THE IMPACT OF DUST POLLUTION FROM UNPAVED ROADS IN THE AKAMAS PENINSULA, CYPRUS, USING UAV AND SENTINEL-2 IMAGES

K. Themistocleous[1,2] *, M. Prodromou[1,2]

[1] Eratosthenes Centre of Excellence, Cyprus - k.themistocleous@eratosthenes.org.cy, maria.prodromou@eratosthenes.org.cy
[2] Cyprus University of Technology, Cyprus – k. themistocleous@cut.ac.cy, ml.prodromou@edu.cut.ac.cy

KEY WORDS: Akamas, NDVI, Dust pollution, Sentinel-2, spectral signatures, thermal and infrared images

ABSTRACT:

This study examines the effects of dust in the Akamas National Park in Cyprus generated from traffic over the unpaved roads on the roadside vegetation. The Akamas National Park is located on the western tip of Cyprus and covers an area of about 230 km², containing valleys, gorges and wide sandy bays. Akamas is a mountainous, relatively inaccessible area to standard vehicles and protected from man-made development. It is home to hundreds of animal species and plants that are essential for the ecology of the Mediterranean region. There are several unpaved roads to access the area and more than one million people visit the Akamas peninsula each year, mostly in the summer period, primarily in 4X4 and all-terrain vehicles, which are rented in the nearby area. This unregulated traffic results in dust, especially during the dry weather conditions in the summer that can fall up to a kilometre away on all sides of the vehicle.

In this study, images acquired from an Unmanned Aerial Vehicle (UAV) of the roads within the Akamas peninsula were compared with Sentinel-2 satellite images during different seasons. Using the Normalized Vegetation Index (NDVI) from the Sentinel-2 images, it was shown that the vegetation nearest to the unpaved roads exhibited pronounced stress compared to the vegetation that was more distant. Also, spectral signatures as well as infrared and thermal images were taken at different distance intervals from the unpaved road.

1. INTRODUCTION

The Akamas Peninsula National Park covers an area of 230 square kilometres on the north-western tip of Cyprus. It is a unique unspoilt area, with remarkably diverse features in vegetation, wildlife, geology, beautiful landscapes and coasts, and with a rich historical and cultural heritage. As the area is relatively inaccessible, it is home to a large diversity of flora and fauna. The Akamas Peninsula is famous for its abundance of flora and fauna with more than 650 species of flora, of which 42 are endemic and 200 species of fauna, of which 11 are endemic. The diversity of wildlife in this area ranks it as an area of outstanding ecological importance. The Akamas peninsula is also characterised by a large diversity of vegetation communities which are directly related to the area's very complex and varied geology and morphology.

Due to the mountainous nature of the peninsula, there are only unpaved roads in the Akamas area. The unregulated traffic in the Akamas Peninsula generates vast amounts of dust that can cause health problems to humans and animals, reduced crop yields and negatively affect the health of vegetation in the area.

Figure 1. Dust from unpaved road in Akamas Peninsula (photo taken by the authors)

Unpaved roads produce higher dust levels than paved roads (Farmer. 1993, Roberts et al. 1975, Everett. 1980, Joshi & Abhishek. 2007). Unpaved roads are built based on soil compaction without surface coating. Where contact between the soil and the vehicle wheels is made, the aggregates of soil particles can be torn off and then crumbled, resulting in the formation of fine particles on the road surface, which can be lifted by the passing vehicles which result in large amounts of dust blown into the atmosphere. (Le Vern et al. 2022). The suspended particles fall on the leaves of plants near the emission zone and pose a direct or indirect threat to the survival or productivity of plants (Shah et al. 2017).

Once dust particles are blown onto vegetation, they tend to stick to the surface of the leaf surface until they get washed off with rain or shredding of the leaf itself. (Sett. 2017). As all essential physiological processes are conducted by the leaf, the leaf is the most vulnerable part to air pollution (Muthu et al. 2021). Research indicates that dust may affect photosynthesis, respiration, transpiration and allow the penetration of phytotoxic gaseous pollutants within the plants (Farmer. 1993, Kameswaran et al. 2019, Lewis et al. 2017).

Several studies have measured the effect of dust pollution on plants at varying distances away from the source. Results have consistently found negative effects on plants when dust was deposited near the road and diminishing negative effects the farther away from the unpaved road (Swain et al. 2016, Faisal. 2010, Avon et al. 2013, Mullerova et al. 2011, Gunn. 1998). Several researchers also examined the distance intervals at which there was a marked difference in how vegetation can be affected by dust pollution resulting from a vehicle on an unpaved road. The distance from vegetation with dust deposition to unaffected vegetation can be 200m (Smithers et al.

(2016), 500m (Fazer. 2003) or 1000m (Kameswaran et al. 2019). Research methodologies to examine the impact of dust deposition on vegetation health have tended to utilize three distinct sites located at different distances from the unpaved road (Amarsanaa et al. 2022, Najib et al. 2022, Gill et al. 2014). In all these studies, dust deposition was found to decrease as the distance from the road increased (Lewis et al. 2017, Najib et al. 2022).

As well, the effects of dust on plants are demonstrated by inhibited growth inhibition and visible damage on leaves (Farmer. 1993, Kameswaran et al. 2019, Lewis et al. 2017). Growth inhibition may be due to several factors, such as direct injury to plant tissue by the chemical reactions of dust particles on leaf surfaces, the amount of sunlight received by the leaf and the plugging of the stomata openings by dust (Vijaywargiya & Pandey. 1996, Gupta & Mishra. 1994). The reduction of leaf stomatal conductance influences plant biomass formation and yield. By affecting both the opening and closing of stomata, dust can significantly impact the photosynthetic capacity of plants by decreasing the uptake of CO_2 and increasing water loss. (Lewis et al. 2017, Farmer. 1993, Hirano et al. 1995, Sett. 2017, Kameswaran et al. 2019). Dust deposition on leaves can increase leaf temperature, which negatively affects photosynthesis and results in poor vegetation health (Sharifi et al. 1997, Grantz et al. 2003, González et al. 2014, Guo et al. 2018, Baker & Rosenqvist. 2004).

In this study, the impact of dust deposition on vegetation was examined in the Akamas Peninsula through the use of UAV and satellite images as well as in-situ measurements using spectroradiometers, RGB, multi-spectral and thermal cameras.

2. STUDY METHODOLOGY AND RESULTS

With the assistance of the Cyprus Department of Forestry, UAV images were taken using a 20MP camera along the unpaved roads in the Akamas peninsula. The UAV followed the 4x4 vehicle, taking images along the route at a height of 100 metres to cover enough area on each side of the road. The survey was conducted during October, after the end of the summer period, to show the extent of the dust on the vegetation along the unpaved route. Additionally, Sentinel-2 images were used to show the extent of the dust during the same year by using the NDVI values. The Normalized Difference Vegetation Index (NDVI) is used as an indicator of the vegetation greenness in order to specify the density and health of the vegetation.

The vegetation examined was the Pistacia lentiscus, which is locally known as Schinia. It is an evergreen, aromatic shrub with leathery, green and feather-like leaves. It tends to grow in dense shrubland, open forest and along sandy beaches on stabilized sand dunes. The plant has a wide distribution in the Mediterranean countries and is a widespread native species in Cyprus that grows at altitudes up to 800m.

Figure 2. Left: Roadside vegetation (winter) Right: Roadside vegetation (summer)

It is evident that in the summer the dust accumulates quite heavily on the vegetation and the leaves are covered by dust (Figure 2). Dust deposition on leaves may physically smother the leaves and can result in reduced photosynthesis (Sett. 2017). The accumulation of dust on the vegetation closest to the unpaved road is shown in Figure 3 (left), while vegetation further away from the road has significantly fewer dust deposits.

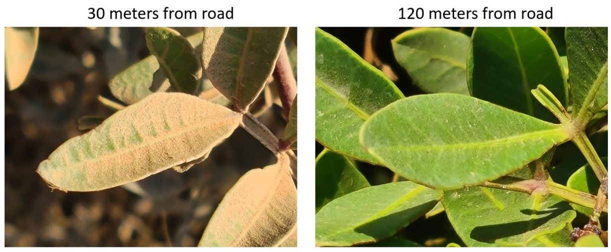

Figure 3. Left: Dust accumulation on leaves closest to the road Right: Dust accumulation on leaves further from the road

2.1 Spectral Signatures

Spectroscopy was used to identify the health of the vegetation. Spectroscopy examines the interaction between matter and electromagnetic radiation to provide valuable information about the composition, structure, and properties of various materials. It is widely used to assess vegetation health and monitor plant physiological parameters. In this study, the SVC HR1024 field spectroradiometer with Leaf Probe was used, which measures between the visible to short-wave infrared wavelength range (350-2500nm).

A leaf probe is a specialized tool that is used as an attachment to the Spectroradiometer, connected with a fiber optic cable, that is designed to measure the spectral reflectance of light on leaves using artificial illumination. The probe is able to make spectral measurements of leaves and enables the selection of either the white or dark plate as a background. Reference measurements are made using a Spectralone panel plate so the white reference plate is facing towards the probe window while taking a measurement. Leaf measurements are then made by inserting the leaves between the holder plate and the window, or by moving the probe window up to the target and taking a contact measurement (Figure 4).

Figure 4. spectral measurements of leaves using a leaf probe

Using the SVC HR1024 Leaf Probe, Spectral signatures were taken of the vegetation at a distance of 30m, 60m, 90m and 120m from the edge of the unpaved road. The results are shown in Figure 5.

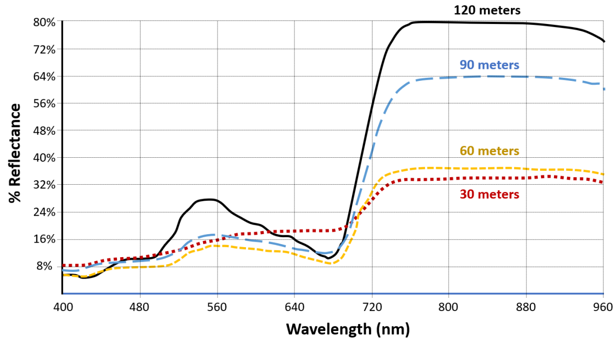

Figure 5. Spectral Signatures of vegetation at various distances from the edge of the unpaved road.

The spectral signatures show a decrease in vegetation health at the closest proximity to the road, at 30m and 60m (red and orange lines in Figure 5), while there is an increase in vegetation health at the distances of 90m and 120m from the edge of the unpaved road (blue and black lines in Figure 5).

In Figure 5, leaf health can be identified by the 'red edge' in the 680-760nm range of the leaf spectrum between the Visible Red and Near Infrared bands. The Red Edge slope can be easily identified by looking at the curve at the region of the spectrum, where the spectral reflectance of green vegetation changes rapidly due to the strong absorption of energy in the Red Edge wavelength by chlorophyll in vegetation. Thus, a healthy plant has more chlorophyll and absorbs more light energy in the 680-760 nm. However, higher absorption means less reflectance and lower spectral value; therefore, stressed vegetation has lower reflectance than healthy plants of the same species. In Figure 5, due to the dust accumulated on the leaves of the plant at the 30m and 60m distances, the 'Red Edge' steep slope to the infrared wavelengths does not exist, in comparison to the spectral values at the 90m and 120m distances.

2.2 Infrared and Thermal Images

Infrared images were acquired using a multi-spectral camera with a spectral width of 30mm and spectral peak at 850nm to identify the reflectance in density within the infrared wavelengths. In addition, thermal images were acquired with a thermal camera to show the variation in temperature of the vegetation depending on the presence of dust. Figure 6 shows the RGB, infrared and thermal images at 30m and 120m from the edge of the unpaved road.

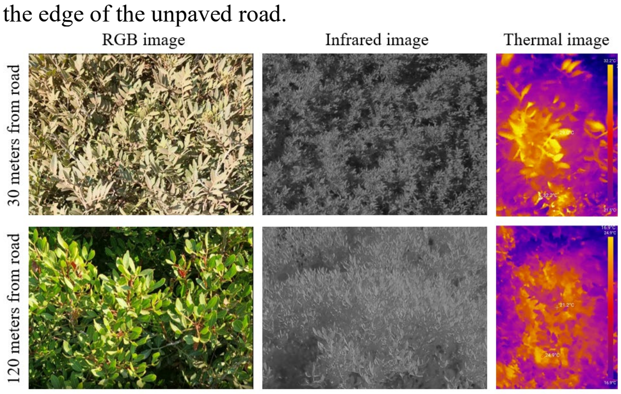

Figure 6. RGB, infrared and thermal images at 30m and 120m from the edge of the unpaved road.

In comparing the above images from the 30m and 120m distance from the unpaved road, the changes in the vegetation impact from the dust can be easily identified. The RGB images show a colour shift from green to grey and the infrared from white to grey, showing higher reflectance values at the infrared wavelengths, which is consistent with the spectral signatures (Figure 5). The thermal images show a range of values between 21.2°C to 24.9°C for the vegetation at 120m from the unpaved road while the thermal values were between 29.0°C to 32.2°C for the vegetation at 30m from the edge of the unpaved road. The temperature measurements indicate that dust deposition increases vegetation temperature, which is consistent with the literature review.

2.3 Normalized Difference Vegetation Index (NDVI)

The NDVI relates the information acquired in the red and near-infrared (NIR) bands with the state and characteristics of the vegetation covers through the normalized difference of the two bands whose range of variation is between −1 and 1. Negative values (−1) to zero (0) are bare surfaces, while values from zero (0) to one (1) show the presence of plants (Song et al. 2021).

Equation (1) for NDVI is shown below:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

where NIR = value from red near-infrared band
Red = value from red band

NDVI can be used as an indicator of a plant's health based on how the plant's cell structures reflect the different light waves in the visible and near-infrared bands, by detecting and quantifying the presence of live green vegetation on the basis of the interaction of objects with light. NDVI is the most used remote sensing method that uses the reflectance of light in the visible and near-infrared (NIR) wavelengths to determine the amount and health of vegetation in an area to monitor the growth and health of vegetation and to identify areas of stress or damage.

Plants have a unique reflectance characteristic as they reflect more near-infrared (NIR) light and absorb more visible light. When plants are healthy, they have a high chlorophyll content, which allows them to absorb more light in the red region of the spectrum and reflect more light in the NIR region. Using this unique characteristic, NDVI values can also be used to detect vegetation health and stress over time.

NDVI has become the most popular index used for vegetation assessment (Huang et al. 2021) as it is simple to use and can rapidly differentiate between vegetation stress and vegetation health. NDVI measures the relationship between the energy absorbed and emitted, the amount of vegetation present on a surface, and its state of health or vegetative vigour (Beltran et al. 2017).

The NDVI Index (equation (1)) was applied to a time series of Sentinel-2 images in order to identify the time periods where dust is more evident. Time series analysis from Sentinel-2 images show that, during the summer period, there is a reduction in NDVI values within the area along the unpaved roads, as shown in Figure 8. This can also be affected by the seasonal changes, especially during the summer, with the increase in temperature and lack of rain. However, the NDVI values show reduced values, especially nearest to the unpaved roads. Figure 7 shows the impact of vegetation health near the unpaved roads, especially during the summer. The area used for the time series analysis was within 300m of the unpaved roads, which is featured in Figure 8.

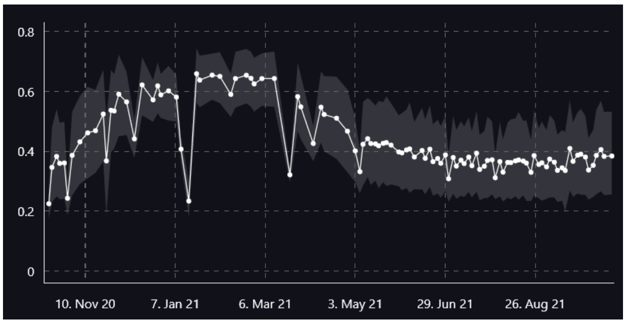

Figure 7. NDVI values over the period of one year

The time series analysis showed that plant degradation occurred during the summer season, where traffic in the Akamas Peninsula is quite pronounced, as indicated by lower NDVI values along the sides of the road and changes in the colour of the vegetation as observed from the images acquired from the UAVs. Two sets of UAV images were taken during the winter and summer period (Figure 2) that show the extent of the colour of the vegetation from the accumulation of dust. As is evident, the leaves of the roadside vegetation are coated with dust during the summer period, resulting in plant degradation, as opposed to the winter period.

The time series analysis indicates that the value of the NDVI index decreased during the summer months from 0.65 to 0.30. This was evident that areas less than 100+ meters from unpaved roads were affected by the dust, which were also verified by the images taken from the UAV (figure 2).

By using the NDVI indices and comparing the Sentinel-2 images during the summer and winter period, the extent of the pollution degradation of the vegetation along the edge of the unpaved roads is evident, as shown in Figure 8, which is consistent with the degradation shown from the UAV images and the spectral signatures.

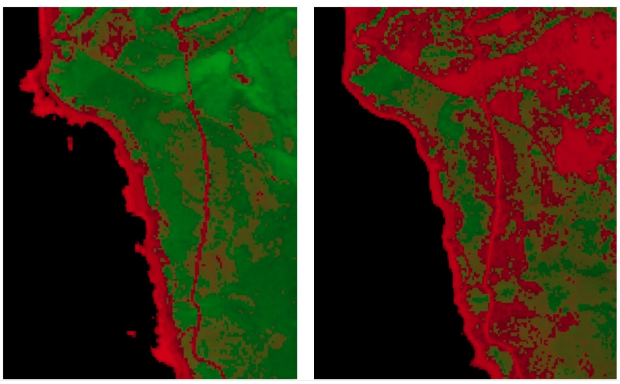

Figure 8. NDVI comparing Sentinel-2 images during the winter and summer periods (27/3/2021 and 15/10/2021)

From the in-situ images acquired of the vegetation using the multi-spectral camera, NIR and Red images were used to calculate the NDVI using Equation 1 with the vegetation located at 30m and 120m. NDVI values indicate that the vegetation closest to the unpaved road feature higher stress and lower vegetation health, in comparison with the vegetation 120m from the unpaved road. The NDVI in Figure 9 shows negative values in red and positive values in green, yellow and orange, which corresponds with the NDVI produced from the Sentinel 2 images, as indicated in Figure 8.

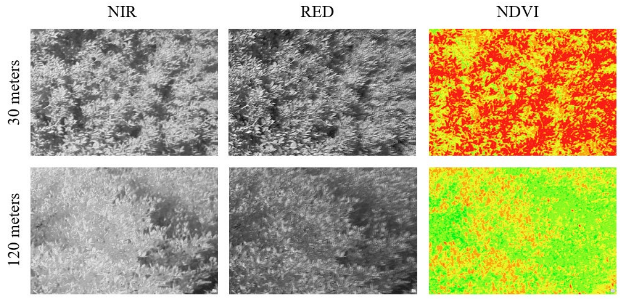

Figure 9. NIR and Red layers from the multi-spectral camera and the resulting NDVI

Usually, the deposition of dust on the surface of the vegetation and the leaves of the plant results in a reduction of the light required for photosynthesis and an increase in the temperature of the leaves due to a change in the optical properties of its surface. Energy exchange in plants is important with air diffusion in and out of leaves, which is affected by dust load, colour and size. Alkaline dust materials may cause leaf surface injury while other materials may be absorbed along the plant epidermis. Dust affects the vitality of vegetation and negatively affects chlorophyll.

3. CONCLUSIONS

Based on the results of this study, it is evident that dust has a significantly negative impact on vegetation near the unpaved roads in the Akamas Peninsula. The Akamas peninsula with its vast variety of flora and fauna species has been proposed for inclusion in the "Natura 2000" network. The inclusion of the peninsula in the European Ecological network and its classification as a special protected area is undoubtedly an important step towards the conservation and protection of its biodiversity and natural beauty. To establish and enforce an integrated Management Plan and legally binding Conservation Decrees for the area, as well as directly allocate funding towards its implementation including concrete conservation measures, close monitoring, patrol of the area and restriction of traffic will resolve several of the issues for the environmental protection and conservation of the area.

The study indicates that there is a need for managing and regulating traffic to the Akamas area, especially during the high-traffic periods. It is recommended that the area be protected due its unique ecosystem and that traffic be restricted, especially during the summer months. This can be done by managing and regulating traffic using people-carrier vehicles or minimizing the entrance of vehicles during high-traffic periods. Managing, organizing and regulating the traffic within the protected areas of the Akamas National Park, will be able to mitigate the pressure on natural ecosystem, which the competent authorities will need to achieve through the operation of the Akamas National Forest Park.

In addition, the declaration of the whole Akamas Peninsula as a national park and protected area with provide the National Park with international protected status.

ACKNOWLEDGEMENTS

The authors acknowledge the 'EXCELSIOR': ERATOSTHENES: EXcellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment H2020 Widespread Teaming project (www.excelsior2020.eu). The 'EXCELSIOR' project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 857510, from the Government of the Republic of Cyprus through the Directorate General for the European Programmes, Coordination and Development and the Cyprus University of Technology.

The authors would also like to acknowledge the Department of Forests, Ministry of Agriculture, Rural Development and Environment of the Government of Cyprus for their assistance in this study.

REFERENCES

Amarsanaa, S., Lkhagva, A., Chogsom, B., Bayaraa, B., Damdin, B., Tsooj, B., Nyamjav, J., Baival, B., Jamsranjav, C., 2022: Quantifying the Spatial Extent of Roads and Their Effects on the Vegetation in Mongolia's Gobi Desert. *Land* 11, 820.

Avon, C., Dumas, Y., Berges, L., 2013: Management Practices Increase the Impact of Roads on Plant Communities in Forests. *Biological Conservation*, 159, 24-31.

Baker, N.R., Rosenqvist, E., 2004: Applications of Chlorophyll Fluorescence Can Improve Crop Production Strategies: An Examination of Future Possibilities. *Journal of Experimental Botany*, 55(403), 1607-1621.

Beltrán Hernández, D.H.. 2017: Aplicación de Indices de Vegetación Para Evaluar Procesos de Restauración Ecológica en el Parque Forestal Embalse del Neusa; Universidad Militar Nueva Granada: Neusa, Colombia.

Everett, K. R., 1980: Distribution and Properties of Road Dust Along the Northern Portion of the Haul Road. in Environmental Engineering and Ecological Baseline Investigations Along the Yukon River-Purdhoe Bay Haul Road, ed. J. Brown & R. Berg. *US Army Cold Regions Research and Engineering Laboratory, CRREL Report* 80-19, 101-28.

Faisal, G., 2010. Effect of Dust Deposits in Physical and Chemical Characteristics of Fruits and Leaves of Date Palm Phoenix dactylifera L. *Basrah Journal for Date Palm Research*, 9(1) 16-34.

Farmer, A.M., 1993: The Effects of Dust on Vegetation - A Review, *Environmental Pollution* 79 (1), 63-75. doi.org/ 10. 1016/0269-7491(93)90179-R.

Fazer, L., 2003: Down with Road Dust. *Environmental Health Perspectives* 111, 892-895.

Gill, H.K., Lantz, T. C., O'Neill, B., Kokelj, S.V., 2014: Cumulative Impacts and Feedbacks of a Gravel Road on Shrub Tundra Ecosystems in the Peel Plateau, Northwest Territories, Canada, *Arctic, Antarctic, and Alpine Research*, 46(4), 947-961, doi: 10.1657/1938-4246-46.4.947

González, J.A., Prado F.E., Piacentini. R.D., 2014: Atmospheric Dust Accumulation on Native and Non-Native Species: Effects on Gas Exchange Parameters. *Journal of Environmental Quality* 43, 801–808.

Grantz, D.A., Garner, J.H.B., Ohnson, D.W.J., 2003: Ecological Effects of Particulate Matter. *Environment International* 29, 213–239.

Gunn, A., (1998). Effect of Gravel Road and Tailing Pond Dust on Tundra Plant Communities Near Lupin Mine, NWT. *West Kitikmeot Slave Study Society, Final Report.*

Guo, Y., Qian, X., Li, X., Hu, Z., Wu, J., Wang, L., 2018: Effects of Dust Deposition on the Physiological and Biochemical Characteristics of Lycium Ruthenicum. *Ecotoxicology and Environmental Safety*, 163, 313-319.

Gupta, A.K., Mishra, R.M., 1994: Effect of Limekiln's Air Pollution on Some Plant Species. *Poll Res*. 13, 1–9.

Hirano, T., Kiyota M., Aiga, I., 1991: The Effects of Dust by Covering and Plugging Stomata and by Increasing Leaf Temperature on Photosynthetic Rate of Plant leaves. *Journal of Agricultural Meteorology*, 46, 215-222.

Huang, S., Tang, L. Hupy, J.P., Wang, Y., Shao, G., 2021: A Commentary Review on the Use of Normalized Difference Vegetation Index (NDVI) in the Era of Popular Remote Sensing. *J. For. Res.* 32, 1–6.

Joshi, P.C., Abhishek, S., 2007: Physiological Responses of Some Tree Species Under Roadside Automobile Pollution Stress Around City of Haridwar, India. *Environmentalist* 27, 365–374.

Kameswaran, S., Gunavathi, Y., Krishna, P.G., 2019: Dust Pollution and its Influence on Vegetation - A Critical Analysis. *Life Science Informatics Publications* 5, 341-363.

Le Vern, M., Razakamanantsoa, A., Murzyn, F., Larrarte, F., Cerezo, V., 2022: Effects of Soil Surface Degradation and Vehicle Momentum on Dust Emissions and Visibility Reduction From Unpaved Roads, *Transportation Geotechnics*, 37, https://doi.org/10.1016/j.trgeo.2022.100842.

Lewis, M.B., Schupp, E.W., Monaco T.A., 2017: Road Dust Correlated with Decreased Reproduction of the Endangered Utah Shrub *Hesperidanthus Suffrutescens*. *Western North American Naturalist,* 77, 430-439.

Mullerova, J., Vitkova, M., Vitek, O., 2011: The Impacts of Road and Walking Trails Upon Adjacent Vegetation: Effects of Road Building Materials on Species Composition in a Nutrient Poor Environment. *Science of Total Environment*, 409, 3839-3849.

Najib, R., Houri, T., Khairallah, Y., Khalil, M., 2022: Effect of Dust Accumulation on *Quercus cerris* L. Leaves in the Ezer Forest, Lebanon. *iForest* 15, 322-330. doi: 10.3832/ifor3959-015

Roberts, J.W., Watters, H.A., Mangold, C.A., Rossano, A.T., 1975: Cost and Benefits of Road Dust Control in Seattle's Industrial Valley. *Journal of the Air Pollution Control Association*. 25, 948-952.

Sett, R., 2017: Responses in plants exposed to dust pollution. *Horticult Int J.* 1(2), 53-56. doi: 10.15406/hij.2017.01.00010

Shah, K., Amin, N.U., Shah, S., Hussain, K., 2017: Dust Particles Induce Stress, Reduce Various Photosynthetic Pigments and their Derivatives in Ficus benjamina: A Landscape Plant. *International Journal of Agriculture and Biology,* 19, 1469-1474.

Sharifi, M.R., Ibson, A.C.G., Rundel P.W., 1997: Surface Dust Impacts on Gas Exchange in Mojave Desert Shrubs. *Journal of Applied Ecology* 34, 837–846.

Smithers, R., Harris, R., Hitchcock, G., 2016: The Ecological Effects of Air Pollution from Road Transport: An Updated Review. *Natural England Commissioned Report, Worcester, UK*, 1-38.

Song, Y., Chen, B., Ho, H.C., Kwan, M.-P., Liu, D., Wang, F., Wang, J., Cai, J., Li, X., Xu, Y., 2021: Observed Inequality in Urban Greenspace Exposure in China. *Environ. Int*. 156, 106778.

Swain, S., Mallick, S.N., Prasad, P., 2016: Effect of Industrial Dust Deposition on Photosynthetic Pigment Chlorophyll and Growth of Selected Plant Species in Kalunga Industrial Areas, Sundargarh, Odisha. *International Journal of Botany*, 1, 1-5.

Vijaywargiya, A., Pandey, G.P., 1996: Effect of Cement Dust Pollution on Soybean: Physiological and biochemical. *Ecol Env and Cons*. 2, 43–145.