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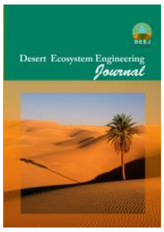

An Evaluation of Petroleum Mulch's Impact on Heavy Metal Concentrations in Coastal Sand Dunes of Eastern Hormozgan Province, Iran

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Extended Abstract

Introduction: Petroleum mulch is widely employed in Iran for wind erosion control, temporary sand dune stabilization, and aiding plant establishment (Jafarian, 2006; FAO, 1993). Applied as an emulsion, it forms a thin, porous layer upon dehydration, effectively stabilizing soil surfaces (Kardavani et al., 2013). However, petroleum mulch contains hydrocarbons, organic compounds, and trace amounts of heavy metals, which present potential risks of soil and groundwater contamination (McGrath, 2002; Wright, 2010; Gupta, 2016). Despite its demonstrated efficacy in reducing wind erosion and promoting vegetation growth, the heavy metal pollution resulting from its application necessitates further investigation (Azoogh et al., 2018). To ensure sustainable desertification mitigation practices, a thorough evaluation of its environmental advantages and drawbacks is crucial.

Materials and Methods: This research was conducted in eastern Hormozgan Province, Iran, a region geographically bordered by the Makran Mountains to the north and the Sea of Oman to the south. Sand dune stabilization projects, employing petroleum mulch, were implemented in this area between 2002 and 2007. The study aimed to analyze heavy metal concentrations in soil samples collected from both treated areas (those subjected to petroleum mulch application and afforestation) and adjacent, untreated control areas. The elements measured included vanadium (V), nickel (Ni), tin (Sn), arsenic (As), lead (Pb), chromium (Cr), iron (Fe), aluminum (Al), cesium (Cs), manganese (Mn), cobalt (Co), and selenium (Se). Steps Involved in Research:

1. **Mapping and Sampling:** Sampling points were identified within treated regions and their corresponding adjacent control areas. A crucial criterion for selection was that at least 15 years had elapsed since the completion of the stabilization projects. Treated areas were defined by the combined application of petroleum mulch and afforestation, while control areas exhibited identical geomorphological features to the treated sites prior to any intervention. Three treated-control pairs were selected for the study: Jagin, Sedich, and Biahi, located approximately 70 km, 100 km, and 150 km east of Jask, respectively. A total of 18 soil samples were collected, comprising 9 from treated areas and 9 from control areas.
2. **Laboratory Analysis:** All collected soil samples were transported to the central laboratory at Hormozgan University for the measurement of heavy metal concentrations.
3. **Statistical Analysis:** Data analysis was performed using SPSS, employing a two-factor factorial design to assess the individual and interactive effects of treatment (petroleum mulch application) and site conditions. Duncan's multiple range test was subsequently applied at a 5% significance level to compare the means of the various data sets.

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Results: Table 1 presents the variance analysis for the effects of location (representing elapsed time since application) and petroleum mulch on heavy metal concentrations in topsoil. The application of petroleum mulch significantly influenced the concentrations of lead (Pb), vanadium (V), nickel (Ni), iron (Fe), aluminum (Al), cesium (Cs), manganese (Mn), cobalt (Co), and selenium (Se) at the 5% significance level. Over time, geographical factors also had a significant effect on most elements, with the notable exceptions of chromium (Cr), arsenic (As), and manganese (Mn). Furthermore, the interaction between mulch application and location significantly impacted elements such as cesium (Cs), aluminum (Al), iron (Fe), tin (Sn), and vanadium (V), highlighting their combined effects.

Figure 3 illustrates the heavy metal concentrations across the three study locations (Sedich: 2006–2007 application; Biahi: 2002 application; Jagin: 2005 application). The results indicate increased concentrations of nickel (Ni), arsenic (As), vanadium (V), chromium (Cr), tin (Sn), cesium (Cs), aluminum (Al), iron (Fe), and cobalt (Co) in Sedich. This elevation is likely attributable to the chemical composition of the petroleum mulch used. Biahi exhibited distinct concentration patterns, possibly influenced by specific local environmental conditions, while Jagin's results reflected a combination of petroleum mulch effects and other site-specific factors. Consistently, control areas maintained lower heavy metal concentrations compared to their corresponding treated areas, underscoring the role of petroleum mulch in elevating heavy metal levels (as further supported by Table 1).

Figure 4 further emphasizes the significant regional differences in heavy metal concentrations. Vanadium (V), lead (Pb), aluminum (Al), and cesium (Cs) were highest in Jagin and lowest in Biahi, showing statistically significant variations among sites. In contrast, elements such as nickel (Ni), tin (Sn), chromium (Cr), iron (Fe), manganese (Mn), cobalt (Co), and selenium (Se) reached their peaks in Sedich, reinforcing the influence of regional variations.

Figure 5 visualizes the average heavy metal concentrations between treated and control areas. Elements including vanadium (V), lead (Pb), nickel (Ni), chromium (Cr), aluminum (Al), arsenic (As), cobalt (Co), tin (Sn), and iron (Fe) consistently showed higher levels in treated areas. This is attributed to the inherent heavy metal content within the petroleum mulch itself. Interestingly, manganese (Mn) levels decreased in treated areas, which could be due to its absorption by plants and microorganisms thriving in the improved environmental conditions. These findings suggest that if these observed concentrations exceed established environmental standards, petroleum mulch could potentially be classified as a significant pollutant.

Discussion and Conclusion: This study confirmed that petroleum mulch significantly impacts the concentrations of heavy metals in surface soil layers. Our variance analysis revealed that elements including lead (Pb), vanadium (V), nickel (Ni), iron (Fe), aluminum (Al), cesium (Cs), manganese (Mn), cobalt (Co), and selenium (Se) were significantly affected by the treatment type (control versus petroleum mulch application) at the 5% significance level. Notably, manganese concentrations decreased in areas treated with petroleum mulch, likely due to absorption by microorganisms and plants in the improved environmental conditions fostered by the mulch.

Geographical location also played a significant role in the concentrations of most elements, with the exceptions of chromium (Cr), arsenic (As), and manganese (Mn). Furthermore, interaction effects between mulch application and location were observed for some elements, emphasizing the crucial role of local conditions in determining heavy metal levels in the soil.

These findings are consistent with previous research. Moghadam et al. (2016) reported on the influence of mulch chemical compounds on soil heavy metal concentrations, similarly concluding that mulch compounds can alter these levels. Likewise, Gholami Tabasi et al. (2014) investigated the effects of petroleum mulches on soil contamination and found a significant increase in heavy metal concentrations due to their application.

While petroleum mulch clearly contributes to elevated heavy metal concentrations in soil, it also offers substantial benefits such as stabilizing sand dunes, reducing wind erosion, improving soil structure, and accelerating soil formation (Akbarian & Nohegar, 2014). Jafari et al. (2017) observed increased richness, diversity, and uniformity in soil macrobiofauna in treated areas, without significant negative changes to vegetation cover compared to control sites.

In conclusion, the application of petroleum mulch undoubtedly raises heavy metal levels in the soil due to its inherent chemical composition. However, it's crucial to note that it should only be classified as a pollutant if these concentrations exceed established environmental standards. Therefore, policymakers and decision-makers must carefully weigh both the positive environmental benefits and the potential negative impacts of petroleum mulch to ensure its sustainable use in desertification mitigation efforts.

Keywords: coastal sand dunes, heavy metals, petroleum mulch, wind erosion.