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Developing datasets for the management and utilization of coastal resources and environment: A case study in Quang Ninh, Hai Phong and Thai Binh (Vietnam)

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Abstract

Digital terrain data constitute a fundamental spatial layer for managing, utilizing and protecting coastal resources and the environment, especially as the northern coastal provinces of Vietnam are undergoing rapid development in the marine economy, aquaculture, seaport infrastructure, tourism and ecological conservation. This study presents a workflow for developing land topographic and seabed bathymetric datasets to support coastal resource and environmental management in Quang Ninh, Hai Phong and Thai Binh. The research methodology integrates GIS and remote sensing technologies, using land DEM sources including SRTM and ALOS PALSAR, open-source bathymetric terrain data from SRTM15+, and reliability enhancement through cross-comparison with official depth points and depth-contour data provided by the Ministry of Natural Resources and Environment. The processing steps include defining the study area, acquiring and checking source data, mosaicking scenes, clipping by the study-area boundary, treating NoData areas, standardizing coordinate systems, generating raster DEM layers, interpolating bathymetric DEMs using IDW and Kriging, smoothing contours, and organizing the outputs in a file geodatabase. The results indicate that SRTM and ALOS PALSAR can adequately represent land topography at the regional scale, whereas SRTM15+ is suitable mainly for general identification of seabed morphology because of large uncertainties in shallow coastal waters. Using official data from the Ministry of Natural Resources and Environment as interpolation input enables the generation of a 12.5 m bathymetric DEM, which is more appropriate for coastal spatial analysis, aquaculture suitability assessment, ecosystem conservation, environmental risk management and marine spatial planning. The study also proposes an integrated terrain database structure comprising administrative boundary layers, land DEMs, depth points, seabed depth contours, bathymetric raster surfaces and derivative layers, thereby providing a foundation for a digital data platform that supports digital transformation in coastal resource and environmental management.

Keywords: Digital elevation model, bathymetric DEM, SRTM, ALOS PALSAR, SRTM15+, GIS, remote sensing, coastal zone, Quang Ninh, Hai Phong, Thai Binh

Introduction

The coastal zone is a distinctive transitional space between the continent, the sea and estuarine, tidal-flat, mangrove, lagoon, island and shallow nearshore ecosystems. Within this space, socio-economic activities such as aquaculture, marine resource exploitation, port development, tourism, coastal urbanization and ecological conservation often take place simultaneously and interact strongly with one another. Therefore, coastal-zone management cannot rely solely on administrative information layers or simple base maps; it requires a continuous terrain database capable of representing land surfaces, nearshore belts, intertidal zones and seabed topography at the same time. Within such a data system, land Digital Elevation Models (DEMs) and seabed bathymetric models form the fundamental spatial layers because they control surface runoff, drainage direction, inundation risk, erosion, sediment accumulation, channel depth, aquaculture conditions and the connectivity of coastal ecosystems.

Quang Ninh, Hai Phong and Thai Binh form an important coastal corridor in northern Vietnam, located on the western side of the Gulf of Tonkin and characterized by diverse natural, economic and ecological conditions. Quang Ninh is distinguished by its system of islands, bays, shallow-water areas and unique tourism and ecological resources; Hai Phong is

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a major seaport, industrial and logistics center of the Northern Coastal Region; and Thai Binh contains extensive tidal flats, estuaries and wetlands that are favorable for brackish-water aquaculture, nearshore resource exploitation and mangrove ecosystem conservation. According to the thematic report, the total coastline length of the three localities is approximately 429 km, of which Quang Ninh accounts for about 250 km, Hai Phong for 125 km and Thai Binh for 54 km. Marked differences in topography, geomorphology, hydrology and marine economic activities make it necessary to develop an integrated terrain dataset for the entire region.

In geography, geomatics, cartography and remote sensing, a Digital Elevation Model (DEM) is generally understood as a digital representation of spatial variation in elevation. A raster DEM organizes terrain into a grid of cells, with each cell storing the elevation value at the corresponding location. This structure allows spatial analyses such as slope and aspect derivation, watershed delineation, surface-runoff modelling, low-lying area identification, flood-risk assessment and infrastructure planning. In coastal zones, DEMs are also important for sea-level-rise modelling, assessment of storm and tidal impacts, and shoreline-change analysis. However, if land DEMs are not accompanied by bathymetric terrain data, coastal analysis becomes discontinuous at the shoreline, whereas many environmental processes occur continuously between land and sea.

A seabed digital depth model, or Bathymetric DEM, is a raster dataset that represents water depth or seabed elevation for marine, river or lake bottoms. Unlike land DEMs, which express positive or negative elevation relative to a vertical datum, Bathymetric DEMs usually express either water depth below the water surface or seabed elevation, depending on the standardization method. For coastal resource and environmental management, Bathymetric DEMs support the identification of shallow-water areas, deep channels, steep seabed slopes, sediment accumulation or erosion zones, anchorage conditions, navigation routes and suitable sites for aquaculture. In ecological conservation, water depth and seabed morphology directly affect the distribution of coral reefs, seagrass beds, tidal flats, benthic habitats and the resilience of coastal ecosystems.

Current DEM data sources are highly diverse. For land areas, global DEM products such as SRTM, ASTER GDEM and ALOS PALSAR are widely used because of their broad coverage, low cost or free availability, and ease of integration into GIS software. SRTM is advantageous in terms of accessibility, popularity and regional-scale stability; ASTER GDEM is generated from stereo optical imagery and provides global coverage; and ALOS PALSAR is based on an L-band radar sensor capable of cloud-penetrating, day-and-night data acquisition, which is particularly useful in frequently cloudy tropical regions. In addition, LiDAR, UAV photogrammetry and GPS/RTK can provide very detailed elevation data, but they are usually more suitable for local surveys because of their higher cost and processing workload.

For the seabed, data can be collected using single-beam or multibeam echo sounding, bathymetric LiDAR, GPS/RTK

integrated with depth sensors, optical remote sensing in shallow waters, or global bathymetric models such as SRTM15+, GEBCO and ETOPO. Each source has its own strengths and limitations. Sonar data provide high accuracy but require costly surveys; satellite-derived bathymetry (SDB) can provide rapid coverage but depends strongly on water clarity; bathymetric LiDAR offers high spatial resolution but requires specialized equipment; and global bathymetric datasets are convenient for broad-scale analyses but are often insufficiently reliable for shallow coastal waters. Therefore, combining open-source data with official survey data is a more practical approach for coastal-zone research in Vietnam.

From this practical context, the present study approaches the problem as a comprehensive data-development task: it does not merely collect a few elevation map layers, but builds a workflow for creating a digital terrain dataset that serves the management and utilization of coastal resources and the environment. The pilot area focuses on Quang Ninh, Hai Phong and Thai Binh; the data objects include land DEMs, seabed depth data, seabed depth contours, interpolation products and a geodatabase structure. The content is based on the thematic report for Task 4.1.3 on the collection of land digital elevation models and seabed bathymetric data under Project KC-4.0-38/19-25.

The objectives of this paper are to: (i) systematize the data sources and technologies used to develop land DEMs and Bathymetric DEMs for the Quang Ninh - Hai Phong - Thai Binh coastal zone; (ii) present the workflow for processing, standardizing and organizing data in a GIS structure; (iii) assess the usability of open-source data, particularly SRTM15+, under shallow coastal-water conditions; and (iv) discuss the application value of the dataset for resource management, environmental management, ecological conservation and aquaculture. The main contribution of the study is not the proposal of a completely new interpolation algorithm, but the integration of multiple data sources into a workflow that can be implemented in practical coastal-zone management.

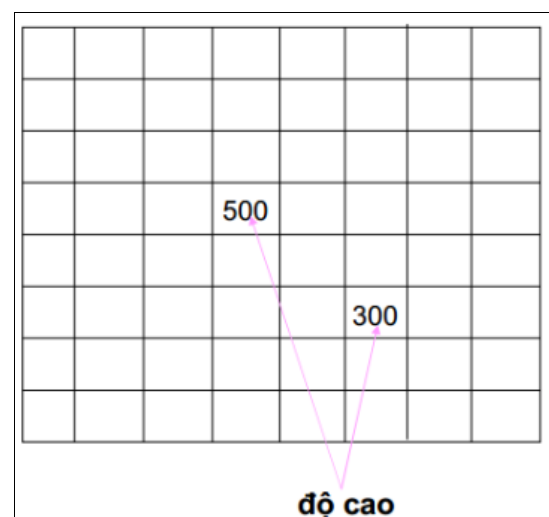


Fig 1: Illustration of the raster structure of a Digital Elevation Model (DEM). (Source: Project KC-4.0-38/19-25)

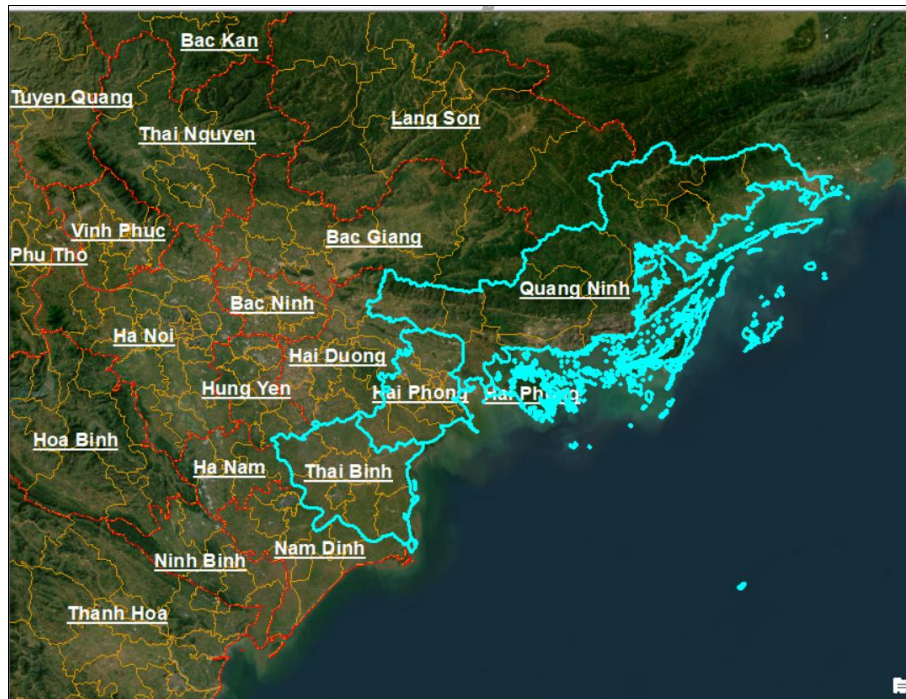


Fig 2: Study-area extent in Quang Ninh, Hai Phong and Thai Binh. (Source: Project KC-4.0-38/19-25)

2. Data and Research Methods

2.1. Study area and data requirements

The study area comprises the coastal zones of Quang Ninh, Hai Phong and Thai Binh. This coastal belt is characterized by a strong transition from hilly terrain and limestone islands in Quang Ninh, to the seaport system, Cat Ba Islands and estuaries in Hai Phong, and to the low-lying delta, broad tidal flats of Thai Binh. Such diversity requires spatial data capable of representing land topography, islands, nearshore belts, tidal zones and shallow seabed terrain. From a management perspective, the data need to serve multiple application groups, including marine spatial planning, coastal resource management, ecological conservation, aquaculture suitability assessment, identification of areas at risk of erosion and accretion, and support for marine environmental analysis.

Quang Ninh has a dense island system, enclosed and semi-enclosed bays, numerous tidal flats and marine-farming areas. The complex topography requires land DEMs to differentiate islands, nearshore belts and low mountainous areas, while Bathymetric DEMs need to describe depth variations around islands, straits and water channels. Hai Phong has a sea area of about 4,000 km², with many islands concentrated in the Cat Ba Archipelago, tidal flats, estuarine zones and port-development areas. For Hai Phong, seabed depth data are directly relevant to fairway planning, aquaculture zoning and the conservation of coral reefs, seagrass beds and mangrove ecosystems. Thai Binh has low-lying terrain, many estuaries, turbid waters and broad alluvial flats; its terrain data should support the identification of low-lying areas, tidal flats, brackish-water zones and sediment-accumulation conditions.

The technical requirement of this study is to develop a dataset with continuous coverage for the entire pilot region, in which land data are sufficiently detailed for regional-scale analysis and bathymetric data are checked and improved using official survey data. The post-processed data structure must be compatible with GIS, enabling querying, analysis and sharing. The main data layers include

the study-area boundary, land DEMs from SRTM, land DEMs from ALOS PALSAR, open-source SRTM15+ bathymetry, seabed depth points, depth contours, interpolated Bathymetric DEM rasters, smoothed contour layers and derivative map layers.

2.2. Data sources: ALOS PALSAR DEM was selected as a radar-derived data source with relatively higher spatial resolution, commonly available at 12.5 m and 30 m depending on the product. Because it uses an L-band synthetic aperture radar sensor, PALSAR has an advantage under cloud-cover conditions and is particularly suitable for tropical monsoon areas. The thematic report used ALOS PALSAR data to generate a DEM of the study area after identifying the required scenes, downloading the data, checking coverage and treating NoValue errors. The parallel use of SRTM and ALOS PALSAR increases the ability to compare, verify and select suitable sources for coastal terrain analyses.

For seabed topography, the study uses SRTM15+ as an initial open-source bathymetric dataset. SRTM15+ is a global topography-bathymetry dataset with a spatial resolution of 15 arc-seconds, equivalent to approximately 500 m, developed by a research group at the Scripps Institution of Oceanography. It integrates land elevation data, shipborne sounding measurements, satellite gravity data and global bathymetric sources such as GEBCO and ETOPO1. The advantages of SRTM15+ include global coverage, ease of download, availability in NetCDF or GeoTIFF formats, and convenient integration into GIS. However, in shallow nearshore zones with complex terrain and many islands such as the study area, the resolution and accuracy of SRTM15+ may not satisfy the requirements of detailed analysis.

The key data source for checking and refinement is the seabed depth dataset provided by the Ministry of Natural Resources and Environment, including depth points and depth contours for parts of the coastal waters of Quang Ninh, Hai Phong and Thai Binh. This source has higher

legal validity and reliability than open-source bathymetry because it is developed through specialized surveying, quality-control and processing procedures. In this study,

these depth points are used to cross-check free data and to provide input for Bathymetric DEM interpolation using IDW and Kriging.

Table 1: Main data sources used in the study. (Source: Project KC-4.0-38/19-25)

Data source	Spatial domain	Resolution/characteristics	Role in the study
SRTM DEM	Land	30 m; global coverage; free of charge	Construction of a regional land DEM and comparison with ALOS PALSAR
ALOS PALSAR DEM	Land and islands	12.5 m or 30 m; radar data; less affected by cloud cover	Generation of a more detailed land DEM to support coastal and island terrain analysis
SRTM15+	Seabed and global topography	15 arc-seconds, approximately 500 m; global bathymetry dataset	Initial reference data for seabed topography and assessment of open-source data usability
MONRE depth points	Nearshore waters	Official point-based survey data	Checking, cross-comparison and interpolation of Bathymetric DEMs
MONRE depth contours	Nearshore waters	Vector layer representing lines of equal depth	Reference for seabed morphology and organization of contour layers in the database

2.3. Workflow for processing land DEMs

The land DEM processing workflow consists of six main groups of operations. First, the study-area boundary is defined for Quang Ninh, Hai Phong and Thai Binh. This step is important because the boundary determines the number of scenes to be downloaded, the clipping extent, processing volume and final data-layer structure. Next,

suitable DEM sources are selected based on coverage, resolution, cost, accessibility and suitability for regional-scale analysis. SRTM was selected because it is free, widely used and provides sufficient coverage; ALOS PALSAR was selected because of its radar-data advantage and higher spatial resolution.

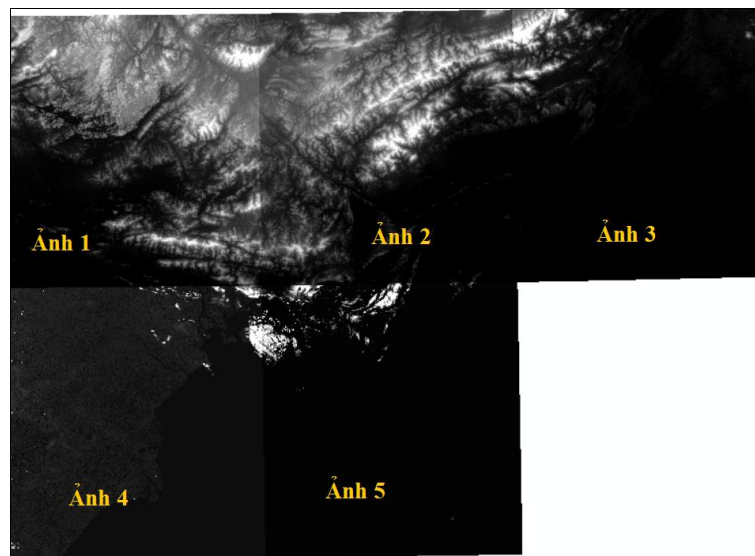


Fig 3: Mosaicking SRTM scenes covering the study area using the Mosaic tool. (Source: Project KC-4.0-38/19-25)

2.4. Workflow for processing bathymetric terrain data

The workflow for processing seabed terrain data is designed around two levels of objectives: first, acquiring open-source bathymetry to obtain a broad overview, and second, using official survey data to check and build a more detailed Bathymetric DEM. For SRTM15+, the study selected an updated version, downloaded the data in NetCDF or GeoTIFF format, read the data in a GIS environment or spatial-processing libraries, clipped it to the Quang Ninh - Hai Phong - Thai Binh extent and converted the coordinate system where necessary. The SRTM15+ data were then displayed as a raster bathymetry layer to identify general seabed morphology.

Depth contours can be extracted and smoothed from the bathymetric raster. The thematic report used the Smooth Line tool in ArcGIS with the PEAK (Polynomial Approximation with Exponential Kernel) parameter to smooth depth contours and improve cartographic representation. This step is necessary because contours

extracted directly from coarse-resolution rasters often appear jagged or stair-stepped, making them difficult to use for map presentation and spatial analysis. However, smoothing should not be interpreted as increasing the accuracy of the original data; it only improves the geometric representation of the line layer.

To assess the reliability of free data sources, the study cross-compared open-source depth data with measured depth points. Errors were evaluated using indicators such as deviation, squared deviation, RMSE and rRMSE. In principle, RMSE reflects mean absolute error in depth units, while rRMSE indicates relative error against the mean depth. The thematic report uses an approximate rRMSE threshold of 0.2 as a relative acceptance level for depth data derived from imagery or free datasets. When rRMSE greatly exceeds this threshold, open-source data should be used only for general reference and not as the basis for detailed analysis.

The depth-point data from the Ministry of Natural Resources and Environment were processed in ArcGIS to build a 12.5 m Bathymetric DEM. Two interpolation methods were used: IDW and Kriging. IDW estimates values at unknown locations by using a weighted average of surrounding points, in which nearer points have greater influence than farther points. This method is simple, easy to implement and suitable where point data have relatively

uniform density. Kriging is a geostatistical method that considers spatial correlation structure through a variogram; it can produce smoother surfaces and reflect spatial trends if an appropriate variogram model is selected. Using both IDW and Kriging enables comparison of interpolated surface morphology and selection of products suitable for management objectives.

Table 2: Comparison of technology groups for collecting shallow-water bathymetric data. (Source: Project KC-4.0-38/19-25)

Method	Cost	Relative accuracy	Advantages	Limitations
Acoustic sounding	High	Very high (cm-dm)	High accuracy; applicable in turbid water	Requires survey vessels; costly; difficult in very shallow water
Remote sensing/SDB	Low to medium	Moderate; dependent on water clarity	Wide coverage; available data; low cost	Requires field calibration; limited in turbid water
Bathymetric LiDAR	Very high	Very high (cm-dm)	High resolution; rapid acquisition in shallow-water areas	Specialized equipment; limited accessibility in Vietnam
GPS/RTK + single-beam sounding	Medium	High (dm-m)	Flexible in very shallow water	Limited coverage; requires survey lines and interpolation

2.5. Organization of the spatial database

The processed data are organized in an ArcGIS file geodatabase. A geodatabase is suitable for managing medium- to large-scale spatial datasets because it can store feature classes, raster datasets, attribute tables, domains, topology and relationships among data layers. In coastal-zone studies, a geodatabase helps standardize data layers derived from different sources, reduces the risk of coordinate-system discrepancies, supports quality control and facilitates data sharing among specialized teams.

The proposed structure comprises the administrative boundary layers of the three provinces, the merged study-area boundary, land DEM layers from SRTM, land DEM layers from ALOS PALSAR, the SRTM15+ open-source bathymetry layer, depth-point data from MONRE, depth-contour layers, the IDW-interpolated Bathymetric DEM raster, the Kriging-interpolated Bathymetric DEM raster and derivative layers. Data layers are named consistently and include descriptions of source, resolution, acquisition or processing time, processing method and use limitations. This is an important requirement if the dataset is to be used in a digital platform for resource and environmental management.

3. Research Results

3.1. Land topography DEM products

The SRTM processing results show that the DEM scenes fully cover the pilot area and can be mosaicked into a continuous terrain surface for Quang Ninh, Hai Phong and Thai Binh. After the Mosaic step, the composite raster is clipped to the study-area boundary, removing redundant areas outside the area of interest. NoData treatment improves surface continuity, especially in areas where data voids or local errors may occur. The SRTM DEM product represents the main topographic trends of the region: Quang Ninh has more complex terrain with hills, islands and bays; Hai Phong has transitional terrain between plains, estuaries and islands; and Thai Binh is dominated by low-lying coastal plains.

The main advantage of SRTM in this study is its stability and ease of implementation at the regional scale. Its 30 m resolution is sufficient to represent major terrain forms and support general analyses of the coastal zone. However, SRTM is not sufficiently detailed for problems involving

narrow tidal flats, coastal residential areas, sea dikes, aquaculture ponds or small islands. In addition, in low-lying coastal areas, elevation errors of several meters can significantly affect inundation or sea-level-rise analyses. Therefore, SRTM is more suitable for developing an initial base dataset and conducting provincial or regional-scale analysis, and should not replace detailed surveys in priority areas.

The ALOS PALSAR processing results show that radar data can generate a DEM with higher spatial resolution and good coverage of the study area. Scenes are identified for the three-province extent, downloaded, corrected for NoValue errors and classified by elevation values. Compared with SRTM, ALOS PALSAR has an advantage in describing island terrain, nearshore belts and transition zones in greater detail. This is particularly important for Quang Ninh and Hai Phong, where there are numerous islands, low mountains and complex coastal areas. ALOS PALSAR products can be prioritized in analyses that require higher spatial resolution, while SRTM serves as a comparison layer and reference base.

3.2. Bathymetric terrain data products from SRTM15+

After downloading, reading and clipping SRTM15+ to the study-area extent, a general bathymetry layer was created for the coastal waters of Quang Ninh - Hai Phong - Thai Binh. This layer represents broad-scale variations in seabed terrain, helping to identify preliminary shallow-water areas, deeper offshore areas, seabed forms around islands and the overall trend of depth variation. The product also allows the extraction of depth contours and the visualization of seabed topography together with land DEMs, thereby providing a continuous view from land to sea.

The illustrations in the thematic report show that SRTM15+ can be used to build seabed elevation models combined with contours for several areas, such as Chang Ngo Island, Ba Mun Island, Ngoc Vung Island and Quan Lan in Quang Ninh. Smoothing the contours improves display quality and creates a more usable map layer. Nevertheless, this product remains a reference layer because its 15 arc-second resolution, equivalent to about 500 m, is insufficient for describing detailed bathymetry in shallow nearshore waters, especially in areas with small islands, tidal flats, navigation channels or strong depth variations over short distances.

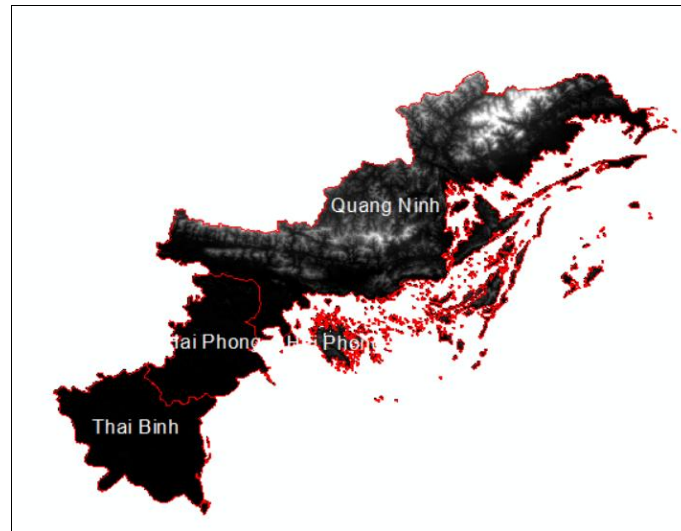


Fig 4: Land topography DEM of the study area derived from SRTM. (Source: Project KC-4.0-38/19-25)

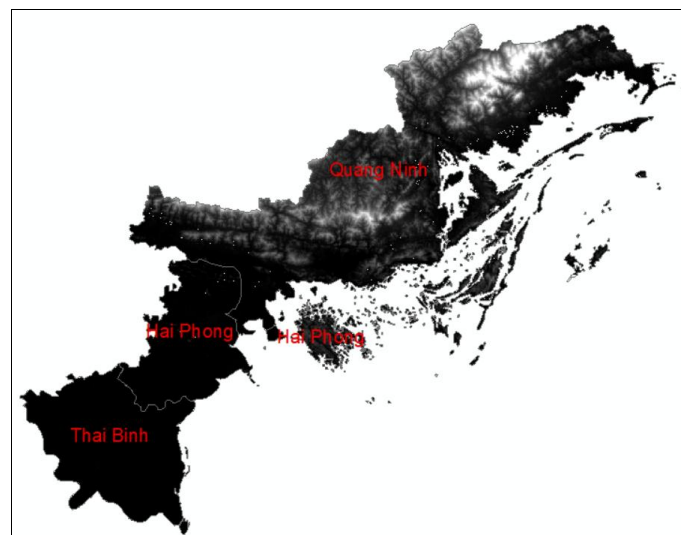


Fig 5: DEM of the study area generated from ALOS PALSAR data. (Source: Project KC-4.0-38/19-25)

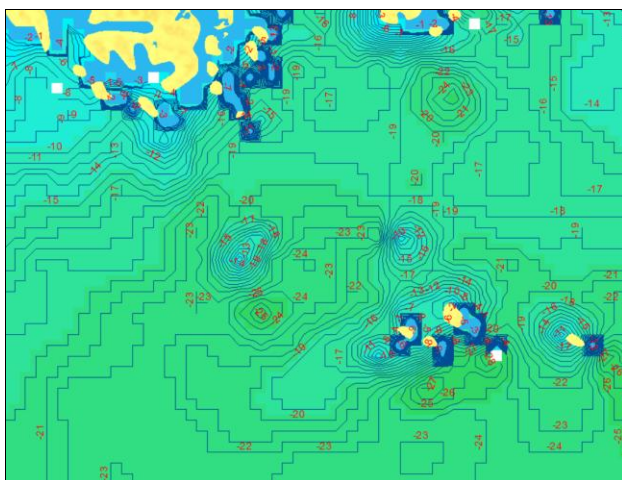


Fig 6: Bathymetric DEM combined with seabed topographic contours. (Source: Project KC-4.0-38/19-25)

3.3. Assessment of the usability of open-source bathymetric data

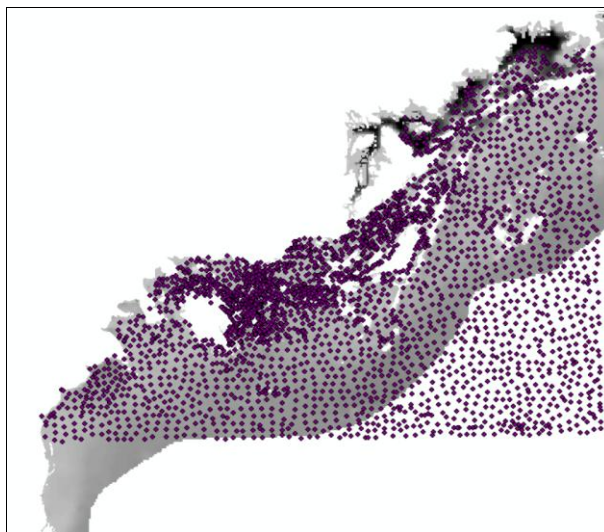
The thematic report cross-compared depth data from a free source with usable depth points to evaluate error. The

illustrative table shows that the RMSE of the free dataset is approximately 22.88 m and the rRMSE is approximately 1.399 for the presented set of points. If an rRMSE threshold of 0.2 is used as a relative acceptance level, this error far exceeds the requirement for detailed shallow-water analysis. This confirms that SRTM15+ and similar free bathymetric sources should not be used directly as official depth data for tasks such as aquaculture-site planning, coastal infrastructure design, risk assessment in tidal-flat areas or detailed hydrodynamic modelling.

The error-assessment results have clear practical value. They help avoid a common assumption in open-data applications: global coverage does not mean that the data are accurate enough for every purpose. In coastal zones, especially shallow-water areas and dynamic environments, open-source data must be checked against measured points before use. In this study, SRTM15+ should be regarded as an initial reference layer that supports general morphological identification and additional data-collection planning, whereas detailed analysis must rely on official sounding data or dedicated survey data.

Table 3: Selected error indicators from cross-comparing free-source bathymetric data with reference data. (Source: Project KC-4.0-38/19-25)

Indicator	Illustrative value in the report	Interpretation
RMSE	22.8797384 m	Large mean absolute error; unsuitable for detailed shallow-water analysis
rRMSE	1.399493	Far above the reference threshold of 0.2; open-source data should be used only as a reference
Mean depth in the assessment table	-16.34306 m	Mean depth of the point set used in the error-assessment illustration

**Fig 7:** Seabed-depth map from a free source and points used for error assessment. (Source: Project KC-4.0-38/19-25)

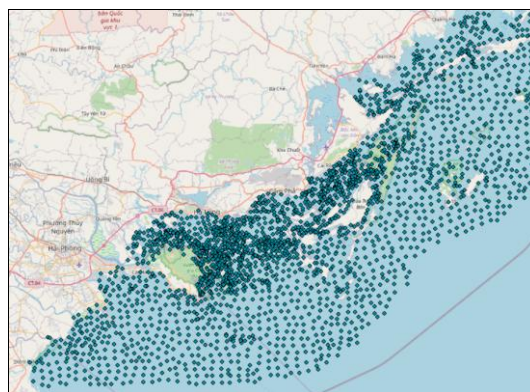
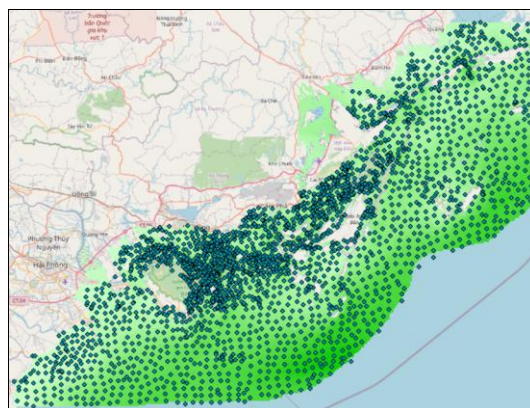
3.4. Bathymetric DEM from Ministry of Natural Resources and Environment data

Given the limitations of SRTM15+, the study uses depth points and depth contours provided by the Ministry of Natural Resources and Environment to build a more detailed seabed model. The depth points are processed, checked and imported into ArcGIS as input for interpolation algorithms. The outputs include a 12.5 m raster Bathymetric DEM and depth-contour layers generated from the interpolated surface. This step marks an important transition from global reference data to local data with higher reliability.

The IDW method generates a depth surface based on the principle that influence decreases with distance. In areas with sufficient point density, IDW can reasonably reflect local variations and allows parameter control. The IDW product in the thematic report shows a seabed terrain surface generated from MONRE measurement points while maintaining a visual relationship between measured points and interpolated values. However, IDW may create a 'bull's-eye' effect around measurement points when the point distribution is uneven or the power parameter is inappropriate. Therefore, IDW products need to be checked against contours and marine geomorphological understanding.

Interpolation results based on MONRE data have greater application value than open-source data. The 12.5 m resolution allows more detailed representation of nearshore seabed terrain, particularly in areas related to aquaculture, estuaries, tidal flats, navigation channels and islands. These data can support the identification of zones with suitable depths for marine farming, areas to be avoided because of strong currents or steep terrain, zones at risk of sediment accumulation, ecologically important areas and locations requiring additional survey. However, the report also notes limitations in the coverage of measured data in some parts

of Thai Binh and Quang Ninh; therefore, the dataset should be updated as new survey data become available.

**Fig 8:** Seabed depth points collected from the Ministry of Natural Resources and Environment. (Source: Project KC-4.0-38/19-25)**Fig 9:** IDW interpolation of seabed terrain in ArcGIS from MONRE depth points. (Source: Project KC-4.0-38/19-25)

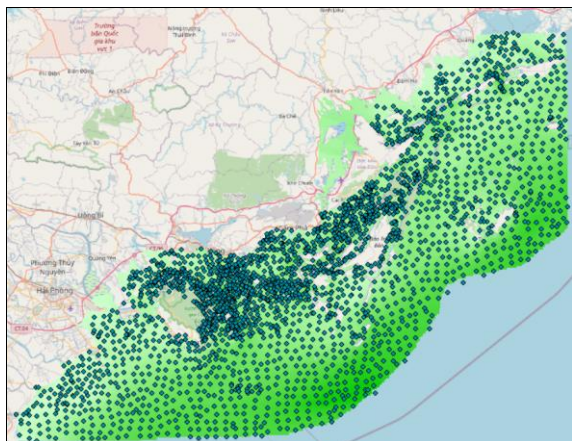


Fig 10: Kriging interpolation of seabed terrain in ArcGIS from MONRE depth points. (Source: Project KC-4.0-38/19-25)

3.5. Integrated terrain database structure

The final result of the study is not merely a set of separate raster and vector layers, but an integrated terrain database structure within a geodatabase. This structure includes the overall file geodatabase, feature datasets containing seabed contours, provincial boundaries, the merged three-province boundary, land DEM rasters from SRTM and ALOS PALSAR, depth-point layers, contour layers and Bathymetric DEM products. Organizing the data in a geodatabase makes the dataset orderly, easier to update and share, and compatible with existing GIS systems.

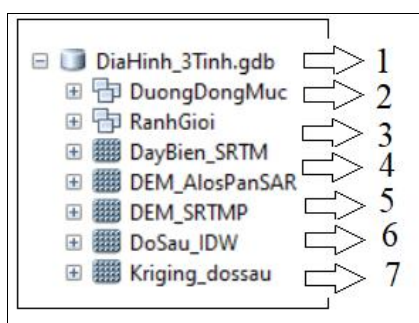


Fig 11: Structure of the land and seabed terrain database in a geodatabase. (Source: Project KC-4.0-38/19-25)

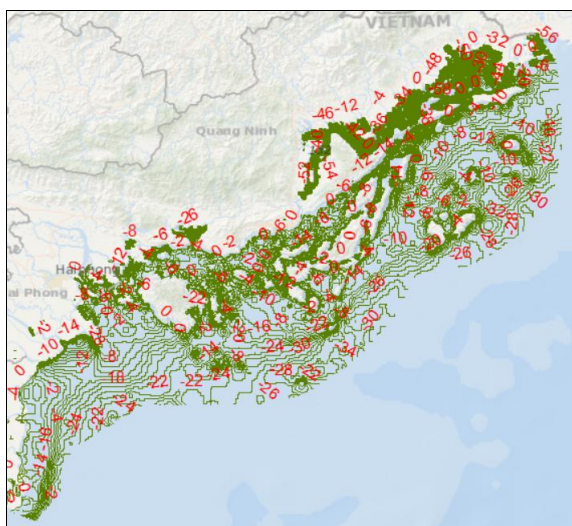


Fig 12: Seabed topographic contour layer for the study area. (Source: Project KC-4.0-38/19-25)

4. Discussion

4.1. Significance of the multi-source data integration approach

The results show that coastal-zone data development should not rely on a single data source. SRTM has advantages in coverage and popularity; ALOS PALSAR has advantages in spatial resolution and radar acquisition capability; SRTM15+ provides a convenient global bathymetry layer; and data from the Ministry of Natural Resources and Environment provide a more reliable basis for nearshore areas. Each source answers only part of the problem, and the value of this study lies in combining them through a standardized workflow. This approach is suitable for digital-transformation projects in natural resources and the environment, where the goal is not only to create an attractive map but to build a dataset that can be used, verified, updated and expanded.

The integrated approach also helps balance cost and accuracy. If specialized sounding data were used for the entire sea area, costs would be very high and implementation would be difficult within a short timeframe. If only free datasets were used, accuracy would be insufficient for many detailed management applications. Therefore, a reasonable strategy is to use open data to provide broad coverage, identify data gaps and prioritize areas, and then use official survey data or supplementary surveys to upgrade key areas. In this study, the error assessment of SRTM15+ and the subsequent interpolation from MONRE data clearly demonstrate this logic.

However, multi-source data integration also carries risks. Different sources may vary in coordinate system, vertical datum, acquisition time, spatial resolution, acquisition method and reliability. Without careful standardization, data mosaicking and integration can introduce spatial or value discrepancies. This is particularly important for seabed depth data, because differences between depths referenced to mean sea level, chart datum, lowest astronomical tide or other datums can cause considerable errors. Therefore, subsequent work should supplement detailed metadata on vertical datum, survey date, data source, processing method and data quality for each layer.

4.2. Applicability to coastal resource and environmental management

The land DEM and Bathymetric DEM datasets can directly serve multiple coastal-zone management applications. In ecological conservation, terrain data help identify tidal flats, shallow-water zones, areas with low or high seabed slope, potential sediment-accumulation zones and morphological conditions suitable for mangrove forests, seagrass beds or benthic organisms. When combined with land-cover, vegetation, water-quality and species-distribution data, the terrain dataset can support conservation zoning, ecological sensitivity assessment and environmental-change monitoring.

In aquaculture, depth and seabed morphology are important input variables. Cage-farming areas require suitable depth to ensure water exchange, avoid excessive sedimentation and reduce risks during tidal changes. Intertidal aquaculture areas require consideration of tidal-flat elevation, slope, exposure duration, alluvial accumulation and connectivity with currents. Land DEMs and Bathymetric DEMs can be combined with information on currents, salinity, temperature, water quality, existing aquaculture and

planning data to develop aquaculture suitability maps. This is consistent with the project objective of supporting the management and utilization of coastal resources and the environment in the two fields of ecological conservation and aquaculture.

4.3. Limitations to be considered

Although the study has developed an important workflow and foundational dataset, several limitations should be recognized. First, the accuracy of the land DEMs has not been assessed using an independent set of check points in this paper. SRTM and ALOS PALSAR can represent general topographic trends, but elevation errors in low-lying coastal zones may affect sensitive applications such as inundation, sea-level rise or engineering design. Therefore, for detailed technical applications, GPS/RTK points, elevation benchmarks or topographic survey data should be added for validation and correction.

Second, the coverage of MONRE sounding data is not uniform across the entire region, especially in some parts of Thai Binh and Quang Ninh. Interpolation is reliable only where it is supported by sufficient point density; in areas far from measurement points or where points are unevenly distributed, the interpolated surface may reflect mathematical trends rather than actual seabed morphology. Therefore, when using Bathymetric DEMs for detailed planning, it is necessary to check the distance to the nearest measurement point, point density and the suitability of the interpolation method for local terrain conditions.

4.4. Directions for improvement and expansion

To improve the dataset, the first priority is to add accuracy validation using measured data. For land areas, GPS/RTK points, elevation benchmarks, LiDAR or UAV data can be used in key areas such as tidal flats, sea dikes, small islands and aquaculture zones. For seabed areas, additional sounding lines using echo sounders or multibeam systems should be collected in areas with large errors, low existing point density and high planning priority. This supplementation does not need to be implemented uniformly across the whole region; instead, it can follow a priority-sampling strategy based on risk and management needs.

A third direction is to integrate additional thematic data layers. To support ecological conservation and aquaculture, land DEMs and Bathymetric DEMs should be combined with data on water quality, currents, waves, salinity, temperature, bottom sediments, current mangrove extent, seagrass, coral reefs, aquaculture zones, fishing areas, protected areas and coastal infrastructure. In this way, the terrain database will become the spatial foundation for suitability-assessment models, risk assessment and decision support.

5. Conclusion

This study has presented a workflow for developing a digital terrain dataset to support the management and utilization of coastal resources and the environment in Quang Ninh, Hai Phong and Thai Binh. By integrating GIS and remote sensing technologies, the study uses SRTM and ALOS PALSAR to build land DEMs, uses SRTM15+ as an initial reference source for bathymetry, and exploits depth points and depth contours from the Ministry of Natural Resources and Environment to interpolate a more detailed Bathymetric DEM. The processing workflow includes defining the study

extent, downloading data, mosaicking scenes, clipping by boundary, treating NoData areas, standardizing data, applying IDW/Kriging interpolation, smoothing contours and organizing products in a geodatabase.

The results indicate that land DEMs derived from SRTM and ALOS PALSAR can meet the need for developing regional topographic base layers. SRTM is suitable for broad coverage and general analysis, whereas ALOS PALSAR has higher potential for detailed representation of coastal and island terrain. For seabed data, SRTM15+ is useful for identifying general morphology but is not sufficiently reliable for detailed analysis in shallow waters. The error assessment, with an RMSE of approximately 22.88 m and an rRMSE of approximately 1.399, indicates the need for caution when using open-source bathymetry. Official sounding data from the Ministry of Natural Resources and Environment, after IDW and Kriging interpolation, enable the generation of a 12.5 m Bathymetric DEM that is more suitable for coastal analysis requirements. The practical contribution of the study is the proposal of an integrated terrain database structure consisting of land DEMs, depth points, seabed contours, interpolated bathymetric rasters and boundary layers within a file geodatabase. This dataset can serve as a foundation for applications in ecological conservation, aquaculture planning, environmental risk management, marine spatial planning and digital transformation in coastal resource management. However, for detailed technical applications, it is necessary to add accuracy validation using measured data, standardize elevation and depth datums, increase sounding density in data-sparse areas and develop complete metadata for each data layer.

From the Quang Ninh - Hai Phong - Thai Binh pilot case, a broader conclusion can be drawn: open data are an important input source but cannot completely replace official survey data in coastal zones. An effective approach is to combine open-source data, official data and supplementary survey data within a unified GIS workflow, in which data quality is quantitatively assessed and organized into an updateable database. This is an appropriate direction for digital-transformation programs in natural resources and the environment, especially where spatial data infrastructure is needed to support sustainable marine economic development.

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