



Research Article

GIS-Based Mapping and Geodatabase Development for Expansive Soils: A Case Study of Selected Towns in the Wolaita Zone, Southern Ethiopia

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Abstract

Expansive soils cause costly damage to infrastructure through seasonal moisture-driven swelling and shrinkage, yet in many developing regions the geotechnical data needed to manage this hazard remains fragmented across paper records and individual project reports. This study addresses that gap by evaluating the engineering properties of expansive soils in three rapidly urbanizing towns in the Wolaita Zone of southern Ethiopia, namely Tebela, Wolaita Sodo, and Boditi, and consolidating the results into a spatially referenced ArcGIS geodatabase to support preliminary engineering design. Fourteen test pits were investigated following ASTM and AASHTO standards, combining ten newly collected field samples with four secondary data sources; index and strength properties, including Atterberg limits, free swell index, swelling pressure, and California Bearing Ratio, were determined in the laboratory, and all test-pit locations were captured by GPS and georeferenced onto rectified imagery in UTM Zone 37N. The results classified the soils at Tebela and Wolaita Sodo as highly plastic clays (CH, AASHTO A-7-5) with high fines contents of 91.8 to 95.1%, free swell indices exceeding 100%, and swelling pressures of 145 to 170 kPa, while the Boditi soils were similarly classified as high-plasticity clays (CH, A-7-6) but showed low California Bearing Ratio values of 2.2 to 2.8%, indicating weak subgrade support. These laboratory results, together with the GPS coordinates, were structured in an ArcGIS file geodatabase organized by town and test pit, with fully searchable laboratory attributes. The resulting system converts scattered paper-based geotechnical records into an interactive, query able geospatial tool and offers an adaptable workflow that can be extended to manage expansive soil risk in other regions facing similar infrastructural and data-management challenges.

Keywords

Atterberg Limits, ArcGIS, Expansive Soil, Geodatabase, Geotechnical Data Management, Swelling Pressure

1. Introduction

Expansive soils expand upon absorbing moisture and contract as they dry out, creating a continuous cycle of ground motion that remains a major cause of structural damage to

light buildings, roads, and underground utilities globally [2].

The behaviour is driven largely by the presence of montmorillonite and related smectite clay minerals, whose layered

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structure admits water between the sheets and produces volume change out of proportion to the moisture involved. Because the damage accumulates gradually and often appears only after several wet–dry cycles, it is frequently misattributed to workmanship rather than to ground conditions, and the cost is absorbed in repeated repair rather than prevented at design stage. Ethiopia contains extensive deposits of expansive soil derived from both weathered basic igneous rocks and montmorillonite-bearing sedimentary parent material [4, 16].

In the Wolaita Zone of southern Ethiopia, the combination of flat, poorly drained terrain and rapid urban growth has put an increasing volume of construction onto precisely the ground most prone to shrink–swell movement. Towns such as Wolaita Sodo, Boditi and Tebela have expanded onto former farmland and black cotton soil flats, and a substantial share of residential construction proceeds without a site-specific geotechnical investigation, largely because such investigations are perceived as slow and expensive relative to the scale of the individual project, [15].

The problem is compounded by how geotechnical information is held once it has been generated. Laboratory results from individual projects typically remain in project files or paper reports, unconnected to any spatial reference, so a test pit logged a hundred metres from a new site contributes nothing to the design of that site. What is missing is not always new data but an organised way of finding and reusing the data that already exists. Geographic Information Systems address exactly this problem by binding attribute data to location, and a growing body of work has applied GIS to geotechnical data management in settings ranging from university campuses to entire municipalities [7, 17].

Comparable applications within Ethiopia remain limited, and to the authors' knowledge no published study has developed a spatially referenced expansive-soil geodatabase for the Wolaita Zone [1].

This study presents the geotechnical evaluation of expansive soils across three towns in the Wolaita Zone and their mapping into an ArcGIS geodatabase tailored for initial engineering design. The primary goals were: (i) to measure the soil properties in the target areas using standardized laboratory procedures; (ii) to categorize the soils under the AASHTO and USCS classification frameworks and map regions with similar engineering performance; (ii) to generate spatial distribution maps of the geotechnical data using ArcGIS; and (iv) to create a structured geodatabase that allows planners and engineers to access location-specific test pit data straight from a digital map interface.

2. Literature Review

2.1. Properties and Engineering Significance of Expansive Soils

The engineering difficulty presented by expansive soils follows from a cluster of related properties. High plasticity,

quantified by the plasticity index, indicates a wide moisture range over which the soil deforms without fracturing, and correlates strongly with volume-change potential. Swelling potential itself is measured directly through free swell and swelling pressure tests, the latter quantifying the force the soil exerts against a restrained boundary such as a footing or a retaining structure. A high cation exchange capacity reflects the soil's affinity for water molecules and exchangeable cations and underlies the shrink swell cycle. Expansive soils also tend to have low shear strength and low permeability; the latter is significant because it prolongs saturation, extending the period over which swelling pressure acts [11, 12].

2.2. Identification and Classification Approaches

Expansive soils can be identified mineralogical, through X-ray diffraction, differential thermal analysis or electron microscopy, or indirectly through index property tests. Mineralogical methods give the most fundamental answer but require equipment that is rarely available outside specialist laboratories. Indirect methods, relying on liquid limit, plasticity index, free swell index and clay fraction, are therefore the practical standard for routine investigation, and correlations between these indices and observed swell behaviour are well established [13].

Classification under AASHTO and the USCS provides a common vocabulary for describing the result: soils in the A-7-5 and A-7-6 groups, and in the CH category of the USCS, are recognised as highly plastic clays with poor subgrade performance [22].

In Ethiopia, Saba [20] investigated the index properties and swelling potential of expansive soils in the Lege Tafo area. This study is relevant to the characterization of expansive soils because index properties provide useful information for assessing soil plasticity and potential swelling behavior. Such investigations provide a basis for evaluating expansive soil characteristics and interpreting their implications for geotechnical engineering.

2.3. GIS Applications in Geotechnical Data Management

GIS has been applied to geotechnical data in several distinct ways: as a means of visualising subsurface conditions at inaccessible sites, as a platform for processing and presenting borehole data and as a decision-support tool in site investigation planning [10, 14].

Work in Nigeria and India has demonstrated campus- and city-scale mapping of index and strength properties, and studies in Ethiopia have begun to apply comparable methods to index and shear behaviour at town scale. The common finding across this literature is that the value of a geotechnical GIS lies less in any single map than in the geodatabase behind it, which allows data to be queried, updated and extended as new investigations are completed [21].

2.4. Research Gap

Expansive soil characterisation in Ethiopia and GIS-based geotechnical data management elsewhere have each been studied, but they have rarely been brought together. For the Wolaita Zone specifically, prior work has addressed stabilisation of expansive subgrade in individual towns without producing the spatial analysis or geodatabase structure needed to make the resulting data reusable across projects. This study addresses that gap by combining laboratory characterisation, classification, spatial mapping and geodatabase development into a single workflow for three towns in the zone [18].

3. Materials and Methods

3.1. Study Area

The study was carried out in three towns of the Wolaita

Zone, southern Ethiopia. Wolaita Sodo, the zonal capital, lies at approximately 6.87°N, 37.75°E, some 330 km southwest of Addis Ababa, at elevations between roughly 1600 and 2100 m above mean sea level. Boditi is about 15 km north of Sodo at 7.03°N, 37.85°E, and Tebela about 20 km south at 6.7°N, 37.75°E. The three differ in degree of urbanisation – Sodo is the administrative and commercial centre, Boditi a smaller but growing town, and Tebela the least urbanised but share broadly similar topographic and soil conditions, with flat to gently sloping terrain and restricted drainage that favours the development of shrink swell behaviour. They were selected on the basis of visual site reconnaissance indicating susceptibility to expansive soils, their significance for ongoing construction, and the availability of prior investigation data for comparison [6].

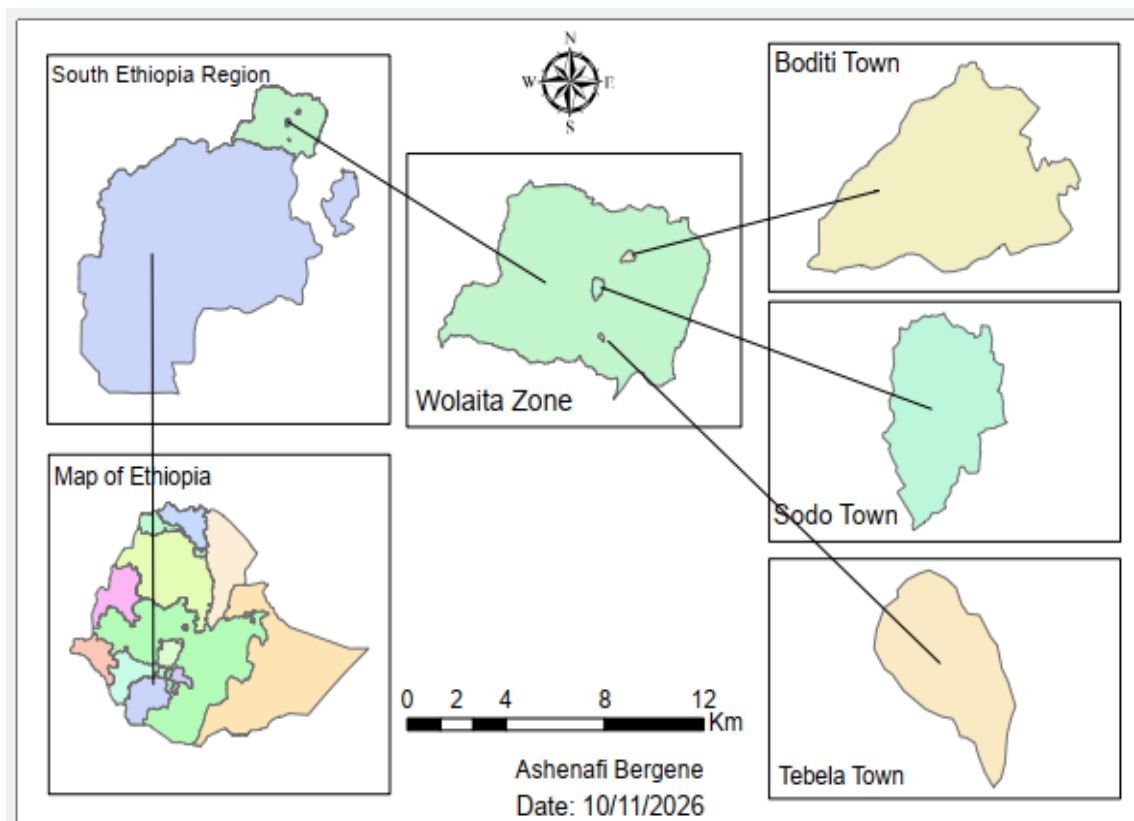


Figure 1. Map of the study area.

3.2. Sampling and Test Pit Locations

Purposive sampling was used, on the grounds that the objective was to characterise and map known expansive-soil areas rather than to estimate a population parameter. Following site reconnaissance, test pit locations were chosen to represent

the dominant soil profiles observed, principally grey and black cotton soils. Ten test pits were excavated for this study four at Tebela (TP1–TP4) and six at Sodo (TP5–TP10) – to depths of 1.5 to 1.85 m using local labour and hand tools. Data for four further pits at Boditi (TP11–TP14), at depths of 1.5 to 2.0 m, were obtained from a published prior investigation and are treated throughout as secondary data [5].

Disturbed samples were collected in sealed plastic bags for index and compaction testing. Undisturbed samples were recovered in steel tubes sealed at both ends to preserve in-situ conditions, and were used for swelling pressure, unconfined

compressive strength and natural moisture content determination. Position and elevation at each pit were recorded using the UTM Measure application and are summarised in Table 1.

Table 1. Test pit locations, depths and elevations.

Test pit	Town	Location	Depth (m)	Latitude	Longitude	Elev. (m)
TP1	Tebela	TVET area	1.60	6°41'53.57"N	37°46'31.67"E	1580
TP2	Tebela	Primary hospital	1.70	6°42'17.00"N	37°46'32.79"E	1572
TP3	Tebela	Universal College 1	1.50	6°41'58.75"N	37°46'38.77"E	1576
TP4	Tebela	Universal College 2	1.50	6°42'0.76"N	37°46'38.11"E	1573
TP5	Sodo	Larrena	1.80	6°47'21.06"N	37°45'20.54"E	1811
TP6	Sodo	Gandaba	1.70	6°48'27.10"N	37°44'54.41"E	1821
TP7	Sodo	Deri	1.85	6°49'47.38"N	37°44'23.47"E	1846
TP8	Sodo	Diaspora	1.65	6°49'15.77"N	37°45'12.63"E	1837
TP9	Sodo	Sodo–Gasuba exit	1.70	6°50'29.01"N	37°43'41.85"E	1850
TP10	Sodo	Sodo–Gununo exit	1.70	6°53'42.10"N	37°42'44.70"E	1918
TP11	Boditi	City stadium	2.00	6°57'19.00"N	37°51'37.00"E	2038
TP12	Boditi	Bus station	1.50	6°57'15.00"N	37°51'22.00"E	2050
TP13	Boditi	Adventist church	2.00	6°57'02.00"N	37°51'41.00"E	2019
TP14	Boditi	Mosque	1.50	6°57'16.00"N	37°51'30.00"E	2045

Note: TP11–TP14 are secondary data compiled from [9].

3.3. Laboratory Testing Programme

All testing was performed at the Wolaita Sodo University Geotechnical Laboratory in accordance with ASTM and AASHTO procedures. Natural moisture content was determined by oven drying at 105 °C for 24 h (ASTM D2216). Specific gravity was measured by the small pycnometer method on material passing the 2 mm sieve and oven-dried at 110 ± 5 °C (ASTM D854). Particle size distribution combined wet sieve analysis with hydrometer analysis for the fine fraction (ASTM D422), using sodium hexametaphosphate as dispersant. Atterberg limits were determined on material passing the 425 µm sieve using the Casagrande apparatus for the liquid limit and the 3 mm thread-rolling method for the plastic limit (ASTM D4318), with the plasticity index taken as the difference between the two.

The free swell index followed IS 2720 (Part 40), which remains the common reference for this test in the absence of an equivalent ASTM or AASHTO standard. Two 10 g oven-dried samples passing the 425 µm sieve were placed in separate 100 ml graduated cylinders, one filled with distilled water and the other with kerosene, and the settled volumes were read

after 24 h. Because kerosene is non-polar and induces no swelling, the kerosene reading provides the reference volume, and the index is calculated as:

$$FSI (\%) = [(V_d - V_k) / V_k] \times 100 \quad (1)$$

Where V_s is the settled volume in distilled water and V_k the settled volume in kerosene.

Compaction characteristics were established by the standard Proctor test on material passing the 19 mm sieve (ASTM D698), yielding maximum dry density and optimum moisture content. Unconfined compressive strength was determined on trimmed cylindrical specimens (nominally 38 mm diameter by 76 mm height) loaded at approximately 1 per cent axial strain per minute until failure (ASTM D2166). One-dimensional swelling pressure was measured on remoulded specimens confined in a rigid ring and inundated under constant-volume conditions until equilibrium (ASTM D4546).

3.4. Spatial Data Acquisition and Georeferencing

Test pit coordinates were recorded in the field in WGS84

and exported as KML files. High-resolution aerial imagery for each town was obtained from Google Earth Pro and imported into ArcGIS 10.8, where it was georeferenced against ground control points and rectified to correct geometric distortion. All layers were projected to UTM Zone 37N to ensure consistency between the imagery, the test pit points and any subsequently added datasets. Test pit points were overlaid on the rectified imagery and checked visually against identifiable features such as roads and buildings to confirm positional accuracy before any attribute data were attached.

3.5. Geodatabase Design

A file geodatabase was created in ArcGIS 10.8 as the central repository for both spatial and attribute data. The structure was organised hierarchically: feature datasets correspond to towns (Tebela, Sodo, Boditi), maintaining administrative boundaries and a consistent coordinate system within each, while feature classes correspond to individual test pits. Each test pit feature carries an attribute table populated with the laboratory results for that location gradation fractions, Atterberg limits, compaction parameters, strength and swell values with field aliases and data types (double for numeric parameters, text for classification and colour descriptors) configured explicitly to constrain entry errors. Domain and validation rules were applied during digitisation to maintain internal consistency.

Soil type context was added by extracting the relevant extent from the FAO Digital Soil Map of the World for each town's area of interest, clipped to the administrative boundary and rendered as a thematic layer beneath the test pit points. Retrieval in use is deliberately simple: selecting the Identify tool and clicking a test pit returns the full set of geotechnical

parameters recorded at that location, without the user needing to query the underlying tables directly [19].

4. Results and Discussion

4.1. Geotechnical Properties at Tebela

The four Tebela test pits returned a consistent picture of fine-grained, highly plastic soil with pronounced swelling potential (Table 2). Natural moisture contents were high, between 38.50 and 40.82 per cent, consistent with sampling under moist conditions in soils that retain water readily. Specific gravity varied over a narrow band of 2.60 to 2.65, typical of clay-mineral-dominated soils. Free swell indices exceeded 100 per cent at every pit, ranging from 103.25 to 113.33 per cent, which places all four samples firmly in the expansive category.

Gradation confirmed the fine-grained character: gravel contents were below 1.6 per cent and sand between 5.19 and 6.29 per cent, leaving silt (51.04–59.69 per cent) and clay (34.76–42.13 per cent) as the dominant fractions. Liquid limits of 82.25 to 87.80 per cent and plasticity indices of 50.37 to 52.03 per cent classify the soils as A-7-5 under AASHTO and CH under the USCS. Optimum moisture contents of 26.00 to 29.28 per cent with maximum dry densities of 1.32 to 1.36 g/cm³ are consistent with expansive clays, which compact to relatively low densities at high moisture. Unconfined compressive strengths of 118 and 121 kPa indicate moderate shear strength, and the swelling pressure of 145 kPa measured at TP1 confirms a significant restrained-swell force. These values agree closely with reported characteristics of expansive soils elsewhere in Ethiopia [10].

Table 2. Geotechnical properties of soils at Tebela town.

Property	TP1	TP2	TP3	TP4
Natural moisture content (%)	38.50	38.54	40.54	40.82
Specific gravity, G _s	2.61	2.60	2.64	2.65
Free swell index (%)	106.67	103.25	113.33	112.24
Gravel (%)	1.56	1.07	0.85	0.18
Sand (%)	5.27	6.29	5.19	5.37
Silt (%)	51.04	52.52	55.56	59.69
Clay (%)	42.13	40.12	38.40	34.76
Liquid limit (%)	85.56	82.25	86.40	87.80
Plastic limit (%)	34.54	31.88	35.14	35.77
Plasticity index (%)	51.02	50.37	51.26	52.03
AASHTO class	A-7-5	A-7-5	A-7-5	A-7-5
USCS class	CH	CH	CH	CH

Property	TP1	TP2	TP3	TP4
Optimum moisture content (%)	26.00	29.28	27.34	27.61
Maximum dry density (g/cm ³)	1.35	1.35	1.32	1.36
Unconfined compressive strength (kPa)	121	118	—	—
Swelling pressure (kPa)	145	—	—	—

Note: indicates the test was not performed on that sample.

4.2. Geotechnical Properties at Wolaita Sodo

The six Sodo pits (Table 3) returned a broadly similar but somewhat more variable profile. Natural moisture contents ranged from 38.93 to 42.90 per cent and specific gravity from 2.59 to 2.71, a slightly wider spread than at Tebela. Free swell indices of 109.52 to 117.78 per cent were marginally higher, and liquid limits of 82.84 to 90.06 per cent with plasticity indices of 50.27 to 54.02 per cent again place all samples in the A-7-5 and CH categories.

The variability at Sodo is most evident in the strength and

swell results. Unconfined compressive strengths spanned 112 to 120 kPa and swelling pressures 145 to 170 kPa, the latter representing the highest restrained-swell values recorded anywhere in the study. TP6 also stands out in gradation, with a silt fraction of 66.23 per cent and a correspondingly reduced clay fraction of 28.04 per cent against 35–39 per cent at the other Sodo pits. This degree of local heterogeneity over a few kilometres is itself a practical finding: it indicates that a single investigation cannot safely be extrapolated across the town, which is precisely the argument for maintaining an accumulating spatial database rather than treating each project investigation as self-contained.

Table 3. Geotechnical properties of soils at Wolaita Sodo town.

Property	TP5	TP6	TP7	TP8	TP9	TP10
Natural moisture content (%)	41.69	40.65	40.35	42.90	38.93	40.00
Specific gravity, G _s	2.64	2.60	2.71	2.69	2.63	2.59
Free swell index (%)	116.67	114.84	116.19	117.78	109.52	109.68
Gravel (%)	0.46	0.24	0.83	0.11	0.10	0.31
Sand (%)	5.43	5.49	5.92	4.81	4.96	7.89
Silt (%)	55.06	66.23	55.16	56.07	59.27	53.25
Clay (%)	39.05	28.04	38.09	39.01	35.67	38.55
Liquid limit (%)	88.07	87.71	86.26	90.06	83.40	82.84
Plastic limit (%)	36.85	36.94	34.22	36.04	32.66	32.57
Plasticity index (%)	51.22	50.77	52.04	54.02	50.74	50.27
AASHTO class	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5
USCS class	CH	CH	CH	CH	CH	CH
Optimum moisture content (%)	25.50	22.06	23.92	24.67	25.07	26.00
Maximum dry density (g/cm ³)	1.31	1.34	1.31	1.30	1.37	1.31
Unconfined compressive strength (kPa)	120	—	—	—	116	112
Swelling pressure (kPa)	—	167	162	170	145	155

4.3. Geotechnical Properties at Boditi (Secondary Data)

The Boditi data compiled from describe soils that are expansive but distinguishable from those at Tebela and Sodo (Table 4). Natural moisture contents of 15.40 to 20.50 per cent are markedly lower, which may reflect genuine differences in drainage and in-situ condition, seasonal timing of sampling, or both; without control over the original sampling programme this cannot be resolved here, and the comparison should be read with that caveat in mind. Clay contents of 55.90 to 60.51 per cent are higher than at the other two towns, yet liquid limits of 62.81 to 71.87 per cent and plasticity indices

of 37.97 to 44.75 per cent are lower, placing these soils in the A-7-6 group rather than A-7-5 while remaining CH under the USCS.

The most consequential result for design is the California Bearing Ratio, which falls between 2.20 and 2.75 per cent with CBR-swell values of 3.51 to 3.94 per cent. Bearing ratios in this range indicate a subgrade that is unsuitable for pavement construction without stabilisation or replacement, irrespective of the somewhat lower plasticity relative to Sodo and Tebela. Maximum dry densities of 1.65 to 1.68 g/cm³ at optimum moisture contents of 20.38 to 22.62 per cent are consistent with the higher clay, lower moisture profile.

Table 4. Geotechnical properties of soils at Boditi town (secondary data).

Property	TP11	TP12	TP13	TP14
Natural moisture content (%)	20.50	19.70	17.20	15.40
Specific gravity, G _s	2.58	2.62	2.65	2.57
Gravel (%)	2.50	0.00	0.00	0.00
Sand (%)	9.88	12.75	12.77	8.77
Silt (%)	31.71	29.13	28.71	30.72
Clay (%)	55.90	58.12	58.52	60.51
Liquid limit (%)	62.81	64.68	71.87	68.30
Plastic limit (%)	24.51	26.71	27.12	25.40
Plasticity index (%)	38.30	37.97	44.75	42.90
AASHTO class	A-7-6 (27)	A-7-6 (27)	A-7-6 (29)	A-7-6 (30)
Optimum moisture content (%)	20.38	20.50	22.62	20.81
Maximum dry density (g/cm ³)	1.67	1.68	1.65	1.66
CBR (%)	2.75	2.66	2.53	2.20
CBR-swell (%)	3.51	3.70	3.88	3.94

Source: compiled from Esubalew and Wondemagne [18].

4.4. Classification and Zoning

Table 5 summarises the classification of the ten primary test pits. Fines contents (passing the 75 µm sieve) of 91.80 to 95.08 per cent confirm that these are fine-grained soils throughout. Group indices of 54 to 62 fall well into the range associated with poor subgrade performance, and all ten pits classify as A-7-5 under AASHTO and CH under the USCS. Field colour descriptions were consistently dark grey at Tebela and black at Sodo, consistent with the black cotton soils characteristic of the region.

The practical implication of this uniformity is that the study area does not subdivide into meaningfully different engineering zones on classification grounds alone. What distinguishes locations is not class but degree – the swelling pressure measured at TP8 (170 kPa) is 17 per cent higher than at TP9 (145 kPa) despite identical classification. This is a point worth emphasising for practitioners: classification establishes that a design problem exists, but the magnitude of the problem at a given site has to be read from the measured swell and strength parameters, which is exactly the information the geodatabase is built to deliver.

Table 5. Classification of primary test pit samples.

Test pit	F200 (%)	LL (%)	PI (%)	GI	AASHTO	USCS	Colour
TP1	93.17	85.56	51.02	57	A-7-5 (57)	CH	Dark grey
TP2	92.64	82.25	50.37	55	A-7-5 (55)	CH	Dark grey
TP3	93.96	86.40	51.26	58	A-7-5 (58)	CH	Dark grey
TP4	94.45	87.80	52.03	59	A-7-5 (59)	CH	Dark grey
TP5	94.11	88.07	51.22	59	A-7-5 (59)	CH	Black
TP6	94.27	87.71	50.77	58	A-7-5 (58)	CH	Black
TP7	93.25	86.26	52.04	58	A-7-5 (58)	CH	Black
TP8	95.08	90.06	54.02	62	A-7-5 (62)	CH	Black
TP9	94.94	83.40	50.74	58	A-7-5 (58)	CH	Black
TP10	91.80	82.84	50.27	54	A-7-5 (54)	CH	Black

F200 = percentage passing the 75 μ m sieve; GI = group index.

4.5. Spatial Mapping and Geodatabase Output

Georeferencing and rectification of the Google Earth imagery in UTM Zone 37N produced base maps for each of the three towns against which test pit positions could be verified visually. All fourteen pits were located within a few metres of their expected positions relative to identifiable features, which was taken as confirmation of positional adequacy for the intended preliminary design use [3].

The completed geodatabase organises the data in three tiers: the file geodatabase itself, feature datasets by town, and feature classes by test pit. Attribute tables carry the full laboratory record for each location. In use, an engineer opens the town of interest, selects the Identify tool, and clicks a test pit to return its gradation, plasticity, compaction, strength and swell parameters in a single panel. Two operational advantages follow. First, retrieval time for existing data is reduced from a manual file search to a single click, which materially changes the economics of consulting prior data at the preliminary stage. Second, where several pits lie near a proposed site, the designer can compare them directly and select either the nearest or the most conservative for design, rather than defaulting to whichever report happens to be available. For high-rise foundations in particular, where the consequences of underestimating swell pressure are severe, the ability to see all nearby measurements at once is a meaningful improvement over the current fragmented practice [8].

Thematic soil layers extracted from the FAO Digital Soil Map of the World were added beneath the point data to give regional context. These are coarse relative to the test pit data and are intended for orientation rather than design; the distinction between the two resolutions is preserved explicitly in the geodatabase metadata so that users do not mistake the regional

layer for site-specific information [23].

4.6. Engineering Implications

Taken together, these findings demonstrate that expansive soil conditions prevail throughout the entire project site, marked by swell pressures of 145 to 170 kPa and unconfined compressive strengths between 112 and 121 kPa in Tebela and Sodo, along with sub-3 percent bearing capacities in Boditi. Constructing standard shallow foundations directly on untreated ground poses a severe risk of differential movement, while the low CBR values at Boditi present clear subgrade challenges for road design. Remediation strategies such as chemical treatment using lime or cement, moisture management via drainage and barriers, or deep foundation systems extending past the active zone are well established, with the optimal solution depending entirely on local site characteristics. Rather than endorsing a single engineering remedy, this research provides accessible, location-specific data to help engineers select the most appropriate option during the design phase.

5. Conclusions

Experimental testing of ten test pits across Tebela and Wolaita Sodo, alongside published data from four pits in Boditi, confirmed high plasticity and expansive behaviour throughout the region. Soil samples from Tebela and Sodo demonstrated fines contents ranging from 91.8 to 95.1 percent, liquid limits between 82.3 and 90.1 percent, plasticity indices of 50.3 to 54.0 percent, and free swell indices exceeding 100 percent. These properties placed every sample into the AASHTO A-7-5 group (group indices 54 to 62) and the USCS CH category. Unconfined compressive strength values (112 to

121 kPa) coupled with swelling pressures (145 to 170 kPa) point to moderate load capacity alongside significant swelling potential under confinement. The Boditi soils exhibited comparable plasticity but categorized as A-7-6, yielding low California Bearing Ratio values of 2.2 to 2.8 percent.

All findings were incorporated into an ArcGIS 10.8 file geodatabase, organized by municipality and test pit, and georeferenced over rectified aerial imagery within UTM Zone 37N. This system enables users to pull location-specific geotechnical values directly through a spatial map interface, transforming disconnected paper records into a centralized, searchable digital model. Given the relative uniformity of soil classifications across the study site, the primary practical benefit of the tool lies in identifying localized variations in swell severity rather than distinguishing broad soil types.

This methodology combining targeted field sampling, standard soil testing, spatial mapping, and structured geodatabase design offers an adaptable framework for any expanding urban area contending with expansive soil risks.

6. Recommendations

Building on the use of both primary and secondary data to demonstrate geotechnical data management, it is recommended that these results be utilized solely for preliminary design purposes. This research offers a solid framework for data storage and display; we encourage continued exploration and development of this methodology by subsequent researchers through:

- 1) Conducting comprehensive laboratory tests on secondary data, assuming responsibility for the accuracy of said data, and managing it using this ArcGIS-based approach.
- 2) Applying this method to real-world construction projects to enhance data accessibility and storage, addressing the current gap in practical application.
- 3) Implementing soil stabilization techniques, such as lime or cement treatment, and moisture control strategies in construction projects located within the high-expansive soil zones identified in Tebela, Sodo, and Boditi.
- 4) Continuously updating the GIS geodatabase with new geotechnical data to improve predictive accuracy and support informed decision-making processes.
- 5) Extending GIS-based expansive soil management practices to other regions facing similar soil challenges, to improve regional construction planning and risk management strategies.

Abbreviations

ArcGIS	Aeronautical Reconnaissance Coverage Geographical Information System
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society of Testing and Materials

CBR	California Bearing Ratio
CSA	Central Statistical Agency
FSI	Free Swell Index
GIS	Geographical Information System
GPS	Global Positioning System
Gs	Specific Gravity
GSE	Geology Survey of Ethiopia
MDD	Maximum Dry Density
NMC	Natural Moisture Content
OMC	Optimum Moisture Content
PL	Plastic Limit
UCS	Unconfined Compression Strength
UTM	Universal Transverse Mercator

Author Contributions

Ashenafi Bergene Balango: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft

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Conflict of Interest

The authors declare no conflicts of interest.

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