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Leveraging Deep Learning for the Detection and Mapping of Illegal Sand Mining in the Pungwe River Basin: A Review of Methodologies and African Remote Sensing Applications, 2007

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Abstract

Illegal sand mining poses a major environmental and socio-economic threat across Africa, causing severe degradation to riverine ecosystems. The Pungwe River basin in Mozambique exemplifies this issue. Conventional ground-based monitoring is frequently insufficient, necessitating more scalable solutions. While remote sensing with high-resolution imagery provides a platform for monitoring, manual interpretation remains prohibitively labour-intensive. This review critically evaluates the application of deep learning methodologies for detecting and mapping illegal sand mining activities from satellite imagery, with a specific focus on the Pungwe River basin. It aims to synthesise prevalent deep learning architectures and data processing workflows, and to assess their potential transferability to analogous African contexts. A systematic literature review was undertaken, examining peer-reviewed articles, conference proceedings, and technical reports. The analysis focused on studies employing convolutional neural networks, including object detection and semantic segmentation models, applied to very high-resolution optical satellite imagery for identifying land disturbances characteristic of sand mining. The review indicates that deep learning models, particularly U-Net for semantic segmentation and region-based CNNs for object detection, show considerable promise for this task. A consistent finding is the paramount importance of high-quality, context-

specific training data. Models trained in one geographical area often require substantial fine-tuning for effective application elsewhere. A significant constraint identified is the scarcity of publicly available, annotated satellite imagery datasets for African river basins. Deep learning offers a viable and potent approach for automating the detection of illegal sand mining from satellite imagery. However, its successful deployment in African settings like the Pungwe basin is dependent on overcoming key challenges related to data scarcity, computational requirements, and model adaptation to local conditions. Future research should prioritise the development of open-access, annotated image datasets for African river systems. Efforts should also focus on creating more computationally efficient, lightweight models and on robust techniques for model transferability across different regions with limited training data. deep learning, illegal sand mining, remote sensing, satellite imagery, Pungwe River, Mozambique, convolutional neural networks, environmental monitoring. This review synthesises the current state of deep learning applications for monitoring illegal sand mining in a critical African river basin, highlighting methodological considerations and specific challenges for remote sensing in African contexts to guide future research and application.