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An Open-Source Geospatial Framework for Karst Mapping: Integrating GNSS and Quantum GIS (QGIS) for Topographic Reconstruction of the Gunungsewu Karst Region

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Abstract

The Gunungsewu Karst Region represents one of Indonesia's most extensive and intricate karst landscapes, characterized by profound geological, ecological, and socio-cultural significance. The complex geomorphological attributes—defined by prominent dolines, cave systems, and subterranean drainage networks—necessitate sophisticated mapping techniques capable of multi-source spatial data integration. This study evaluates the efficacy of Quantum Geographic Information System (QGIS) as a robust, open-source alternative to commercial software for mapping the Gunungsewu karst terrain. The methodology encompasses field-based data acquisition using Global Navigation Satellite Systems (GNSS) and theodolites, followed by coordinate processing and spatial visualization within the QGIS environment through thematic layering, contour analysis, and karst feature extraction. Our findings demonstrate that QGIS effectively synthesizes topographic and geospatial datasets to produce high-resolution morphological maps. The platform exhibits superior capabilities in processing raster-vector synergies and multi-format spatial compatibility. The implementation of this QGIS-based workflow significantly enhances mapping efficiency and the accuracy of karst feature representation, thereby providing a critical framework for the conservation and sustainable management of the Gunungsewu Karst Region.

Keywords: QGIS; Gunungsewu Karst; Spatial Mapping; Geoinformatics; Conservation Management.

1. Introduction

Karst regions represent unique and geologically sensitive landscapes, characterized by high porosity, the prevalence of sinkholes (dolines), intricate cave networks, and complex subterranean drainage systems. These distinct geomorphological features necessitate specialized mapping approaches to delineate structural configurations, groundwater dynamics, and associated environmental risks. The Gunungsewu Karst, spanning the southern reaches of Central Java and the Special Region of Yogyakarta, is one of Indonesia's most representative tropical karst environments, possessing significant scientific, ecological, and cultural value (Mussoddaq & Pili, 2025).

Accurate topographic mapping in karst terrains serves as the foundational framework for environmental conservation, groundwater resource management, spatial planning, and the mitigation of geological hazards, such as land subsidence and surface collapse. Premised on the hypothesis that the distribution of archaeological cave sites correlates with specific landscape attributes, this study develops a predictive model for identifying such sites within the Gunungsewu region. By leveraging Remote Sensing and Geographic Information Systems (GIS), this methodology aims to track archaeological occurrences with high precision. Within this context, Quantum GIS (QGIS)—an open-source GIS platform—offers an effective and

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versatile solution for spatial analysis and digital mapping based on georeferenced data (Ristić et al., 2020; Chiozza, 2017).

QGIS facilitates the seamless integration of heterogeneous spatial datasets, including Global Navigation Satellite System (GNSS) surveys, satellite imagery, LiDAR data, and field-derived contour measurements. Through advanced topographic analytical tools—such as Digital Elevation Models (DEM), hillshading, and slope analysis—QGIS supports the generation of high-precision topographic maps of karst environments (Senduk, 2021; Fahrizal et al., 2022). Furthermore, its capacity for simultaneous raster-vector management, thematic layering, and three-dimensional visualization is critical for the rigorous interpretation of karst morphology (Putri et al., 2021; Lee et al., 2024).

In contrast to conventional CAD-based software such as AutoCAD, QGIS provides superior spatial analytical depth and data interoperability. The platform can process raw field data and transform it into thematic layers encompassing elevation contours, subterranean river networks, and the distribution of dolines and ponors (Zhang et al., 2024; Caesario et al., 2024). Consequently, QGIS serves not merely as a visualization tool but as a sophisticated analytical instrument for elucidating the relationships between diverse geomorphological elements.

In the practical mapping of the Gunungsewu Karst, the QGIS-based workflow involves: 1) The systematic acquisition of spatial data (GNSS, total station, and digital cave surveys); 2) Data conversion and cleaning into standardized geodatabase formats; 3) The generation of topographic layers and digital elevation models; 4) Spatial analysis and 3D model visualization; and 5) Final cartographic synthesis in accordance with national standards. Through this integrated approach, QGIS plays a pivotal role in producing precise, informative topographic data that underpins the sustainable management and conservation of the Gunungsewu Karst Region.

2. Methods

The methodology employs an integrated field survey approach coupled with Geographic Information System (GIS)-based spatial processing to generate an accurate topographic reconstruction of the Gunungsewu karst region. The research was executed through a systematic workflow, transitioning from primary data acquisition to digital modeling using AutoCAD Civil 3D and Quantum GIS (QGIS) as the primary analytical platforms.

a. Instrumentation and Data Acquisition

Prior to field operations, a comprehensive suite of surveying instruments was deployed, including theodolites for horizontal and vertical angular measurements, leveling rods for differential leveling, benchmarks, and high-precision GPS units for coordinate referencing. These primary datasets were supplemented by secondary sources, including base maps, multispectral satellite imagery, and National Elevation Data (DEMNAS) to establish an initial geodetic framework.

b. Site Selection and Sampling Strategy

Representative study areas within the Gunungsewu karst were identified based on morphological variability and altitudinal gradients. Measuring stations were strategically distributed across three distinct zones: coastal lowlands (low elevation), transitional footslopes (intermediate elevation), and karst summits (high elevation). This stratified sampling design ensures a holistic representation of vertical landform variations and the spatial relationships between geomorphological zones.

c. Terrestrial Survey Operations

Field measurements were conducted using terrestrial surveying techniques, observing horizontal and vertical angles alongside slope distances between the instrument stations and target points. To ensure data integrity and minimize systematic errors, observations were performed in multiple iterations. Field notes recorded not only numerical data but also localized geomorphological characteristics and terrain conditions.

d. Data Processing and Geodetic Conversion

Raw survey data were transformed into Cartesian coordinates (X, Y, Z) using trigonometric algorithms. These coordinates were subsequently projected into the WGS 84 datum to ensure full compatibility with global geospatial standards. This phase resulted in a structured spatial database ready for integration into digital topographic models.

e. Digital Topographic Modeling

The processed coordinates were ingested into AutoCAD Civil 3D to construct a Triangulated Irregular Network (TIN) surface and generate high-fidelity three-dimensional contour maps. By connecting coordinate points according to actual field elevations, a continuous visualization of the karst landscape—from coastal plains to rugged hills—was achieved.

f. GIS Integration and Spatial Analysis

The CAD-derived contour models were exported into vector formats (.shp or .dxf) and integrated into the QGIS environment. This stage involved thematic layering, elevation classification, and slope analysis. Furthermore, Digital Elevation Models (DEMs) were generated to refine topographic interpretations. QGIS was specifically utilized for hydrological modeling, including flow direction analysis and the delineation of subterranean drainage patterns, recharge zones, and discharge points within the karst system.

g. Cartographic Synthesis and Interpretation

The final topographic outputs were synthesized using QGIS layout tools, incorporating standard cartographic elements (scale, legends, coordinate grids, and orientations) in compliance with national standards. The resulting digital maps delineate the connectivity between topographic zones from the coast to the interior highlands, serving as a fundamental dataset for advanced geomorphological studies, groundwater management, and geohazard mitigation.

This integrated workflow successfully yielded topographic maps that articulate both vertical elevation variance and inter-zonal geomorphological relationships. The synergy between AutoCAD Civil 3D and QGIS facilitates high-precision data processing, comprehensive spatial analysis, and robust 3D morphological visualization. These results are critical for supporting geological research, environmental conservation strategies, and sustainable spatial planning tailored to the unique characteristics of the Gunungsewu Karst Region.

3. Results

a. Analysis of Field Measurements

Field surveys across the Gunungsewu Karst were categorized into three altitudinal zones: low-elevation (<150 m a.s.l.), intermediate (150–250 m a.s.l.), and high-elevation (>250 m a.s.l.). Utilizing GNSS RTK and total station units, measuring stations and sampling targets were systematically established. Data acquisition encompassed Cartesian coordinates (X, Y, Z) and secondary attributes, including land cover types (paddy fields, orchards, secondary forests), slope gradients (%), and surface lithological characteristics (limestone outcrops, dolines, and depressions).

The results revealed elevations ranging from 80 to310 m a.s.l., with slope gradients varying from 8% (plains) to 42% (steep limestone escarpments). Distinct karst features—specifically closed dolines, depressions, and spring channels—predominated in the intermediate and high zones. These findings align with tropical karst characteristics defined by undulating relief and complex subterranean drainage. Recent studies underscore that karst landforms are heavily dictated by morphology and lithological structures sensitive to dissolution (Damayanti et al., 2025) and surface collapse risks (Zamroni et al., 2023). These measurements provide the critical geometric foundation for high-fidelity modeling, where precision is paramount due to the landscape's hypersensitivity to surface and subsurface hydrological fluctuations.

b. Geometric Reconstruction via AutoCAD Civil 3D

Following data acquisition, coordinates were ingested into Civil 3D to construct a Triangulated Irregular Network (TIN). The workflow involved importing CSV datasets, defining breaklines for sharp geological features, and surface refinement to generate 2 m contour intervals. The resulting model exhibited dense contour patterns in high-elevation karst hills (> 250 m) and closed-basin morphologies in lower zones (100-150 m).

3D visualizations elucidated the transition from steep limestone slopes to sinkhole depressions, likely linked to karst dissolution and subsurface drainage. The primary advantage of Civil 3D in this framework is its geometric precision in surface modeling. However, capturing micro-karst features (e.g., small dolines and limestone fissures) necessitated significant manual intervention through breakline adjustment and mesh sharpening. As noted by Damayanti et al. (2025), karst mapping demands high resolution to avoid overlooking critical morphological features.

c. Integrated Geospatial Analysis in QGIS

The refined surfaces were exported to QGIS to undergo transition into raster-based Digital Elevation Models (DEM) and vector-thematic layers. Advanced spatial analyses—including hillshading, slope classification, and multi-layer overlays—were performed. The integrated maps revealed that areas <150 m are primarily utilized for agriculture and are significantly influenced by karst depressions, whereas zones > 250 m are characterized by limestone outcrops and secondary forests.

Slope analysis indicates that gradients >30% are highly susceptible to rapid surface runoff and erosion, findings critical for landslide and subsidence mitigation (Bachri et al., 2020). This integration facilitates a holistic understanding: the topographic data acts as a proxy for identifying risk zones and subterranean drainage patterns. Furthermore, the 3D visualizations provided by QGIS enhance accessibility for non-technical stakeholders, fostering community-based management.

4. Discussion

The synergy between AutoCAD Civil 3D and QGIS provides a robust workflow for karst topography. While Civil 3D excels in technical geometric accuracy, QGIS offers superior spatial analytical depth.

Key advantages include:

1. Geometric Fidelity, TIN modeling captures karst ridges and dolines that are often smoothed over in simple raster methods.
2. Informed Decision-Making, overlays of lithology, land use, and slope enable the creation of high-precision risk maps for conservation and spatial planning.
3. Stakeholder Engagement, 3D GIS visualizations facilitate participatory mapping, bridging the gap between scientific data and local community understanding (Zamroni et al., 2023).

Challenges and Technical Constraints:

1. Resolution Sensitivity, micro-geomorphology requires dense sampling and specific breaklines to prevent data loss.
2. Interoperability, maintaining data integrity during CAD-to-GIS transformation is vital (Boria et al., 2020).
3. Policy Application, topographic products must be translated into actionable zoning policies (e.g., agricultural restrictions or safe tourism routes) to mitigate sinkhole and contamination risks.

   For future karst mapping endeavors, we recommend the following protocol:

1. Field Strategy, employ bracketing surveys for critical zones like doline basins and slopes > 30%.
2. Surface Definition, use explicit breaklines in Civil 3D to delineate geological boundaries (limestone/alluvium).
3. Data Standards utilize DXF/SHP formats anchored to the WGS84 UTM coordinate system.

4. Spatial Auditing, conduct slope and hillshade analysis in QGIS to identify potential land-use conflicts.

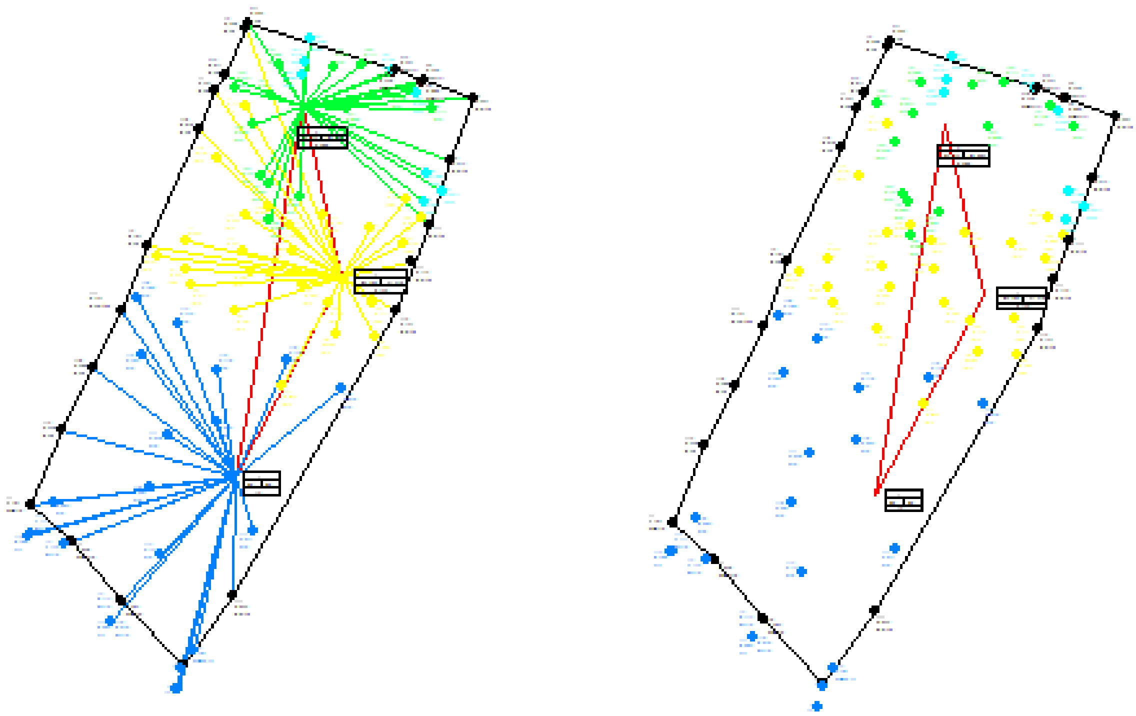

Figure 1. Topographic Mapping via Theodolite Surveys within a QGIS Framework

Table 1. Results of Theodolite-Based Topographic Surveys

1	Nomor Titik		Tinggi Alat	Bacaan Benang(M)			Sudut Vertikal			Sudut Horizontal			Ket						X	Y	Z	Ket Alat
2	Alat	Titik		BA	BT	BB	DER	MEN	DET	DER	MEN	DET		Cek BT	D	Δh	D Cos	D Sin	250	250	75	
3	THEO 1	1	1,35	2,335	2,19	2,045	84	2	50	262	13	35		2,19	28,688	2,151	-28,424	-3,880	221,576	246,120	77,151	
4	THEO 1	2	1,35	2,325	2,198	2,07	84	2	5	248	48	40		2,1975	25,225	1,788	-23,519	-9,117	226,481	240,883	76,788	
5	THEO 1	3	1,35	2	1,87	1,742	84	1	45	248	39	55		1,871	25,521	2,149	-23,772	-9,285	226,228	240,715	77,149	
6	THEO 1	4	1,35	1,7	1,583	1,466	86	11	0	222	5	5		1,583	23,296	1,321	-15,614	-17,289	234,386	232,711	76,321	
7	THEO 1	5	1,35	1,3	1,181	1,063	86	11	45	222	3	15		1,1815	23,596	1,738	-15,805	-17,520	234,195	232,480	76,738	
8	THEO 1	6	1,35	2,6	2,02	1,88	86	11	35	195	21	55		2,24	71,683	4,100	-18,994	-69,120	231,006	180,880	79,100	
9	THEO 1	7	1,35	2,025	1,885	1,75	86	11	35	195	17	45		1,8875	27,379	1,287	-7,223	-26,409	242,777	223,591	76,287	
10	THEO 1	8	1,35	2,31	2,155	2	86	12	5	195	12	40		2,155	30,864	1,244	-8,098	-29,783	241,902	220,217	76,244	
11	THEO 1	9	1,35	2,63	2,475	2,32	86	11	10	194	57	0		2,475	30,863	0,932	-7,962	-29,818	242,038	220,182	75,932	
12	THEO 1	10	1,35	1,555	1,42	1,29	86	10	50	220	29	35		1,4225	26,382	1,691	-17,132	-20,063	232,868	229,937	76,691	
13	THEO 1	11	1,35	1,815	1,685	1,55	86	11	0	220	24	5		1,6825	26,383	1,425	-17,100	-20,091	232,900	229,909	76,425	
14	THEO 1	12	1,35	1,225	1,075	0,93	86	10	50	254	21	15		1,0775	29,369	2,236	-28,281	-7,921	221,719	242,079	77,236	
15	THEO 1	13	1,35	1,53	1,38	1,23	86	10	30	254	13	30		1,38	29,866	1,967	-28,742	-8,120	221,258	241,880	76,967	
16	THEO 1	14	1,35	1,73	1,605	1,475	86	10	40	262	13	45		1,6025	25,387	1,441	-25,154	-3,433	224,846	246,567	76,441	
17	THEO 1	15	1,35	1,28	1,155	1,03	86	11	40	285	35	55		1,155	24,890	1,851	-23,973	6,693	226,027	256,693	76,851	
18	THEO 1	16	1,35	2,2	2,145	2,01	86	10	25	307	25	30		2,105	18,915	0,470	-15,022	11,495	234,978	261,495	75,470	
19	THEO 1	17	1,35	1,41	1,265	1,145	83	29	40	325	45	50		1,2775	26,160	3,068	-14,718	21,627	235,282	271,627	78,068	
20	THEO 1	18	1,35	1,335	1,26	1,185	89	27	35	351	30	15		1,26	14,999	0,231	-2,216	14,834	247,784	264,834	75,231	
21	THEO 1	19	1,35	2,15	2,052	1,955	87	40	5	50	3	0		2,0525	19,468	0,091	14,924	12,501	264,924	262,501	75,091	
22	THEO 1	20	1,35	1,94	1,85	1,76	87	40	25	24	49	15		1,85	17,970	0,230	7,544	16,310	257,544	266,310	75,230	
23	THEO 1	21	1,35	1,69	1,658	1,61	87	43	0	160	44	55		1,65	7,987	0,010	2,634	-7,541	252,634	242,459	75,010	
24	THEO 1	22	1,35	2,19	2,11	2,025	87	2	25	180	27	45		2,1075	16,456	0,091	-0,133	-16,455	249,867	233,545	75,091	
25	THEO 1	23	1,35	1,99	1,915	1,84	87	14	55	223	2	20		1,915	14,965	0,154	-10,214	-10,938	239,786	239,062	75,154	
26	THEO 1	24	1,35	1,57	1,51	1,45	87	17	0	263	48	25		1,51	11,973	0,408	-11,903	-1,292	238,097	248,708	75,408	
27	THEO 1	25	1,35	2,72	2,595	2,47	86	20	15	193	24	10		2,595	24,898	0,349	-5,771	-24,220	244,229	225,780	75,349	
28	THEO 1	26	1,35	1,81	1,77	1,73	86	18	45	341	15	35		1,77	7,967	0,093	-2,560	7,545	247,440	257,545	75,093	
29	THEO 1	27	1,35	1,665	1,61	1,555	86	20	15	301	18	0		1,61	10,955	0,441	-9,361	5,691	240,639	255,691	75,441	
30	THEO 1	28	1,35	2,22	2,11	2,005	86	21	10	322	51	50		2,1125	21,413	0,605	-12,927	17,071	237,073	267,071	75,605	
31	THEO 1	29	1,35	2,33	2,265	2,15	86	21	0	339	44	45		2,24	17,927	0,229	-6,206	16,819	243,794	266,819	75,229	
32	THEO 1	30	1,35	2,29	2,148	2,005	86	20	45	331	16	45		2,1475	28,384	1,015	-13,640	24,892	236,360	274,892	76,015	

This study demonstrates that the integration of AutoCAD Civil 3D and QGIS provides a comprehensive framework for modeling the complex Gunungsewu Karst. The methodology bridges the gap between precise field measurement and advanced spatial analysis, resulting in highly applicable topographic models. Despite challenges regarding scale and interoperability, this dual-platform approach offers significant potential for the regenerative and sustainable management of sensitive karst ecosystems.

5. Conclusion

This study demonstrates that the strategic integration of AutoCAD Civil 3D and Quantum GIS (QGIS) effectively facilitates a high-precision, comprehensive topographic reconstruction of the Gunungsewu karst landscape. Primary datasets acquired via GNSS, theodolite, and total station surveys were successfully synthesized within Civil 3D to generate robust Triangulated Irregular Network (TIN) surfaces. The subsequent interoperability with QGIS enabled advanced geospatial analytics, including the generation of Digital Elevation Models (DEMs), slope and hillshade analyses, and the multi-criteria overlay of lithological and land-cover datasets.

The resulting topographic models delineate more than mere altitudinal gradients from coastal zones to karst uplands; they accurately represent critical geomorphological features, such as closed dolines, depressions, and subterranean drainage architectures. These findings are instrumental in underpinning the sustainable management of the Gunungsewu Karst, particularly regarding environmental conservation, geohazard mitigation, spatial planning, and the optimization of local economic sectors such as agrotourism and sustainable agriculture.

Despite inherent technical challenges—namely the requirement for high-resolution data acquisition and the complexities of cross-platform format conversion—the integrated CAD–GIS framework provides a highly representative methodology. Consequently, this synergistic approach is recommended as a standard modeling protocol for karst environments and other regions characterized by complex geomorphological configurations.

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