Bruno (2020), "Windblown Sand Mitigation Along Railway Megaprojects: A Comparative Study". *Structural Engineering International* 30 (3): 355-364.

Rahdari, M. R. and A. Rodríguez-Seijo (2021), "Monitoring Sand Drift Potential and Sand Dune Mobility over the Last Three Decades (Khartouran Erg, Sabzevar, NE Iran)." *Sustainability* 13 (16): 9050.

Rahim, M. (1945), "Behaviour of Drift Sand and Method of Dealing with it". *Pakistan Engineering Congress*.

Rjoub, A. and R. Al-Shawabkeh (2018), "Urban and Architectural Impacts of Hejaz Railway in Mafraq-Jordan". *International Journal of Humanities and Social Science* 8 (1): 121-131.

Román, J. R., A. Chilton, Y. Cantón and M. Muñoz-Rojas (2020), "Assessing the Viability of Cyanobacteria Pellets for Application in Arid Land Restoration". *Journal of Environmental Management* 270: 110795.

Sampath, D. M. R., J. Beattie and J. G. de Freitas (2022), "Managing Coastal Sand Drift in the Anthropocene: A Case Study of the Manawatū-Whanganui Dune Field, New Zealand, 1800s–2020s". *Environment and History*.

Sato, A. and M. Ono (1990), "Snowstorm Guard Fence Structures and Jet Roofs", *Google Patents*.

Stipho, A. (1992), "Aeolian Sand Hazards and Engineering Design for Desert Regions". *Quarterly Journal of Engineering Geology and Hydrogeology* 25 (2): 83-92.

Zakeri, J. A. (2012), "Investigation on Railway Track Maintenance in Sandy-Dry Areas". *Structure and Infrastructure Engineering* 8 (2): 135-140.

Zhang, K.-c., J.-j. Qu, K.-t. Liao, Q.-h. Niu and Q.-j. Han (2010), "Damage by Wind-Blown Sand and Its Control Along Qinghai-Tibet Railway in China". *Aeolian Research* 1 (3-4): 143-146.

Zhang, N., J.-H. Kang and S.-J. Lee (2010), "Wind Tunnel Observation on The Effect of a Porous Wind Fence on Shelter of Saltating Sand Particles". *Geomorphology* 120 (3-4): 224-232.

Landgraf, Matthias, Martina Zeiner, Dieter Knabl, and Francesco Corman (2022), "Environmental impacts and associated costs of railway turnouts based on Austrian data". *Transportation Research Part D: Transport and Environment* 103: 103168.