

DIGITAL TOPOGRAPHIC MAP ACCURACY ASSESSMENT AND OPTIMIZATION: A CASE STUDY OF SIRDARYA REGION, UZBEKISTAN (SCALE 1:50,000)

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Abstract: *Accurate digital topographic mapping plays a fundamental role in national spatial planning, geo-monitoring, water management, land cadastre systems, and infrastructure development, particularly in regions where economic productivity depends on land and water resources. Despite continuous progress in Geographic Information Systems (GIS), remote sensing, and cartographic data processing, the challenge of positional error minimization remains critical in developing countries, including Uzbekistan. This research provides a methodological, statistical, and comparative evaluation of digital topographic map accuracy at a medium-scale resolution of 1:50,000, with a specific focus on Sirdarya Region. The region presents a suitable case due to its intensive irrigated agriculture, vulnerable soil salinity conditions, and frequent land-use changes. Data accuracy is assessed through Root Mean Square Error (RMSE), Circular Error at 90% confidence (CE90), and Linear Error Probability (LEP), using control points extracted from GNSS measurements, Copernicus DEM, and high-resolution Sentinel-2 imagery. International datasets including USGS, NASA EOS, and ESA Copernicus are compared to national cartographic products. The results reveal significant positional deviations ranging from 4.1 to 21.6 meters, depending on land cover type, vector feature class, and interpolation method. Based on these findings, optimization strategies are proposed through enhanced GNSS integration, AI-assisted feature classification, adaptive DEM interpolation, and geodatabase standardization. The research concludes that the optimal improvement approach involves hybrid RS-GIS processing combined with regulated national standards, which can drastically decrease positional uncertainty while enabling high-fidelity national mapping for long-term land management.*

Keywords: *Digital topography, RMSE, CE90, Copernicus, Sentinel-2, Sirdarya, GNSS, map accuracy, DEM optimization, GIS.*

The increasing reliance on digital cartography has transformed the role of topographic maps from static reference artifacts into dynamic spatial databases supporting environment analysis, hydrological planning, and territorial governance. Unlike earlier analog map production paradigms, contemporary topography is intertwined with geoinformatics, multi-source satellite imagery, artificial intelligence-based classification, and real-time GNSS measurements. In Uzbekistan, the shift to digital cartographic infrastructures comes at a time when water scarcity, land degradation, urban expansion, and agricultural transformation require precise geospatial information. The Sirdarya Region exemplifies this necessity. Its farmland productivity depends heavily on irrigation networks derived from transboundary water systems, while its landscape continuously evolves through reclamation, drainage reconstruction, canal dredging, and soil desalinization practices. Consequently, spatial errors in topographic maps may lead to misallocated land

assessments, inaccurate hydrological modeling, and inefficient investment decisions. Medium-scale topographic mapping at 1:50,000 remains essential for regional planning, particularly because it balances feature visibility and mapping cost. Yet, the scale's accuracy remains vulnerable to distortions during digitization, coordinate transformation, and automated classification phases.

The modern topographic workflow frequently incorporates remote sensing products such as Sentinel-2 (10–20 m spectral bands), Landsat-8/9 (15–30 m), and Copernicus DEM (30 m). Although these datasets enable efficient digital feature extraction, they introduce pixel-based uncertainties into linear and polygonal vector features such as irrigation channels, administrative boundaries, drainage collectors, and local roads. When these features are digitized, their geometric representation suffers from pixel boundary ambiguity and sensor distortion, particularly in agricultural landscapes with homogeneous spectral textures. Vegetated irrigated fields complicate edge detection as crop reflectance mimics soil and water patterns, generating inconsistent segment boundaries. Such uncertainties propagate across topographic datasets and must therefore be quantified using positional accuracy equations such as Root Mean Square Error (RMSE):

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (X_m - X_t)^2 + (Y_m - Y_t)^2}$$

$$\text{CE90} = 1.6449 \times \text{RMSE}$$

In the Sirdarya Region, the error calculation was performed using a distributed set of GNSS checkpoints located across irrigated fields, settlements, canal embankments, and main road intersections. A total of 118 control points were processed. The observed RMSE values varied according to land cover and feature type: polygons (land parcels, farm boundaries) recorded an average RMSE of 14.5 m; line features (irrigation canals, secondary roads) displayed slightly lower uncertainty at 12.8 m, while settlements and building footprints measured through Sentinel-2 showed the highest deviation, averaging 21.6 m due to coarse spatial resolution. In contrast, drainage collectors, wide canals, and large transportation corridors demonstrated significantly reduced positional error at 4.1–7.9 m, consistent with their large physical width relative to pixel size. These findings align with international studies such as Yang et al. (2020), who noted that agricultural landscapes in China's Fujian Province produced elevated misclassification rates due to spectral homogeneity, and Charou et al. (2021), who reported that Mediterranean farmland mosaics introduced boundary uncertainty of up to 30 m under Sentinel-derived mapping.

The comparison with international products revealed notable disparities. The Copernicus DEM-derived hydrographic layers, when resampled to vector formats, presented positional deviations averaging 12.2 m in Sirdarya. USGS Hydrosheds exhibited a slightly higher error of 15.4 m, while NASA SRTM-based cartography showed deviations exceeding 19 m for narrow canals. Such discrepancies underscore the limitation of global DEMs when applied to precision irrigation networks in Central Asia, where canals are narrow and engineered at meter-level widths. Uzbekistan's analog maps (produced before 1991) contain relatively accurate vector geometry but suffer from outdated landscape attributes. Digital conversion conducted without geodatabase topology rules amplifies errors through repeated raster-vector conversions and projection inconsistencies.

Furthermore, local GIS operators frequently employ unregulated interpolation methods, shifting coordinate baselines by up to 2 m at municipal boundaries.

To optimize accuracy at this scale, several scientifically grounded measures must be applied. First, hybrid GNSS-sentinel correction workflows need implementation, whereby vector edges are updated using differential GNSS adjustment and machine learning feature extraction, particularly convolutional neural networks (CNNs) trained to detect irrigation channels through texture analysis. Second, DEM products should undergo adaptive interpolation using local kriging models rather than default cubic or spline algorithms, reducing elevation-derived hydrographic distortion. Third, a national geodatabase standard must be legally enforced to control attribute uniformity, topology errors, and projection transformations.

ISO-compatible metadata schemas must accompany topographic products, enabling reproducibility and uncertainty disclosure. Fourth, in agricultural landscapes, UAV photogrammetry can be selectively utilized in high-salinity zones, where spectral uniformity undermines satellite classification. UAV-optical fusion techniques markedly reduce polygon edge distortion, enabling nationwide agricultural monitoring at relatively low cost.

In addition to these operational solutions, institutional reforms are advisable. National cartographic agencies should revise their technical specifications to reflect NSSDA and ISO 19157 accuracy prescriptions, ensuring metric clarity in public datasets. Scientific collaboration between Uzbek universities, the Ministry of Agriculture, and the Geodesy Agency will enable innovative adoption of AI-assisted cartography. Furthermore, partnerships with ESA and USGS would facilitate access to refined datasets and training materials. Through these measures, Uzbekistan may transform its digital mapping environment into a more resilient geospatial infrastructure supportive of long-term land and water management.

The findings demonstrate that digital medium-scale maps, while difficult to maintain at high precision due to satellite resolution constraints, can be significantly optimized through hybrid geospatial methodology, GNSS control integration, interpolation reforms, and metadata regulation. For a region like Sirdarya, where agricultural economics and land reform depend on spatial stability, reduced positional uncertainty represents not merely a cartographic improvement, but a strategic investment in national resource sovereignty.

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