Positional Accuracy Assessment for Effective Shoreline Change Analyses*

C. B. Boye, K. Appeaning Addo and E. A. Williams

Abstract

The usefulness of any geographic data depends on its fitness for a particular purpose. The critical measure of that fitness is referred to as data quality. Data quality may be expressed in terms of several indicators such as attributes, temporal or positional accuracies. In this research, positional accuracy assessment was carried out on two datasets using Root Mean Square Error (RMSE) technique. Coordinates of nineteen ground controls points were measured in the field using Differential Global Positioning System technique which served as a reference base. The coordinates of these points were compared with their corresponding positions extracted from the two datasets, Town Sheet (1: 2500) and orthophoto (1: 5000). The Town Sheet was scanned, rescaled (1:5000) and georeferenced in Ghana Meter Grid coordinate system to conform to the orthophoto. The digitised Town Sheet and the reference base were superimposed with the orthophoto serving as backdrop in GIS environment. Positional error of 1.23 m was obtained for points extracted from the Town Sheet, while an error of 2.79 m was registered for points from the orthophoto. Shoreline features extracted from these two datasets and appended for shoreline change analysis recorded a total positional error of 3.98 m. The study has shown that the original scale (large) of the Town Sheet may have contributed significantly to the quality of data extracted. In the orthophoto, though geometrically rectified, the scale representation of a unit measure on the photo explains the uncertainties in the dataset. The integrated dataset obviously bore the cumulative effect of the input datasets. It is concluded that for the purpose of shoreline change analysis, such as shoreline change trends, large scale data sources should be used where possible for accurate decision-making. It is recommended that the positional accuracy of any spatial data be ascertained before using it to support decision.

Keywords: Positional Accuracy, Shoreline Change, Differential GPS, Root Mean Squared Error, Orthophoto

1 Introduction

Spatio-temporal data deal with geographic features which change geometry over a period of time (Erwig *et al.*, 1999). Strictly speaking, all physical features on the surface of the earth (e.g. rivers, forest etc.) fall within this category due to plate tectonic movements. In practice, however, such changes in geometry over a time period are assumed to be negligible compared to those recorded in some features such as shoreline which changes its location over relatively shorter period of time due to factors like tides, storm or climate change.

The shoreline, which is the interface between land and water (Boak and Turner, 2005), is swayed by several factors but it serves as a good indicator to coastal erosion (Srivastava *et al.*, 2005). Erosion of the coast is a worldwide challenge attributed mainly to sea-level rise, change in storm climate (Nicholls *et al.*, 2010; Zhang, 2004) and human interference with coastal processes. Since most of these causative factors are dependent on physical processes and human induced climate change, averting the trend is often difficult. An alternate solution could be achieved through numerical modelling, which enables future shoreline change trend to be predicted. The prediction of shoreline change trend is crucial for coastal management and infrastructural development.

Positional accuracy assessment is an important method of evaluating the quality of spatial dataset (Girres and Touga, 2010). It determines how closely the positions of discrete objects or features are compared to their actual locations on ground (Congalton and Green, 2008). Effective resource mapping requires accurate maps or at least maps of known accuracy. Earlier studies attest to this fact. Potere (2008), for instance, tested for positional accuracy of Landsat Geocover dataset using 436 control points located in 109 cities; Becek and Ibrahim (2011) estimated the positional accuracy of runways compiled from multiples sources using 2045 controls. Other useful studies have been carried out in this respect in other parts of the world (Yousefzadeh and Mojaradi, 2012; Naji *et al.*, 2013; Pujotomo and Sudibyakto, 2009). Although the positional accuracies of individual datasets are assessed, the total uncertainties of the integrated data are rarely determined.

This research used Root Mean Square Error (RMSE) technique to assess the horizontal accuracy associated with individual input datasets as well as determine the uncertainties in the integrated dataset.

2 Resources and Methods Used

Sekondi-Takoradi, the administrative capital of the Western Region of Ghana, is the study area (Fig. 1). It lies between latitude 01° 46'W and longitude 4° 55'N and has elevation range not exceeding 100 m above mean sea level. It has a land area of 385 km^2 and is strategically located in the South-Western part of Ghana, about 242 kilometers to the West of Accra, the capital city. It is also approximately 280 kilometers from the La Cote d'Ivoire border in the West. It is surrounded by Mpoho-Wassa East District Assembly on the north, Gulf of Guinea on the south, Shama District Assembly on the East and Ahanta West District on the West (Anon., 2006).

Data used for the study comprises a Town Sheet of scale 1:2500 produced in 1992, a rectified aerial orthophoto of scale 1:5000 taken in 2005 obtained from the Survey and Mapping Division of the Lands Commission (Ghana), and GPS measurement of ground controls - adopting the differential GPS technique. The leap frog method was used in the traverse over the nineteen (19) ground controls points and the data was post processed using the Spectrum Survey Software. For the assessment of planimetric positional errors of each data, the coordinates of the controls, which were clearly visible in both the Town Sheet and the orthophoto were extracted and their corresponding coordinates compared with those of the GPS observation. Assuming negligible errors in the post processed GPS data (i.e. reference base data), the positional accuracy of each dataset was assessed by the RMSE technique. The technique allows comparison between coordinates of ground controls points extracted from maps, orthophoto etc., and those of their responding reference base data (Farah and Agarni, 2014; Anon., 1998; Paredes-Harnandex *et al.*, 2013). The RMSE of the X and Y coordinates of any point P as well as the RMSE of the position are given in Equations 1-3.

$$RMSE_x = \sqrt{\frac{(X_{data\,i} - X_{ref\,data\,i})^2}{n}} \qquad \text{Eqn 1}$$

$$RMSE_Y = \sqrt{\frac{(Y_{data\,i} - Y_{ref\,data\,i})^2}{n}} \qquad \text{Eqn 2}$$

$$RMSE_P = \sqrt{(RMSE_X)^2 + (RMSE_Y)^2} \qquad \text{Eqn 3}$$

where data i is the coordinates of the ith extracted point from the map or orthophoto and ref data i is the coordinates of the responding ith coordinates of point measured from the field.

For effective data integration, the Town Sheet was scanned, rescaled to 1:5000 and georeferenced in Ghana Meter Grid (GMG) coordinate system to conform to that of the orthophoto. The digitized Town Sheet layer and the reference base point data layer were displayed together with the orthophoto serving as a backdrop in a GIS environment. The deviations of the coordinates were computed applying the RMSE Equations for the eastings, northings and the overall positional accuracy. By similar analysis, the positional errors inherent in the integrated data (such as shorelines) from these two data sources were also evaluated and analysed. The RMSE technique was used because it is simple to understand and also gives an indication of the data quality used therefore a measure of goodness of fit.
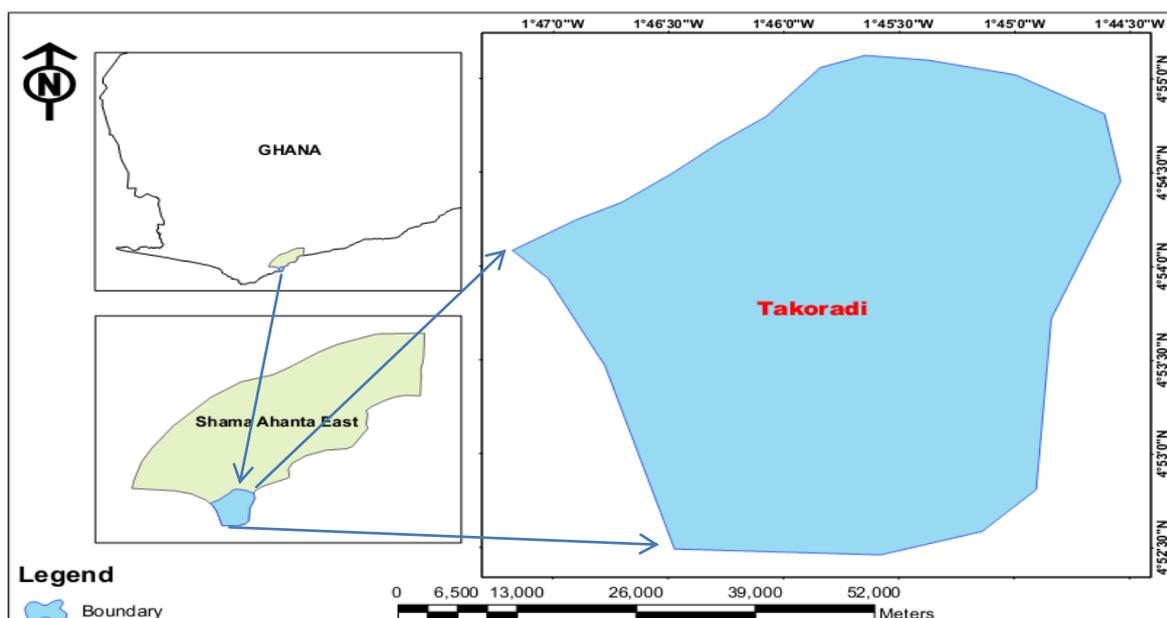

Fig. 1 Map of the Study Area

3 Results and Discussion

The shifts in coordinates of the extracted points from the Town Sheet as compared to that of the GCPs are presented in Table 1 and Fig. 2. The deviations in the Northings, Eastings and their positional errors computed at each site are also shown. With the exception of points 4 and 17, all the discrepancies range between 0 and 2 m in the Eastings, Northings and the positional errors, except for point 8 which deviated in excess of 3 m. Minimal deviations were recorded from GCP 9 through to 14 and points 18 and 19. Considering points 4, 8 and 17 as outliers, a RMSE of 1.23 m is obtained for the Town sheet. A comparison of the GPS coordinates and that of the orthophoto (see Table 2) showed relatively higher deviations; points 5 and 13 showing the most deviance (see Fig. 3). A RMSE of 2.78 m was obtained by considering points 5 and 13 as outliers (deviations: $\delta > 3x\sigma$).

3.1 Uncertainties in the Town Sheet

From Fig. 2, the discrepancies of the coordinates of the controls extracted from the Town Sheet relative to the GPS data generally show a deviation less than 2 m. This represents an error of 0.8 mm on Town Sheet at same scale. Both the northings and the eastings coordinates from the Town Sheet vary slightly from the reference coordinates in varying magnitudes giving an indication of the presence of random errors. It was observed that minimal deviations were recorded from GCP 9 through to 14. This observation supports the study assumption of negligible errors about the GPS reference base data used. The mean positional accuracy of 1.2 m in the dataset connotes high quality in the Town Sheet used.

The outcome of the overlay of the three datasets is shown in Fig. 4 and the errors in the integrated data were also evaluated. Excluding the outliers, an average RMSE of 3.98 m was realized in the integrated dataset. For instance, shoreline features extracted from these two dataset and appended for shoreline change analysis would record a total positional error of 3.98 m. A scatter plot of the inherent errors and the integrated datasets errors are shown in Fig. 5.

Reliance on spatial data to support decision-making is essential at all levels. However, the quality of the information derived is tied to the uncertainties inherent in the datasets employed. Although some degree of errors exist in most datasets at all scales, it is imperative that efforts be made to declare the uncertainties in datasets so that users may decide on their fitness for a given purpose or otherwise.

This makes the dataset useful for engineering applications as well as for spatio-temporal predictions. The achieved positional errors may be due to the following reasons:

(i) The Town Sheet was produced from aerial photographic sources with a touch of ground verification coupled with cartographic enhancement.

(iii) The data was free from excess pictorial information which is capable of causing mismatch of ground features.

(iii) The large scale of the source Town Sheet (1:2500) presented relatively higher details per unit measure of area, thus the accuracy obtained.
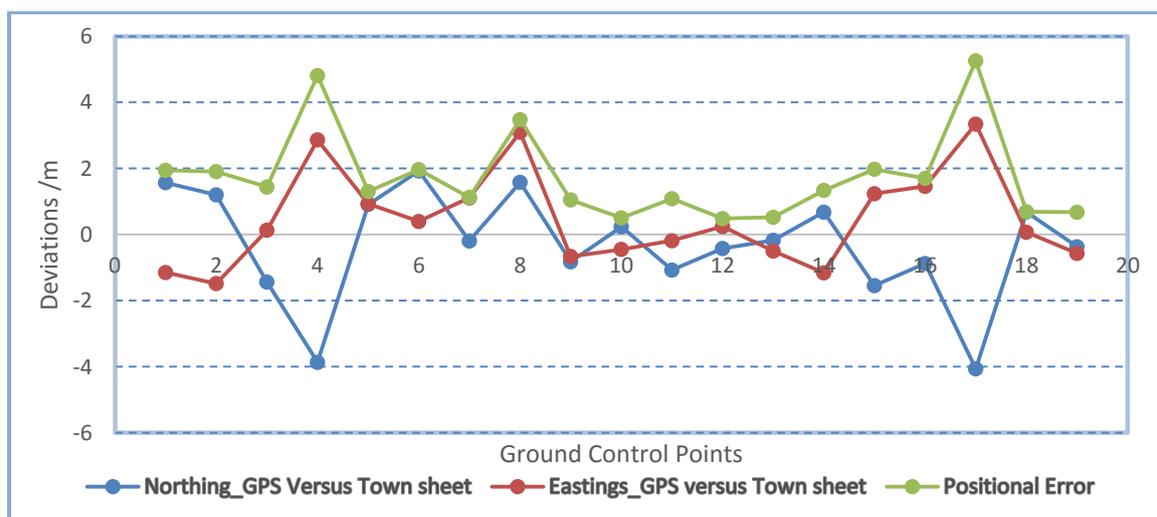

Fig. 2 Discrepancies between GPS Coordinates and Town sheet Coordinates

Table 1: Positional Accuracy Assessment for Points Extracted from Town Sheet

| ID	GPS Coordinates		Town Sheet Coordinates		Deviations		Variances	
	(N)/m	(E) /m	E_T	N_T	$\Delta N_T N$	$\Delta E_T E$	$(\Delta N_T N)^2$	$(\Delta E_T E)^2$
1	23679.814	191062.335	23678.240	191063.481	1.570	-1.146	2.4649	1.3133
2	23551.115	191126.037	23549.910	191127.517	1.205	-1.480	1.4520	2.1904
3	23648.106	191210.249	23649.540	191210.116	-1.434	0.133	2.0564	0.0177
4	23434.665	191320.981	23438.530	191318.112	-3.866	2.869	14.9460	8.2312
5	23597.887	190931.773	23596.970	190930.841	0.913	0.932	0.8336	0.8686
6	23219.069	190743.241	23217.140	190742.842	1.934	0.399	3.7404	0.1592
7	23662.627	190558.784	23662.820	190557.673	-0.189	1.111	0.0357	1.2343
8	23786.024	190914.283	23784.440	190911.183	1.582	3.100	2.5027	9.6100
9	23615.619	190530.418	23616.440	190531.076	-0.823	-0.658	0.6773	0.4330
10	23854.659	190556.227	23854.420	190556.673	0.238	-0.446	0.0566	0.1989
11	23571.347	190108.281	23572.420	190108.465	-1.074	-0.184	1.1535	0.0339
12	23761.791	190129.255	23762.210	190129.011	-0.422	0.244	0.1781	0.0595
13	23806.329	190114.532	23806.500	190115.029	-0.166	-0.497	0.0276	0.2470
14	23321.07	190028.599	23320.390	190029.754	0.678	-1.155	0.4597	1.3340
15	23874.667	190884.311	23876.210	190883.072	-1.541	1.239	2.3747	1.5351
16	23914.205	190515.711	23915.080	190514.251	-0.876	1.460	0.7674	2.1316
17	23981.299	190976.499	23985.360	190973.154	-4.063	3.345	16.5080	11.1890
18	23553.895	190759.318	23553.210	190759.245	0.690	0.073	0.4761	0.0053
19	23161.723	190071.223	23162.090	190071.792	-0.369	-0.569	0.1362	0.3238
						Sum	50.8467	41.1159
						RMSE	1.68072	1.51136
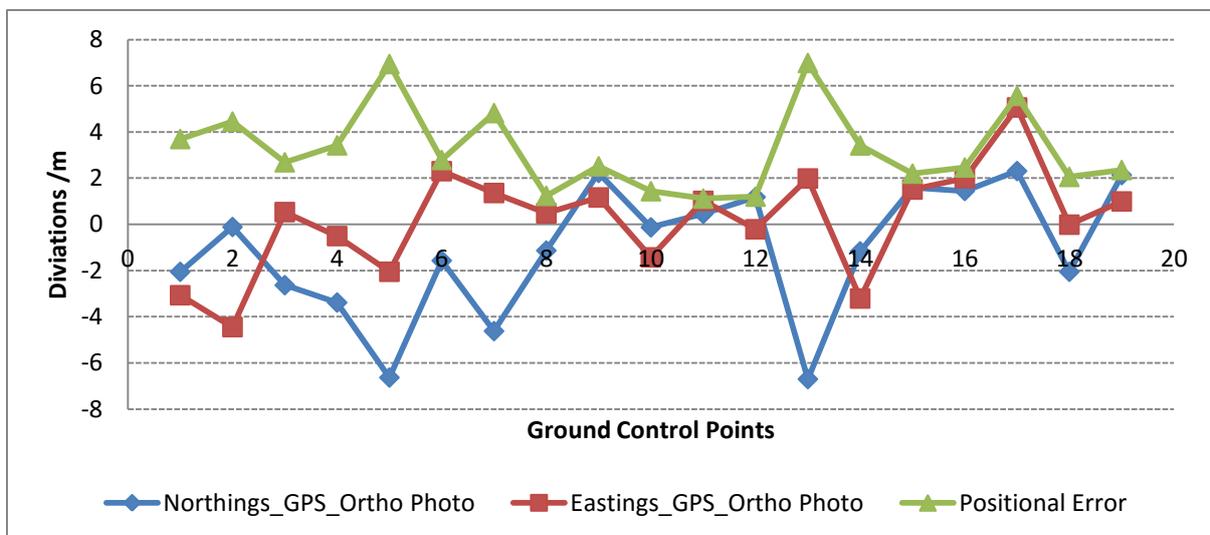
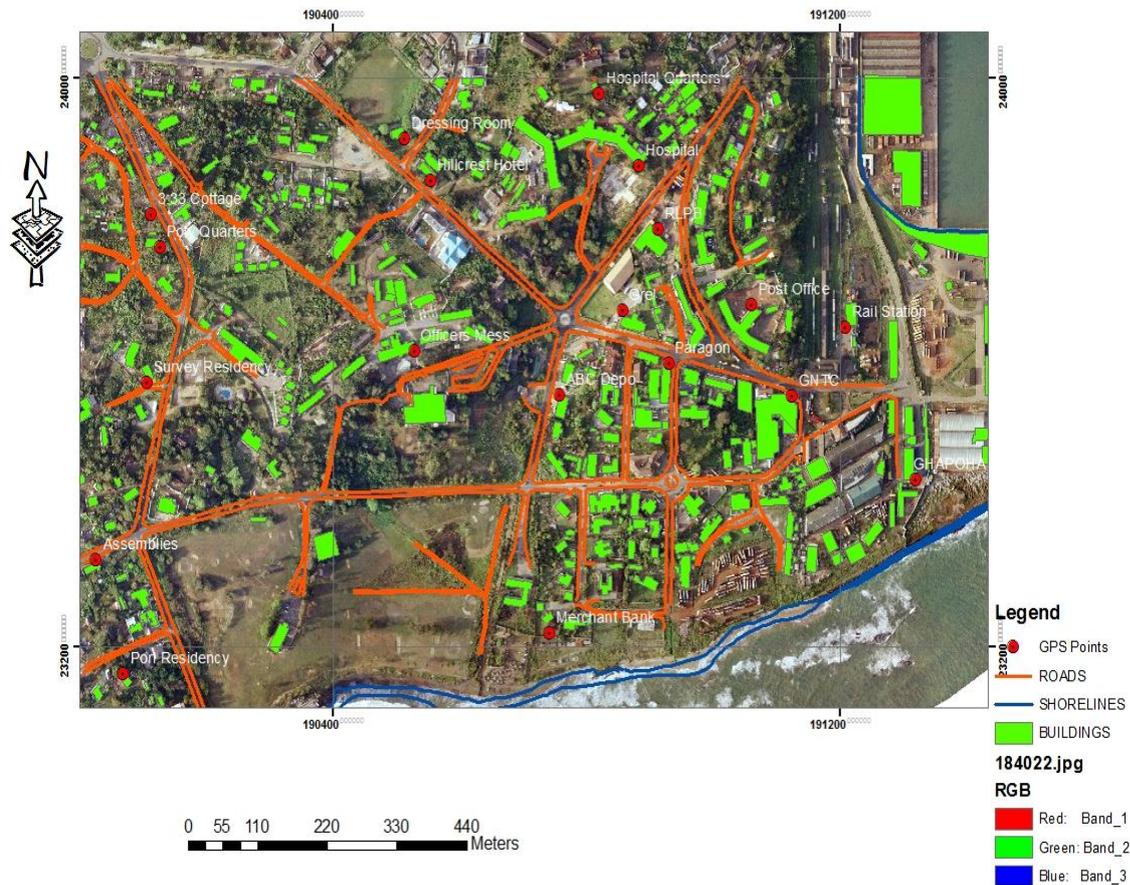**Fig. 3 Discrepancies between GPS Coordinates and Ortho Photograph**

Fig. 4 The Integrated Map

Table 2: Positional Accuracy Assessment for Points Extracted from orthophoto

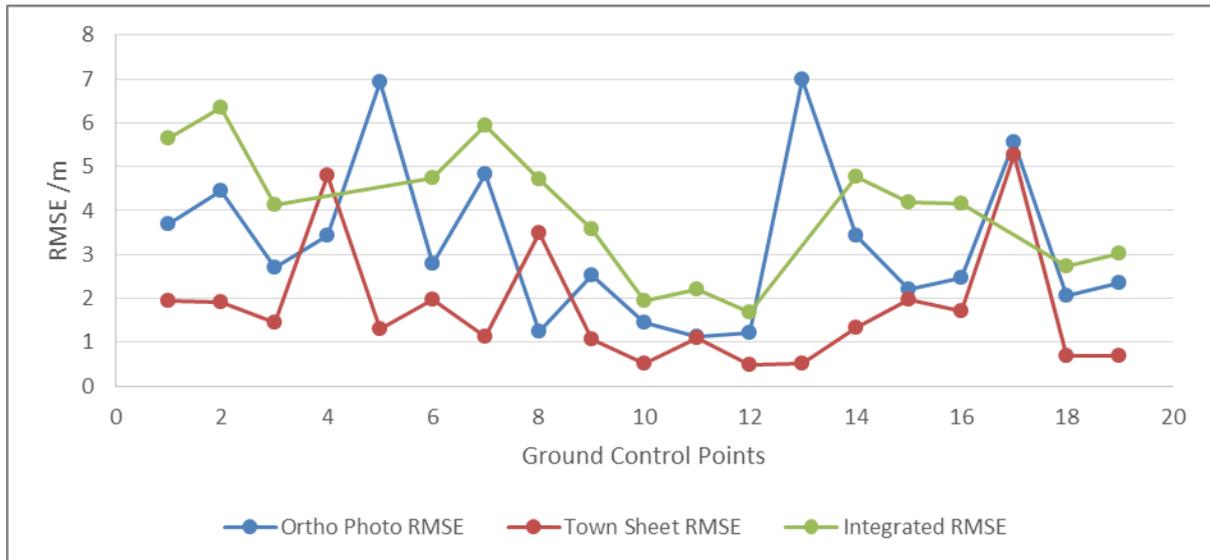|	GPS Coordinates		Orthophoto	Coordinates	Deviations		Variances	
ID	(N)/m	(E) /m	E_O /m	N_O /m	$\Delta N_O N$	$\Delta E_O E$	$(\Delta N_O N)^2$	$(\Delta E_O E)^2$
1	23679.814	191062.335	23681.870	191065.405	-2.054	-3.070	4.2189	9.4249
2	23551.115	191126.037	23551.230	191130.487	-0.118	-4.450	0.0139	19.8025
3	23648.106	191210.249	23650.740	191209.717	-2.636	0.532	6.9485	0.283024
4	23434.665	191320.981	23438.050	191321.488	-3.382	-0.507	11.4379	0.2570
5	23597.887	190931.773	23604.520	190933.826	-6.637	-2.053	44.0498	4.2148
6	23219.069	190743.241	23220.640	190740.938	-1.566	2.303	2.4524	5.3038
7	23662.627	190558.784	23667.250	190557.426	-4.621	1.358	21.3536	1.8442
8	23786.024	190914.283	23787.160	190913.804	-1.138	0.479	1.2950	0.2294
9	23615.619	190530.418	23613.390	190529.254	2.227	1.164	4.9595	1.3549
10	23854.659	190556.227	23854.790	190557.657	-0.130	-1.43	0.0169	2.0449
11	23571.347	190108.281	23570.890	190107.264	0.455	1.017	0.2070	1.0343
12	23761.791	190129.255	23760.610	190129.468	1.181	-0.213	1.3948	0.0454
13	23806.329	190114.532	23813.030	190112.546	-6.702	1.986	44.9168	3.9442
14	23321.07	190028.599	23322.240	190031.811	-1.170	-3.212	1.3689	10.3169
15	23874.667	190884.311	23873.070	190882.803	1.596	1.508	2.5472	2.2741
16	23914.205	190515.711	23912.760	190513.713	1.445	1.998	2.0880	3.9920
17	23981.299	190976.499	23978.990	190971.437	2.308	5.062	5.3269	25.6238
18	23553.895	190759.318	23555.95	190759.331	-2.054	-0.013	4.2189	0.0002
19	23161.723	190071.223	23159.59	190070.232	2.134	0.991	4.5540	0.9821
							163.3690	92.97245
						RMSE	3.0126	2.2727

Fig. 5 RMSE of Integrated Dataset

3.1.2 Uncertainties in the Orthophoto

From Fig. 3, the discrepancies of the coordinates of the controls extracted from the orthophoto relative to the GPS data generally show an average deviation of about 2.79 m *i.e.* close to 3 m. The use of orthophotos is mostly preferred by lots of disciplines since it has both pictorial information and planimetric correctness of ground features. However, some inherent errors in the dataset such as gaps due to cloud cover and limitation of the orthophoto rectification processing software could be responsible for the errors detected.

From Fig. 4, though the integrated data visually seem to match well with the GCP points of the Town Sheet and the orthophoto, Fig. 5 reveal the extent of positional errors in the dataset. These errors, which emanate from the individual data, have a cumulative effect on the overall position accuracy determined.

4 Conclusions and Recommendation

The Town Sheet used was found to have a better positional accuracy with RMSE of 1.2 m followed by the orthophoto with RMSE of 2.79 m. The scale at which original data are produced to a large extent determines the level of accuracy of the data. Integrated dataset bear the cumulative inherent errors of the original data. The techniques adopted in carrying out GPS observations and processing increase the reliability of the results obtained.

It is recommended that dependency on spatial dataset to support decision-making should be encouraged; however, such dataset should be subjected to rigorous positional assessment to enhance the reliability of such decisions.

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