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Ekstraksi Garis Pantai Berbasis Model U-Net dari Sentinel-2 dan Indeks Spektral Studi Kasus Di Pesisir Provinsi Yogyakarta
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BAB V
KESIMPULAN DAN SARAN

V.1 . Kesimpulan

Tujuan utama penelitian ini adalah untuk mengembangan model U-Net untuk melakukan segmentasi garis pantai dengan menggunakan dataset yang mengkombinasikan citra Sentinel-2 dan beberpa indeks spektral. Berdasarkan tujuan, hasil, dan pembahasan dalam penelitian ini, maka dapat ditarik kesimpulan sebagai berikut.

1. Dataset garis pantai telah berhasil dikembangkan dengan jumlah 4.915 pasang citra dan label dengan ukuran 128x128 piksel. Struktur *band* citra adalah kombinasi antara *Red*, *Green*, *Blue*, dengan indeks spektral MNDWI, NDSI, dan NDVI. Label berupa citra biner *masking* antara daratan dan lautan.
2. Model U-Net garis pantai telah dikembangkan sehingga mampu mengakomodasi dataset kombinasi citra Sentinel-2 dan indeks spektral. Pengembangan struktur U-Net dengan menambahkan parameter input dan *batch normalization* sebagaimana Model kedua arsitektur U-Net. Hasil evaluasi model menunjukkan peningkatan akurasi model dalam mensegmentasi garis pantai. Hasil pelatihan model U-Net dengan dataset tanpa indeks spektral (Model-1) menghasilkan akurasi 93,79% dan *loss* 10,84%. Sementara itu, model U-Net yang dilatih dengan dataset citra Sentinel-2 dan kombinasi indek spektral (Model-4) mencapai akurasi terbaik 98,82% dan *loss* 4.30%. Hasil pengujian model U-Net juga menunjukkan peningkatan kinerja. Nilai precision, recall, F1-score, dan IoU Model-1, masing-masing adalah 97,46%; 97,61%; 97,54%; dan 95,19%. Sedangkan pengujian Model-4 mengalami peningkatan precision, recall, F1-score, dan IoU menjadi 97,54%; 97,79%; 97,66%; dan 95,44%.
3. Model terbaik yakni Model-4 yang dilatih dengan dataset kombinasi citra RGB dan ketiga indeks spektral menunjukkan kinerja model U-Net memuaskan. Evaluasi kinerja model U-Net menunjukkan nilai rata-rata *error* berkisar antara 12,88 sampai 24,17 meter di area barat dan berkisar antara 15,59 meter sampai 23,49 meter di area timur. Nilai RMSE hasil evaluasi untuk area barat dan timur

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berturut-turut adalah berkisar antara 17,83 sampai 33,55 dan berkisar antara 20,78 sampai 36,54 meter. Sementara itu nilai STDev hasil evaluasi adalah berkisar antara 11,68 sampai 23,89 meter di area barat dan 13,80 sampai 30,68 meter di area timur.

4. Hasil analisis perubahan garis pantai di pesisir selatan Yogyakarta menunjukkan bahwa area barat (Kabupatan Kulon Progo dan Bantul) mengalami erosi lebih parah dibandingkan area timur (Kabupaten Gunung Kidul). Namun demikian kedua area tersebut juga mengalami akresi di beberapa lokasi, terutama di muara sungai. Sebesar 71,6% area di area barat terkena erosi dengan rata-rata laju erosi (EPR) 4,92 m/tahun dan rata-rata jarak kemunduran garis pantai (NSM) sejauh 40,53 meter. Sementara itu, di area timur sebesar 34,18% area terkena erosi dengan rata-rata EPR 4,18 m/tahun dan NSM sejauh 28,88 m. Hasil analisis menunjukkan bahwa 26,84% area mengalami akresi di area barat dengan rata-rata laju akresi (EPR) 5,71 m/tahun dan rata-rata penambahan daratan (NSM) sejauh 44,02 m. Akresi di area timur sebesar 19,26% area dengan rata-rata laju akresi (EPR) 2,79 m/tahun dan rata-rata penambahan daratan (NSM) 19,26.

V.2 . Saran

Penelitian ini fokus pada optimalisasi penggunaan citra satelit dan *machine learning* U-Net untuk ekstraksi garis pantai. Oleh karena itu, data yang digunakan terbatas pada citra satelit, dengan variasi yang ditambahkan berdasarkan hasil pengolahan citra itu sendiri (dalam hal ini, indeks spektral). Implementasi U-Net, yang dianggap paling cocok untuk menangani data citra, dipilih untuk mempermudah, mengotomatisasi, mempercepat, dan memaksimalkan interpretasi citra. Sebagai hasilnya, output dengan akurasi tinggi diperoleh dengan cepat dan mencakup area yang luas. Namun, hasil yang dianggap akurat (berdasarkan parameter evaluasi kinerja model U-Net) memerlukan pemeriksaan lebih lanjut, misalnya melalui validasi data primer atau pemodelan hidrodinamika. Selain itu, penelitian ini tidak memperhitungkan kondisi pasang surut, di mana garis pantai secara alami ditentukan berdasarkan variasi pasang surut. Mengingat keterbatasan penelitian ini, penulis menyarankan beberapa hal berikut.

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1. Penggunaan data garis pantai hasil digitasi visual sebagai data referensi memiliki keterbatasan pada kemampuan mata dan visualisasi citra saat proses digitasi. Sebagai akibatnya, pada area dengan kompleksitas tinggi (misalnya muara sungai) berpotensi memiliki kesalahan lebih besar. Oleh sebab itu, penelitian selanjutnya disarankan menggunakan referensi data garis pantai yang lebih akurat (misalnya data survei garis pantai dengan metode GNSS) untuk membuat dataset garis pantai dan memvalidasi hasil model U-Net.
2. Faktor pasang surut merupakan hal yang melekat secara alamiah di kawasan pesisir. Oleh sebab itu, ekstraksi dan analisis perubahan garis pantai sebaiknya dilakukan dengan mempertimbangkan data pasang surut.
3. Setelah model ekstraksi garis pantai lebih akurat dan terverifikasi dengan baik, langkah selanjutnya adalah mengembangkan antarmuka pengguna dan membuat sistem ini lebih mudah diakses secara online (misalnya, melalui sistem GIS web) oleh pengguna. Pengembangan sistem ini diharapkan dapat meningkatkan kontribusi penelitian dalam mengurangi degradasi kawasan pesisir dan mendukung pemangku kepentingan dalam pengelolaan pesisir yang lebih efektif dan berkelanjutan.
4. Pada hasil penelitian ini, area dengan kompleksitas tinggi, misalnya muara sungai dan area dengan bentuk pantai rumit, memiliki kesalahan cukup besar. Hal ini ditandai dengan jarak garis pantai hasil ekstraksi dengan garis pantai *ground thruth* cukup besar. Maka dari itu, pada penelitian selanjutnya perlu memperhatikan atau menganalisis lebih detail pada area-area tersebut.

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