Mitigating Latent Land Conflicts in Ghana: The Role of Uniform Coordinate Systems

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ABSTRACT

Keywords: *Land conflicts, Coordinate discrepancies, Geospatial data accuracy, Continuously Operating Reference Stations (CORS), Global Navigation Satellite System (GNSS), Uniform coordinate system. International Terrestrial Reference Framework (ITRF)*

Land conflicts arising from boundary disputes pose a significant challenge in Ghana's land administration system. One major contributor to these conflicts and inconsistencies in geospatial data is the non-uniformity of beacon coordinates. The current Ghana National Grid coordinates, developed from historical triangulation and traverse measurements, introduce inconsistencies in the geodetic reference network. When these coordinates are assigned to Continuously Operating Reference Stations (CORS) in GNSS surveys, inaccuracies are propagated, eventually exacerbating land-related conflict. This study investigates the impact of non-uniform coordinate systems on geospatial data accuracy and its result in latent land conflicts in Ghana. GNSS survey campaigns were conducted, with initial data post-processing based on CORS in the current (Ghana National Grid) coordinate system. A "Uniform Coordinate" system was then developed by projecting uniform ITRF coordinates based on War Office and then WGS84 Datum and the data was processed with it. A third uniform coordinates called GTM2022 were obtained by directly projecting ITRF coordinates of CORS into the Ghana National Grid system using the Transverse Mercator projection. The field data was again re-processed based on these coordinates. The discrepancies between both post-processing results were analyzed. Results showed that using published local (Ghana National Grid) coordinates of CORS in post-processing introduces significant positional displacements, whereas transitioning to uniform coordinates improves data consistency and accuracy. This study advocates for public awareness campaigns, a transition to a uniform reference framework, a least squares adjustment harmonization, and policy revisions to enforce the use of

established uniform CORS for surveys, all aimed at mitigating latent land conflicts toward more effective land administration and resource management.

Mitigating Latent Land Conflicts in Ghana: The Role of Uniform Coordinate Systems

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1. Introduction

A land conflict is a dispute over property rights to land, involving at least two parties. Land conflicts often result from disagreements over land ownership, conflicting boundaries, and use rights (Hui and Bao, 2013). Many conflicts that lead to clashes between different cultures often start as conflicts over land and related natural resources (Collier, 2003). According to Wehrmann, (2008), boundary conflicts can occur between individuals over private lands, or between clans over their common property often due to oral narrative descriptions of boundaries without physically fixed boundaries. Drawing from (Wehrmann, 2008), conflicts result from multiple sales by families or by the wrong allocation of a land parcel by the land registration office due to technical shortcomings or corruption (Wehrmann, 2008). Technical causes may also include inaccurate boundary surveys, and sporadic land use planning not adapted or conforming to local conditions (Deininger, et. al, 2012). The Ghana National Land Policy has identified that one important cause of land disputes in Ghana is due to indeterminate boundaries of stool/skin lands resulting from the lack of reliable maps/plans (Obeng-Odoom, 2014). Most land conflicts in Ghana have been identified as significantly arising from disputes over land ownership, boundaries, and rights. One potential source of these conflicts that remains overlooked is the impact of non-uniform coordinate systems on geospatial data accuracy. Geospatial data is crucial for determining property boundary positions (Owusu-Ansah, & Chigbu, 2020). Geospatial data depends directly on Coordinate systems since these provide the framework for spatial referencing and location-based analysis (Burrough, et. al, 2015). The use of non-uniform coordinate systems can heighten land-related disputes by introducing inaccuracies and inconsistencies in geospatial data depending on which beacons were used to initiate a survey.

In Ghana, classical data for cadastral mapping has been based on terrestrial reference frames established through local observations which, though they were linked to each other in networks, still maintained local deviations and non-uniformities. The current reference network in Ghana is based on triangulation and traverse measurement campaigns made in Ghana in the 1900's. Due to a lack of computational resources at the time, the networks were divided into several separately adjusted triangulation nets making small deformations inescapable (Ayer & Fosu, 2008). Therefore, uniformity in the network as a whole could not be guaranteed. Further degradation of the framework accuracy has also been due to the results of lower order local surveys which were additionally often added as densified controls in the point coordinate database. Understanding the role of such non-uniform coordinate systems on land conflicts is thus essential for developing strategies to improve geospatial data accuracy and reduce land-related disputes.

An initiative to improve network quality involved establishing Continuously Operating Reference Stations (CORS) for differential GNSS surveys. CORS are reliable, consistent, and minimize distance-dependent errors, aligning well with global reference frames (Berber, 2022). However, in Ghana, local Grid coordinates assigned to CORS use nearby ground coordinates, which risks transferring existing non-uniformities into CORS coordinates. This research examines how such non-uniform systems impact geospatial data accuracy and potentially contribute to latent land conflicts. By conducting GNSS survey campaigns across various localities and processing data with different CORS, inconsistencies were revealed. To address these, a uniform system using Gauss-Krüger projection based on WGS84 was applied to analyze discrepancies.

2. Geospatial Data

Geospatial data refers to information that has a geographical or spatial component associated with it so is linked to specific locations on the Earth's surface. This linkage is done by assigning a unique pair or trio values to each position on the surface of the earth called its coordinates (Merodio Gómez, et. al., 2019). In a Smart City context, a relevant aspect is the provision of location and navigation-related services for users using geo-coordinates (Petcovici & Stroulia, 2016; Minetto et al., 2020). Geospatial data may be collected through classical field surveys, remote sensing, GNSS systems etc., and used for modeling, for exploration and to make future predictions, or investigate possible trends (Clarke et al., 2005). Global Navigation Satellite System (GNSS) is a contemporary source of geospatial data collection methodology and describes all the satellite systems that transmit signals for navigation to receivers. To enhance GNSS usage, Continuously Operating Reference Stations (CORS) networks are established to better support geodetic networks.

3. Coordinate Reference Frames for Geospatial Data

Positions are defined in relation to an extrinsic spatial reference frame called a coordinate system. Reference frames used to describe geospatial data are typically based on a spherical coordinate system since the earth is considered spherical. On this location are given in values of latitude, longitude, and elevation (Ayer, & Fosu, 2008). An Earth ellipsoid or Earth spheroid is the mathematical figure approximating the Earth's form. The ellipsoid is defined by its semi-major axis "a" and semi-minor axis "b" or its semi-major axis "a" and flattening "f" (Bossler, et. al., 2001). The relationship between a, b and f is shown in equation 1. The designation of the

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Geodetic Coordinate System (GCS), which uses latitude, longitude, and geometric height is shown in figure 1 (Hooijberg, 2012).

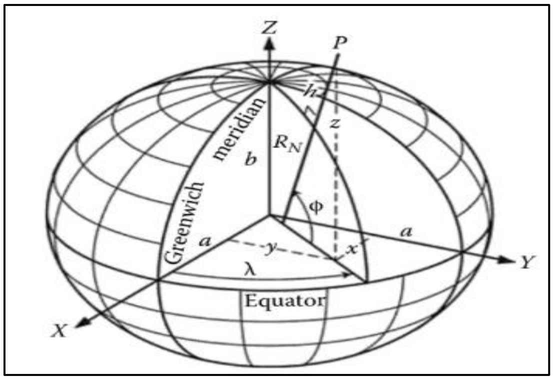

Fig 1. Ellipsoidal Coordinate Definition

$$f = \frac{a - b}{a} \qquad [Equation\ 1]$$

These set of geodetic coordinates are mathematically convertible to Cartesian X, Y, Z values relative to three orthogonal axes referenced to the geodetic center of the chosen ellipsoid called Earth fixed, Earth Centred (EFEC) Cartesian coordinates (Ayer, 2008; Ayer, & Tiennah, 2008). For purposes of Mapping, Projected or Grid Coordinates are defined. These are two-dimensional Easting and Northing values based on a mapping grid plane obtained by projecting the spherical coordinates onto a plane using a map projection methodology (Ayer, 2008; Annan, et. al., 2016). The projected coordinate system or grid reference system is a two-dimensional coordinate system used to represent positions on a flat surface such as a map surface. Each projected coordinate system is defined by a choice of map projection method, a choice of geodetic datum, and a choice of unit of measure (Maling, 2013). The commonest projection used for mapping is the Transverse Mercator type (Karney, 2011). Projected coordinates are Topocentric with the projection origin on the surface of the ellipsoid (Bremner, & Santos, 2019).

3.1 The International Terrestrial Reference Frame

The International Terrestrial Reference Frame (ITRF) is a global coordinate system used for accurately and consistently defining positions of points on the Earth's surface, as well as the orientation of the Earth in space. To ensure global compatibility and consistency between diverse geodetic data and measurements, terrestrial coordinate systems, and datums are defined as an intermediary for different systems (Altamimi, et. al., 2016). The World Geodetic System 1984 (WGS 84) ellipsoid developed and maintained by the National Geospatial Intelligence Agency (NGA) provides a common global reference realization and alignment with the ITRFs.

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3.2 Ghana Coordinate System for seamless Mapping

The Survey Department of Ghana established a nationwide control network for geodetic surveying, using triangulation in the south and precise traversing in the north (Botsyo et al., 2020). However, each triangulation and traverse network was adjusted separately, leading to inconsistencies in coordinate uniformity across the framework (Abukari et al., 2022). The geodetic framework used the War Office ellipsoid with parameters as follows: semi-major axis (a) = 20,926,201.2257 feet, semi-minor axis (b) = 20,855,504.6001 feet, flattening (f) = 1/296, and a conversion factor of 1 ft = 0.3047997062 meters (Ayer, 2008)

For cadastral mapping in Ghana, the adopted coordinate system is the Transverse Mercator Secant projection, also known as the Gauss-Krüger or Gauss conformal projection. This system uses a central meridian at 1°W of Greenwich, an origin latitude of 4˚ 40’ N, a false Northing of 0, and a false Easting of 900,000 feet (or 274,319.74 meters). Designed for integrating old and new surveys, it facilitates data sharing and maintains accuracy for large projects within a uniform reference frame. However, some scale distortions in the projection are inevitable, as illustrated in figure 2 (Canters, 2002).

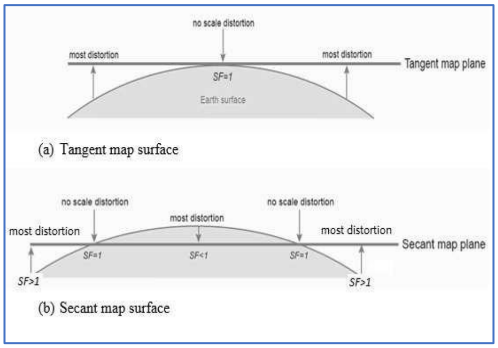

Fig. 2. Scale distortions on a tangent map surface (a). The central point is not distorted on the map. Scale distortions on a secant map surface (b). Line(s) of intersection are not distorted on the map (Georgiadou et al., 2001)

3.3 Challenges in the Ghana Coordinate Framework.

The Ghana Coordinate Framework faces challenges due to the lack of uniform adjustment, with the Survey Department relying on provisional coordinates that may distort accuracy over time. A key issue is that original coordinates were derived from astronomical observations and adopted as geodetic equivalents without correction, causing misalignment between the geoid and ellipsoid and leading to orientation errors across the network (Asante et al., 2023). To resolve these issues, updating and standardizing the geodetic data is essential for a reliable coordinate framework. The rise of GPS in geodetic surveys highlights the need for National Transformation Parameters to integrate 3D GPS coordinates seamlessly into the mapping system for improved cadastral mapping (Ayer & Fosu, 2008; Yevenyo Ziggah et al., 2016). However, inconsistencies in legacy

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coordinates lead to variable transformation parameters, as observed in previous studies (Yevenyo Ziggah et al., 2016).

3.4 Improving Geospatial Data accuracy through CORS

Using CORS for GPS survey data processing enhances data accuracy by allowing differential correction of GPS measurements with a CORS as the reference base. CORS networks, composed of permanent GNSS receivers, continuously broadcast high-precision positioning data, reducing surveying costs and fieldwork time through real-time corrections. While CORS provides consistent ITRF coordinates, the assigned local coordinates for national mapping may still exhibit non-uniformity, depending on the coordination approach (Abukari et al., 2022).

4. Materials and Methods for this study

The study is limited to a 100 km radius around each of three selected CORS used, which are LisagNet_Winneba, LisagNet_Spintex and LisagNet_Koforidua. Data for the project was collected from several locations of which some were Asikuma, Atimpoku, Koforidua, Suhum, Tontro, Krobo Odumasi, Odumase, Asuboe, Aburi, Awukugua, and Old Tafo.

4.1 Research Methodology

The research methodology, shown in Figure 3, involved conducting GNSS survey campaigns to collect data, and then post-processing the GPS data using various CORS as reference points with their published Ghana National Grid coordinates. The CORS ITRF coordinates were then projected into a local coordinate system based on the War Office ellipsoid and WGS84 Datum to create a uniform set of coordinates. This projected data was also used to process GPS data, and the results were referred to as Uniform Coordinates. The same CORS ITRF coordinates were projected directly to Ghana Grid coordinates based on the Transverse Mercator, this is referred to as GTM 2022. Statistical analysis was performed on the results. .

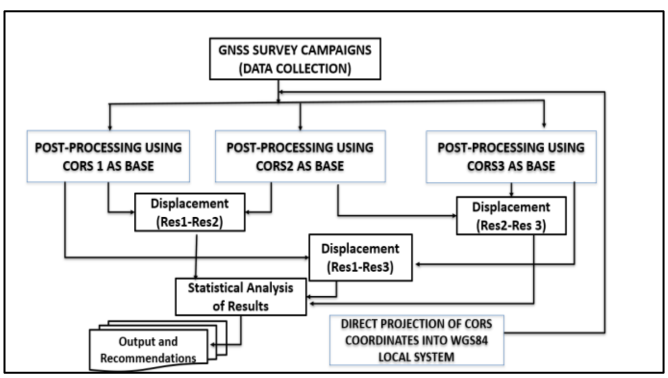

Fig. 3. Flow Chart of Research Work

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5. Results and Discussion

The three references used in this study are the LisagNet_Winneba, LisagNet_Spintex, and LisagNet_Koforidua in turns. Aside from using the published local coordinates of these CORS based on the Ghana National Grid, the ITRF Cartesian coordinates of each of the CORS, considered to be uniform, were obtained and projected to what is termed “Uniform Coordinates” based on the same Ghana ellipsoid using standard transformation parameter values and again into the proposed new GTM herein called “GTM2022” which is a projection based on WGS84 ellipsoid (Table 1). Table 2, shows the results obtained using the published local (Ghana National Grid) coordinates of LisagNet_Winneba, LisagNet_Spintex, and LisagNet_Koforidua as base station coordinates respectively. The linear displacement from each pair of results is also shown. The corresponding results based on each uniform coordinate are shown in Table 3 and Table 4 respectively. Based on the results obtained from our research, the displacement values based on the uniformly projected coordinates showed over 60% improvement in coordinate consistency than those from the published CORS coordinates by SMD. It is expected that, if these coordinates were further adjusted together through a least square or other optimization solution, the results would be further improved. The results nonetheless, confirm that there is the need to adopt some uniform coordinate system for all CORS to avoid conflicting positional fixes due to the choice or use of CORS in differential GNSS surveys for cadastral works.

Table 1 Different coordinates used in the study

Name of CORS	**SMD Published Values (ft)**		**Uniform Project Values (ft)**		**GTM2022 Values (ft.)**	
	Northing	**Easting**	**Northing**	**Easting**	**Northing**	**Easting**
Spintex	349990.456	1231445.473	349985.661	1231447.545	2043584.322	1643882.793
Winneba	250715.197	1033251.402	250715.761	1033251.266	1944313.598	1445688.716
Koforidua	522398.945	1153213.880	522398.687	1153215.684	2215995.444	1565650.154

As evidenced in the projected values, the Winneba CORS coordinate values appear consistent with the projected values followed by the Koforidua CORS which show a slight displacement in Eastings but the Spintex CORS coordinates show the greatest displacement in values.

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6 Table 2 Processed Surveyed Points using published local (Ghana National Grid) CORS coordinates

Name	Winneba		Spintex		Koforidua		Winneba /Spintex	Spintex / Koforidua	Winneba / Koforidua
	Northing	Easting	Northing	Easting	Northing	Easting	Displacement	Displacement	Displacement
Pt1	587709.742	1130037.994	587714.911	1130040.52	587712.228	1130038.639	5.753	3.277	2.568
Pt2	568405.043	1113569.747	568409.995	1113568.57	568407.447	1113570.043	5.090	2.943	2.422
Pt3	568237.882	1113527.554	568241.628	1113529.546	568240.307	1113529.666	4.243	1.326	3.216
Pt4	568289.097	1113326.023	568293.848	1113328.421	568291.568	1113328.072	5.322	2.307	3.210
Pt5	568388.786	1113358.067	568393.732	1113358.697	568391.068	1113360.185	4.986	3.051	3.113
Pt6	568355.016	1113453.697	568358.968	1113454.123	568357.291	1113454.301	3.975	1.686	2.354
Pt7	568433.51	1113468.331	568438.174	1113468.4	568435.89	1113469.053	4.665	2.376	2.487
Pt8	580747.564	1124524.876	580752.592	1124525.165	580750.294	1124524.69	5.036	2.347	2.736
Pt9	580861.115	1124596.835	580865.803	1124596.454	580863.473	1124597.14	4.703	2.429	2.378
Pt10	582276.41	1125534.226	582281.238	1125532.133	582278.672	1125536.073	5.262	4.702	2.920
Pt11	582399.977	1125368.279	582404.767	1125366.865	582401.944	1125369.164	4.994	3.641	2.157
Pt12	582688.183	1125874.837	582693.198	1125876.87	582689.444	1125873.35	5.411	5.146	1.950
Pt13	582390.741	1125707.713	582395.395	1125707.656	582393.317	1125710.668	4.654	3.659	3.920
Pt14	514677.727	1163277.202	514682.475	1163277.433	514679.974	1163278.329	4.754	2.657	2.514
Pt15	553268.401	1290937.02	553273.15	1290937.25	553270.648	1290938.146	4.755	2.658	2.513
Pt16	553233.583	1291028.112	553238.333	1291028.345	553235.672	1291031.565	4.756	4.177	4.036
Pt17	634477.59	1327216.552	634482.335	1327216.775	634479.835	1327217.674	4.750	2.657	2.510
Pt18	634426.312	1327242.493	634431.057	1327242.715	634428.557	1327243.614	4.750	2.657	2.509
Pt19	634400.782	1327141.438	634405.526	1327141.661	634403.026	1327142.558	4.749	2.656	2.508

Pt20	634444.506	1327127.429	634449.25	1327127.657	634446.75	1327128.553	4.749	2.656	2.510
Pt21	635143.915	1328437.185	635148.662	1328437.416	635146.162	1328438.311	4.753	2.655	2.513
Pt22	635185.541	1328574.569	635190.288	1328574.796	635187.787	1328575.693	4.752	2.657	2.512
Pt23	635006.374	1328664.842	635011.123	1328665.071	635008.621	1328665.968	4.755	2.658	2.513
Pt24	634968.101	1328532.259	634972.849	1328532.489	634970.348	1328533.385	4.754	2.657	2.513
Pt25	460577.774	1117031.004	460582.361	1117031.71	460579.037	1117032.293	4.641	3.375	1.805
Pt26	460477.279	1117059.435	460482.015	1117059.643	460479.386	1117060.678	4.741	2.825	2.446
Pt27	511422.538	1176727.073	511416.056	1176727.731	511413.685	1176727.142	6.515	2.443	8.853
Pt28	511383.439	1176694.315	511376.65	1176694.161	511374.419	1176693.323	6.791	2.383	9.074
Pt29	527781.244	1169922.758	527785.784	1169920.316	527784.115	1169924.999	5.155	4.972	3.642
Pt30	516286.071	1170356.095	516290.379	1170357.259	516287.232	1170357.501	4.462	3.156	1.823
Pt31	531297.495	1263970.473	531302.263	1263970.747	531299.757	1263971.646	4.776	2.662	2.548
Pt32	512857.17	1168031.626	512862.132	1168030.841	512859.341	1168032.056	5.024	3.044	2.213
Pt33	510408.789	1166259.839	510413.609	1166256.797	510411.011	1166261.300	5.700	5.199	2.659
Pt34	510273.659	1166218.529	510277.811	1166214.205	510275.202	1166219.482	5.995	5.887	1.814
Pt35	509114.36	1166339.662	509120.223	1166340.086	509117.626	1166340.894	5.878	2.720	3.491
Pt36	509031.269	1166344.642	509036.503	1166341.897	509033.595	1166345.961	5.910	4.997	2.674
Pt37	508476.725	1164889.22	508483.37	1164891.85	508478.718	1164889.697	7.147	5.126	2.049
Pt38	508405.891	1164735.908	508410.474	1164734.962	508407.656	1164735.909	4.680	2.973	1.765
Pt39	508452.784	1164715.78	508458.07	1164716.436	508455.427	1164717.523	5.327	2.858	3.166
Pt40	480040.148	1233891.259	480045.004	1233893.831	480042.42	1233892.343	5.495	2.982	2.517
Pt41	480029.222	1233938.189	480034.016	1233938.383	480031.494	1233939.272	4.798	2.674	2.517
Pt42	480103.719	1233957.356	480109.13	1233958.028	480105.99	1233958.439	5.453	3.167	2.516

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Pt43	557812.214	1293640.168	557818.968	1293641.806	557816.668	1293642.275	6.950	2.347	4.927
Pt44	557567.836	1293573.681	557572.457	1293574.282	557569.709	1293575.344	4.660	2.946	2.505
Pt45	557582.037	1293501.627	557586.641	1293498.552	557583.892	1293499.613	5.536	2.947	2.738
Pt46	557814.738	1293528.572	557820.155	1293528.411	557817.398	1293529.422	5.419	2.937	2.793
Pt47	557675.342	1293507.796	557681.698	1293502.261	557678.493	1293505.478	8.428	4.541	3.912
Pt48	514677.728	1163277.192	514682.478	1163277.429	514679.975	1163278.326	4.756	2.659	2.517
Pt49	514677.739	1163277.216	514682.492	1163277.434	514679.981	1163278.332	4.758	2.667	2.504
Pt50	510288.256	1172202.982	510293.009	1172203.199	510290.498	1172204.097	4.758	2.667	2.504
Pt51	510876.964	1173230.298	510881.744	1173230.551	510879.205	1173231.42	4.787	2.684	2.506
Pt52	510896.785	1172245.841	510901.536	1172246.065	510899.025	1172246.962	4.756	2.666	2.505
Pt53	504578.587	1171695.784	504583.872	1171695.455	504581.205	1171695.063	5.295	2.696	2.715
Pt54	504520.152	1171618.843	504524.943	1171616.553	504522.619	1171617.122	5.310	2.393	3.008
Pt55	504613.168	1171657.674	504617.548	1171660.861	504615.662	1171659.833	5.417	2.148	3.299
Pt56	504476.668	1171669.895	504480.723	1171671.175	504478.814	1171670.07	4.252	2.206	2.153
Pt57	456730.563	1191539.879	456735.52	1191539.98	456732.82	1191540.9	4.958	2.852	2.477
Pt58	456571.819	1191334.727	456576.482	1191336.32	456573.837	1191337.248	4.928	2.803	3.229
Pt59	456752.618	1191188.097	456757.153	1191188.426	456754.48	1191189.415	4.547	2.850	2.281
Pt60	456921.655	1191344.069	456926.19	1191344.399	456923.505	1191345.348	4.547	2.848	2.249
Pt61	723514.794	694433.914	723519.541	694434.163	723517.067	694435.011	4.754	2.615	2.524
Pt62	723594.567	694423.64	723599.314	694423.89	723596.84	694424.738	4.754	2.615	2.524
Pt63	723587.494	694355.192	723592.201	694355.408	723589.74	694356.266	4.712	2.606	2.490
Pt64	723520.069	694358.234	723524.919	694357.993	723522.375	694359.257	4.856	2.841	2.523
Pt65	723583.641	694296.63	723588.409	694296.854	723585.916	694297.713	4.773	2.637	2.520

Pt66	723520.867	694282.628	723525.65	694282.899	723523.18	694283.747	4.791	2.612	2.569
							Min = 3.975	Min = 1.326	Min = 1.765
							Max = 8.428	Max = 5.887	Max= 9.074
							AVG= 5.115	AVG = 3.013	AVG=2.850
							STDV=0.736	STDV=0.877	STDV=1.220

As revealed in table 2, coordinates obtained using the Winneba and Spintex, CORS show positional displacements of between 3.98ft and 8.43ft. These findings reveal significant displacements which may show up as latent overlaps in boundaries resulting from surveys based differently on them. These observed displacements raise questions about the uniformity and the accuracy of the CORS reference stations local coordinates. Comparing Koforidua and Winneba coordinates positional displacements of 1.77 feet to 9.07 feet, whereas a comparison of Spintex and Koforidua show displacements of 1.33 feet to 5.89 feet. These results confirm the non-uniformity in the coordinates of the three CORS coordinates published and confirm that, the significant displacements obtained could generate boundary overlaps, which could lead to conflicts.

Table 3 Processed Surveyed Points using Uniform Coordinates

Name	**Winneba**		**Spintex**		**Koforidua**		**Winneba /Spintex**	**Spintex /Koforidua**	**Winneba /Koforidua**
	Northing	**Easting**	**Northing**	**Easting**	**Northing**	**Easting**	**Displ.**	**Displ.**	**Displ.**
Pt1	587710.300	1130037.856	587710.103	1130042.595	587711.981	1130040.443	4.743	2.856	3.085
Pt2	568405.602	1113569.609	568405.184	1113570.658	568407.2	1113571.848	1.129	2.341	2.751
Pt3	568238.442	1113527.416	568236.816	1113531.634	568240.06	1113531.471	4.521	3.248	4.366

Pt4	568289.657	1113325.887	568289.037	1113330.507	568291.32	1113329.877	4.661	2.368	4.323
Pt5	568389.345	1113357.93	568388.922	1113360.787	568390.821	1113361.99	2.888	2.248	4.320
Pt6	568355.575	1113453.561	568354.157	1113456.208	568357.044	1113456.106	3.003	2.889	2.939
Pt7	568434.069	1113468.194	568433.363	1113470.484	568435.643	1113470.858	2.396	2.310	3.094
Pt8	580748.123	1124524.739	580747.779	1124527.237	580750.047	1124526.495	2.522	2.386	2.605
Pt9	580861.674	1124596.698	580860.993	1124598.526	580863.325	1124599.035	1.951	2.387	2.861
Pt10	582276.97	1125534.091	582276.426	1125534.2	582278.425	1125537.879	0.555	4.187	4.058
Pt11	582400.536	1125368.143	582399.956	1125368.928	582401.697	1125370.969	0.976	2.683	3.055
Pt12	582688.742	1125874.701	582688.39	1125878.966	582689.197	1125875.155	4.280	3.896	0.643
Pt13	582391.3	1125707.577	582390.587	1125709.727	582393.07	1125712.473	2.265	3.702	5.206
Pt14	514678.286	1163277.066	514677.666	1163279.503	514679.727	1163280.134	2.515	2.155	3.390
Pt15	553268.96	1290936.884	553268.339	1290939.321	553270.401	1290939.951	2.515	2.156	3.389
Pt16	553234.142	1291027.976	553233.521	1291030.413	553235.425	1291033.37	2.515	3.517	5.544
Pt17	634478.149	1327216.415	634477.527	1327218.852	634479.587	1327219.479	2.515	2.153	3.385
Pt18	634426.871	1327242.356	634426.249	1327244.793	634428.309	1327245.419	2.515	2.153	3.384
Pt19	634401.341	1327141.301	634400.718	1327143.734	634402.778	1327144.362	2.511	2.154	3.382
Pt20	634445.064	1327127.293	634444.443	1327129.729	634446.502	1327130.358	2.514	2.153	3.386
Pt21	635144.474	1328437.049	635143.854	1328439.486	635145.915	1328440.116	2.515	2.155	3.389
Pt22	635186.099	1328574.433	635185.479	1328576.868	635187.541	1328577.496	2.513	2.156	3.385
Pt23	635006.933	1328664.706	635006.313	1328667.143	635008.374	1328667.773	2.515	2.155	3.389
Pt24	634968.66	1328532.123	634968.041	1328534.559	634970.102	1328535.189	2.513	2.155	3.388
Pt25	460578.333	1117030.868	460577.551	1117033.781	460578.789	1117034.098	3.016	1.278	3.262
Pt26	460477.838	1117059.3	460477.206	1117061.714	460479.138	1117062.483	2.495	2.079	3.438

Pt27	511411.747	1176725.716	511411.244	1176729.81	511413.438	1176728.947	4.125	2.358	3.647
Pt28	511371.891	1176696.393	511371.84	1176696.234	511374.172	1176695.128	0.167	2.581	2.608
Pt29	527781.802	1169922.624	527780.976	1169922.361	527783.868	1169926.804	0.867	5.301	4.663
Pt30	516286.629	1170355.957	516285.579	1170359.333	516286.984	1170359.306	3.536	1.405	3.368
Pt31	531298.057	1263970.341	531297.452	1263972.817	531299.509	1263973.451	2.549	2.152	3.432
Pt32	512857.729	1168031.489	512857.324	1168032.913	512859.094	1168033.861	1.480	2.008	2.737
Pt33	510409.348	1166259.704	510408.799	1166258.869	510410.764	1166263.105	0.999	4.670	3.684
Pt34	510274.218	1166218.393	510273.001	1166216.277	510274.955	1166221.287	2.441	5.378	2.986
Pt35	509114.919	1166339.526	509115.412	1166342.157	509117.378	1166342.699	2.677	2.039	4.014
Pt36	509031.828	1166344.506	509031.693	1166343.972	509033.348	1166347.766	0.551	4.139	3.597
Pt37	508477.284	1164889.083	508478.57	1164893.918	508478.47	1164891.502	5.003	2.418	2.694
Pt38	508406.449	1164735.77	508405.674	1164737.03	508407.409	1164737.714	1.479	1.865	2.168
Pt39	508453.343	1164715.645	508453.27	1164718.504	508455.18	1164719.328	2.860	2.080	4.116
Pt40	480040.707	1233891.123	480040.194	1233895.902	480042.173	1233894.15	4.806	2.643	3.363
Pt41	480029.781	1233938.053	480029.206	1233940.451	480031.247	1233941.077	2.466	2.135	3.361
Pt42	480104.278	1233957.219	480104.321	1233960.1	480105.743	1233960.244	2.881	1.429	3.361
Pt43	557812.773	1293640.032	557814.16	1293643.876	557816.421	1293644.08	4.087	2.270	5.449
Pt44	557568.395	1293573.545	557568.088	1293577.638	557569.461	1293577.149	4.104	1.457	3.758
Pt45	557582.596	1293501.49	557581.53	1293501.124	557583.644	1293501.418	1.127	2.134	1.050
Pt46	557815.296	1293528.436	557814.85	1293533.423	557817.15	1293531.227	5.007	3.180	3.351
Pt47	557675.901	1293507.66	557676.888	1293504.328	557678.245	1293507.282	3.475	3.251	2.374
Pt48	514678.287	1163277.056	514677.668	1163279.5	514679.727	1163280.131	2.521	2.154	3.395
Pt49	514678.298	1163277.079	514677.683	1163279.505	514679.734	1163280.137	2.503	2.146	3.378

Pt50	510288.814	1172202.846	510288.2	1172205.27	510290.251	1172205.901	2.501	2.146	3.376
Pt51	510877.523	1173230.162	510876.934	1173232.624	510878.957	1173233.225	2.531	2.110	3.382
Pt52	510897.344	1172245.705	510896.727	1172248.136	510898.778	1172248.767	2.508	2.146	3.381
Pt53	504579.146	1171695.648	504579.064	1171697.535	504580.958	1171696.868	1.889	2.008	2.184
Pt54	504520.711	1171618.706	504520.133	1171618.624	504522.372	1171618.927	0.584	2.259	1.676
Pt55	504613.727	1171657.537	504612.736	1171662.938	504615.415	1171661.638	5.491	2.978	4.435
Pt56	504477.227	1171669.759	504475.913	1171673.252	504478.566	1171671.876	3.732	2.989	2.505
Pt57	456731.122	1191539.742	456730.713	1191542.044	456731.122	1191539.742	2.338	2.338	0.000
Pt58	456572.378	1191334.59	456571.74	1191338.376	456572.378	1191334.59	3.839	3.839	0.000
Pt59	456753.177	1191187.96	456752.34	1191190.498	456753.177	1191187.96	2.672	2.672	0.000
Pt60	456921.716	1191347.849	456921.376	1191346.471	456921.716	1191347.849	1.419	1.419	0.000
Pt61	723515.383	694433.579	723514.723	694436.242	723516.82	694436.814	2.744	2.174	3.540
Pt62	723595.156	694423.306	723594.496	694425.968	723596.593	694426.541	2.743	2.174	3.540
Pt63	723588.05	694355.055	723587.389	694357.483	723589.474	694358.078	2.516	2.168	3.342
Pt64	723520.628	694358.098	723519.91	694359.871	723522.127	694361.058	1.913	2.515	3.318
Pt65	723584.199	694296.495	723583.606	694298.911	723585.668	694299.518	2.488	2.149	3.361
Pt66	723521.426	694282.493	723520.857	694284.925	723522.932	694285.552	2.498	2.168	3.410
							Min=0.167	Min=1.2718	Min=0.000
							Max=5.491	Max =5.378	Max = 5.544
							AVG=2.654	AVG =2.536	AVG =3.143
							STDV=1.167	STDV=0.837	STDV=1.147

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The results indicate displacements ranging from 0.17 to 5.49 feet between SpinTex/Winneba, 1.27 to 5.38 feet between SpinTex/Koforidua, and 0.00 to 5.54 feet between Winneba/Koforidua. Most positions show displacements under 5 feet, with over a third below 2 feet, marking a significant improvement over using the published CORS local coordinates.

Table 4 Processed Surveyed Points using GTM2022 Coordinates

Name	Winneba		Spintex		Koforidua		Winneba /Spintex	Spintex /Koforidua	Winneba /Koforidua
	Northing	Easting	Northing	Easting	Northing	Easting	Displ.	Displ.	Displ.
Pt1	2281308.164	1542475.224	2281308.688	1542477.705	2281308.67	1542474.886	2.536	2.819	0.609
Pt2	2262003.513	1526007.003	2262003.814	1526005.767	2262003.927	1526006.303	1.272	0.548	0.813
Pt3	2261836.352	1525964.801	2261835.447	1525966.744	2261836.787	1525965.927	2.143	1.569	1.207
Pt4	2261887.566	1525763.289	2261887.666	1525765.623	2261888.047	1525764.332	2.336	1.346	1.149
Pt5	2261987.253	1525795.332	2261987.55	1525795.897	2261987.536	1525796.451	0.638	0.554	1.154
Pt6	2261953.484	1525890.982	2261952.786	1525891.328	2261953.771	1525890.561	0.779	1.248	0.51
Pt7	2262031.975	1525905.607	2262031.991	1525905.604	2262032.37	1525905.313	0.016	0.478	0.492
Pt8	2274346.021	1536962.121	2274346.406	1536962.359	2274346.767	1536960.947	0.453	1.457	1.391
Pt9	2274459.575	1537034.082	2274459.617	1537033.65	2274460.051	1537033.485	0.434	0.464	0.764
Pt10	2275874.885	1537971.534	2275875.057	1537969.336	2275875.151	1537972.324	2.205	2.989	0.834
Pt11	2275998.443	1537805.534	2275998.586	1537804.072	2275998.424	1537805.421	1.469	1.359	0.115
Pt12	2276286.532	1538312.222	2276287.016	1538314.067	2276285.927	1538309.594	1.907	4.604	2.697
Pt13	2275989.207	1538144.968	2275989.212	1538144.847	2275989.796	1538146.922	0.121	2.156	2.041
Pt14	2208276.221	1575714.481	2208276.32	1575714.655	2208276.482	1575714.606	0.200	0.169	0.289
Pt15	2246866.989	1703374.274	2246867.087	1703374.447	2246867.249	1703374.399	0.199	0.169	0.288
Pt16	2246832.172	1703465.372	2246832.27	1703465.546	2246832.273	1703467.818	0.200	2.272	2.448

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Pt17	2328076.173	1739653.725	2328076.271	1739653.898	2328076.434	1739653.85	0.199	0.170	0.289
Pt18	2328024.895	1739679.664	2328024.993	1739679.838	2328025.156	1739679.79	0.200	0.170	0.29
Pt19	2327999.366	1739578.616	2327999.463	1739578.786	2327999.626	1739578.738	0.196	0.170	0.287
Pt20	2328043.088	1739564.609	2328043.186	1739564.783	2328043.349	1739564.735	0.200	0.170	0.290
Pt21	2328742.504	1740874.37	2328742.603	1740874.544	2328742.765	1740874.496	0.200	0.169	0.290
Pt22	2328784.131	1741011.747	2328784.229	1741011.92	2328784.392	1741011.872	0.199	0.170	0.289
Pt23	2328604.965	1741102.025	2328605.064	1741102.198	2328605.226	1741102.15	0.199	0.169	0.289
Pt24	2328566.692	1740969.444	2328566.79	1740969.617	2328566.953	1740969.57	0.199	0.170	0.290
Pt25	2154176.259	1529468.291	2154176.199	1529468.95	2154175.539	1529468.589	0.662	0.752	0.779
Pt26	2154075.768	1529496.737	2154075.854	1529496.885	2154075.887	1529496.974	0.171	0.095	0.265
Pt27	2205009.676	1589163.154	2205009.897	1589164.956	2205010.188	1589163.421	1.816	1.562	0.577
Pt28	2204970.580	1589130.387	2204970.491	1589131.384	2204970.923	1589129.601	1.001	1.835	0.858
Pt29	2221379.726	1582360.032	2221379.623	1582357.54	2221380.619	1582361.27	2.494	3.861	1.526
Pt30	2209884.563	1582793.354	2209884.221	1582794.474	2209883.741	1582793.777	1.171	0.846	0.924
Pt31	2224896.061	1676407.745	2224896.177	1676407.959	2224896.332	1676407.914	0.243	0.161	0.319
Pt32	2206455.665	1580468.896	2206455.979	1580468.063	2206455.851	1580468.335	0.890	0.301	0.591
Pt33	2204007.284	1578697.135	2204007.454	1578694.022	2204007.519	1578697.58	3.118	3.559	0.503
Pt34	2203872.152	1578655.814	2203871.657	1578651.429	2203871.71	1578655.763	4.413	4.334	0.445
Pt35	2202712.856	1578776.953	2202714.068	1578777.312	2202714.134	1578777.174	1.264	0.153	1.297
Pt36	2202629.762	1578781.931	2202630.348	1578779.12	2202630.102	1578782.238	2.871	3.128	0.458
Pt37	2202075.216	1577326.5	2202077.206	1577329.068	2202075.227	1577325.977	3.249	3.670	0.523
Pt38	2202004.377	1577173.161	2202004.31	1577172.18	2202004.166	1577172.189	0.983	0.144	0.995
Pt39	2202051.283	1577153.081	2202051.906	1577153.654	2202051.936	1577153.802	0.846	0.151	0.973
Pt40	2173638.637	1646328.558	2173638.842	1646331.069	2173638.921	1646328.641	2.519	2.429	0.296

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Pt41	2173627.711	1646375.487	2173627.854	1646375.623	2173627.996	1646375.57	0.197	0.152	0.297
Pt42	2173702.207	1646394.652	2173702.967	1646395.267	2173702.491	1646394.736	0.978	0.713	0.296
Pt43	2251410.803	1706077.419	2251412.904	1706078.998	2251413.268	1706078.516	2.628	0.604	2.698
Pt44	2251166.403	1706010.938	2251166.834	1706012.761	2251166.309	1706011.593	1.873	1.281	0.662
Pt45	2251180.624	1705938.866	2251180.276	1705936.246	2251180.491	1705935.862	2.643	0.44	3.007
Pt46	2251413.325	1705965.82	2251413.597	1705968.546	2251413.998	1705965.67	2.740	2.904	0.69
Pt48	2208276.221	1575714.471	2208276.323	1575714.651	2208276.482	1575714.603	0.207	0.166	0.292
Pt49	2208276.229	1575714.493	2208276.336	1575714.656	2208276.489	1575714.609	0.195	0.16	0.285
Pt50	2203886.747	1584640.261	2203886.854	1584640.422	2203887.007	1584640.376	0.193	0.16	0.284
Pt51	2204475.455	1585667.577	2204475.588	1585667.774	2204475.713	1585667.699	0.238	0.146	0.285
Pt52	2204495.276	1584683.12	2204495.381	1584683.288	2204495.533	1584683.241	0.198	0.159	0.284
Pt53	2198177.086	1584133.069	2198177.72	1584132.676	2198177.716	1584131.345	0.746	1.331	1.836
Pt54	2198118.649	1584056.123	2198118.792	1584053.779	2198119.13	1584053.404	2.348	0.505	2.761
Pt55	2198211.667	1584094.951	2198211.397	1584098.085	2198212.173	1584096.115	3.146	2.117	1.269
Pt56	2198075.171	1584107.182	2198074.573	1584108.399	2198075.325	1584106.352	1.356	2.181	0.844
Pt57	2150329.061	1603977.186	2150329.37	1603977.229	2150329.335	1603977.201	0.312	0.045	0.274
Pt58	2150170.318	1603772.032	2150170.334	1603773.569	2150170.349	1603773.554	1.537	0.021	1.522
Pt59	2150351.116	1603625.401	2150350.895	1603625.78	2150350.992	1603625.72	0.439	0.114	0.342
Pt60	2150520.155	1603781.374	2150519.933	1603781.753	2150520.018	1603781.653	0.439	0.131	0.311
Pt61	2417113.306	1106871.41	2417113.381	1106871.379	2417113.57	1106871.415	0.081	0.192	0.264
Pt62	2417193.024	1106861.074	2417193.154	1106861.105	2417193.343	1106861.142	0.134	0.193	0.326
Pt63	2417185.956	1106792.607	2417186.04	1106792.762	2417186.225	1106792.68	0.176	0.202	0.279
Pt64	2417118.574	1106795.65	2417118.487	1106795.167	2417118.837	1106795.72	0.491	0.654	0.272
Pt65	2417182.129	1106734.053	2417182.119	1106734.424	2417182.416	1106734.13	0.371	0.418	0.297

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Pt66	2417119.350	1106720.07	2417119.487	1106720.253	2417119.68	1106720.166	0.229	0.212	0.344
							Min=0.016	Min=0.021	Min=0.115
							Max=4.413	Max=4.604	Max=3.007
							Avg=1.079	Avg=1.042	Avg=0.776
							StDev=1.069	StDev=1.216	StDev=0.710

The GTM2022 results in Table 4 show similar performance in terms of consistency as that of the Uniform System in Table 3. The maximum displacement in this instance is 4.604 feet with most points having displacements of less than 2 feet. These results show more consistency than the results obtained using the published local coordinates in Table 2 and the results of the Uniform coordinates in Table 3. The results therefore buttresses the need for what concerned authorities in Ghana has proposed – the enhancement or creation of new coordinate system for cadastral surveying to deal with the current inconsistencies in the existing system and also to make data portability and integration easier and error-free. This new proposal is what is implemented under GTM2022 and as seen from the results, the use of such projection system would reduce complete displacements of coordinates. The GTM2022 coordinates largely have removed coordinate inconsistencies but some research is still necessary to completely remove distortions introduced by projection methodology.

6. Conclusions and Recommendations

The study concludes that the published coordinates of the CORS in Ghana by SMD, to which most GNSS surveys is referenced could still produce positional displacements depending on which CORS station is used for a study due to the non-uniformity of these published values. Improving geospatial accuracy and seamless integration, a first step should be aimed at improving the uniformity of controls. This research revealed that survey campaigns processed using GNSS revealed significant disparities in coordinates obtained from different CORS stations. The differences were particularly evident when using the published local coordinates of the CORS indicating the presence of non-uniformity in the current coordinate systems used for geospatial data collection in Ghana. Observed positional discrepancies indicate the potential for these discrepancies to contribute to boundary overlaps and conflicts in land ownership. The fact that these discrepancies may remain unnoticed because they are not the result of poor surveys until legal challenges of ownership arise, presents a technical challenge in dispute resolution because of Positional Inconsistencies instead of positional accuracies.

The implementation of a Uniform system may be achieved by a direct projection of the CORS' ITRF coordinates since the ITRF coordinates themselves are uniform. This reduced positional displacements by some 60% compared to the results obtained using the published coordinates. This suggests that adopting a uniform coordinate system has the potential to mitigate the inconsistencies and inaccuracies in geospatial data, thereby reducing the likelihood of land conflicts arising from coordinate discrepancies. This approach can help improve the country's cadastral system.

It is recommended that to address the issue of inconsistencies in geospatial data caused by non-uniform coordinates in Ghana's geospatial data infrastructure, a transition to a uniform system that ensures consistency across reference points and minimizes discrepancies in positioning should be adopted. This transition should be accompanied by comprehensive training for surveyors, land administrators, and policymakers to ensure the accurate and consistent implementation of the new coordinate system. It is also important that once, a uniform CORS is adopted as a reference frame, there must be compelling legislation so it becomes the only standard form of Geospatial data collection for uniformity and consistency. The existing noise that might still be present in the processed uniform coordinates may need to be cancelled through a least square adjustment harmonization of CORS coordinates. As this work was only limited to three CORS, it is expected that even large discrepancies may be present in other parts of the country outside what this scope has covered.

Data Availability Statement

Some or all data that support the findings of this study are available from the corresponding author upon reasonable request. These include CORS station GPS data, GPS data from the study area, and documents of Ghana's Survey and Mapping Division's published coordinates.

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