

## Heavy Metal Contamination and Industrial Expansion in Bayan Lepas, Malaysia: Hydrological and Ecological Implications

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**Abstract :** Over the past three decades, Penang Island in Malaysia has witnessed significant growth in its industrial, urban, tourism, and aquaculture sectors. The Bayan Lepas Free Industrial Zone in Penang hosts a diverse range of industries, with a particular concentration in electronics and semiconductor-related manufacturing, underscoring its reputation as a pivotal high-tech hub. This study examined the spatial and temporal variability of heavy metal parameters (Cd, Cr, Cu, Co, Fe, Pb, Ni, V, and Zn) in the Bayan Lepas area. Water samples were collected from ten stations (upstream, residential, industrial, and coastal) during low tide in both wet and dry seasonal conditions. Each parameter was analyzed, and the spatial distribution of metals was subsequently mapped using Geographic Information System (GIS) techniques. The measured metal concentrations were as follows: Cd, 0.208-1.876 µg/L; Cr, 0.052-14.157 µg/L; Cu, 0.765-1210.5 µg/L; Fe, 5.003-999.501 µg/L; Ni, 0.120-377.510 µg/L; Pb, 1.006-30.512 µg/L; V, 2.135-21.134 µg/L; and Zn, 5.502-169.004 µg/L. A one-way ANOVA revealed that metal concentrations differed significantly among stations ( $p < 0.05$ ). The measured parameter values were compared against Malaysia's National Water Quality Standards (NWQS). Stations were then categorized for each parameter based on the corresponding guidelines. Results revealed that the Keluang River exhibits elevated levels of Cu, Ni, and Cr, with copper, nickel, and chromium concentrations in the industrial area measuring 130, 85, and 29 times higher than in the residential area, respectively. Based on available data, approximately 40% of the industries in the Bayan Lepas Free Industrial Zone are involved in electronics and semiconductor manufacturing. As the demand for semiconductors rises, particularly with the rapid advancement of artificial intelligence, production capacities are likely to expand, generating even larger volumes of wastewater. Consequently, implementing robust wastewater management strategies and sustainable environmental practices will be critical to mitigating potential pollution and preserving the surrounding ecosystems.

**Keywords :** ecological impact, electronics and semiconductor industry, heavy metals, bayan lepas, GIS

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