Optimum Sample Size Determination Scenarios for Orthophoto Positional Accuracy Test in Varied Topography for Urban Land Registration: Case Bahir Dar, Debre Markos, Harar City, Ethiopia

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Abstract. The study used Global Positioning System (GPS) static measurements, which were assumed to be the ground truth, for a positional accuracy test of orthophoto. The GPS data was least-squares adjusted using Leica GeoOffice (LGO) software package at 20 sampling locations. Three checkpoints (CPs) sampling scenarios were developed based on numbers and their distribution at three different cities having varied topography. Thus, the main focus of this study was to test the position accuracy of orthophoto when the CPs sampling is 10 (first scenario), 15 (second scenario) and 20 (third scenario) points with reference to in-situ ground GPS measurement. The test was conducted considering national and international standards and methods for photogrammetric science. The positional accuracy found from the three scenarios didn't vary significantly when the CPs are varied in numbers and spatial distribution. In other words, the positional accuracy acquired while using 10 CPs sampling in terms of RMSE in easting and northing together were ±36, ±40 and ±32, ±38, ±40 and ±33 and ±39, ±40 and ±35 cm while using 10, 15 and 20 sampling CPs in Bahir Dar, Harar and Debre Markos city respectively. All the positional accuracy results obtained from all three scenarios approximately meet the requirement set by Ethiopian Urban Legal Cadastral Standard No.-03/2015, of the maximum allowable error budget ±40 cm for map scale 1:2,000 in urban areas. We can conclude that the coordinate disagreement between orthophoto and GPS static derived in easting, northing and height at each sampling location looks like a systematic shift as seen in the text in Tables 2, 3 and 4. In this case, the numbers of checkpoints aren't as such the decisive factor to acquire the optimum results. In contrary, appropriate location such as sharp or visible corners of manmade features and addressing the topographic variations in each experimental site are important.

Key words. Orthophoto, Positional Accuracy, Optimum Checkpoints, GPS, Urban Cadastre, Scenarios

1. Introduction

The main motivations for using photogrammetric approach for cadastral application is the sack of speed and cost of mapping. (David S., 2009). In order to realize the production of large scale mapping, calibration by in-situ measurement is critical due to the fact that the photogrammetric surveying products are affected by different factors. In this respect, determination of sample size and sampling strategies are the first and critical aspect of positional accuracy assessment. From the statistical point of view, one of the most

controversial aspects of all the methodologies for positional accuracy assessment is the number and distribution of CPs across the experimental site. Regarding numbers, different authors have different interest and opinion as per the objective of the task and the nature of the error; either systematic or random associated with the data sources. For instance, NMAS, EMAS and NSSDA recommend a sample size of 20, Newby 1992 and NJUG 1988 recommend a sample size of 50, and STANAG 2215 recommend a sample size of 167.
On the other hand specifically for positional control, SPRS 2013 standards explained that the sampling sizes and the CP distributions are dependent on topography and area of the experimental site. In support of this, the standards explained that if the experimental site ≤ 500, 501-750, 751-1000, 1001-1250, 1251-1500, 1501-1750, 1751-2000, 2001-2250, 2251-2500 in square kilometers, the recommended number of checkpoints are 20, 25, 30,35, 40, 45, 50, 55, and 60 for clearly identified points respectively for positional verification.

Contrary to the above, the geographical extent of the experimental site isn't the only factor for determination of sample size, but also the spatial distribution of the sample can condition the validity of a statistical sampling assessment. A bad spatial distribution affects the representativeness of the sample. This means that the sample does not capture adequately the structure of the population being sampled, resulting in an erroneous estimation (Francisco et. al, 2008). In support of this, PAAMs provide explicit criteria for a suitable spatial distribution sampling checkpoints. In some cases there is a need for an agreement between the producer and the user (USACE, 2002).

Another controversial idea stated that due to the diverse user requirements for digital geospatial data and maps, it is not realistic to include statements that specify the spatial distribution of sampling checkpoints. Data and/or map producers must determine checkpoint location (FGDC/NSSDA, 1998). This standard also explained that checkpoints may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. So far, the standard determines that a minimum of 20 sample points are required to test positional accuracy with reliable statistical rigor.
Therefore, the aim of this study is to determine/model optimum sampling checkpoints(CPs) size in varied topography for digital orthophoto positional verification with reference to in-situ ground GPS measurement by developing various scenarios (varied topography, varied sampling checkpoint spatial distribution, and varied number of sampling checkpoints). This will help us to quantify the influence of topography variation and geographical extent of the experimental site on sampling size determination.

2. Materials and Methods

2.1. Experimental Site

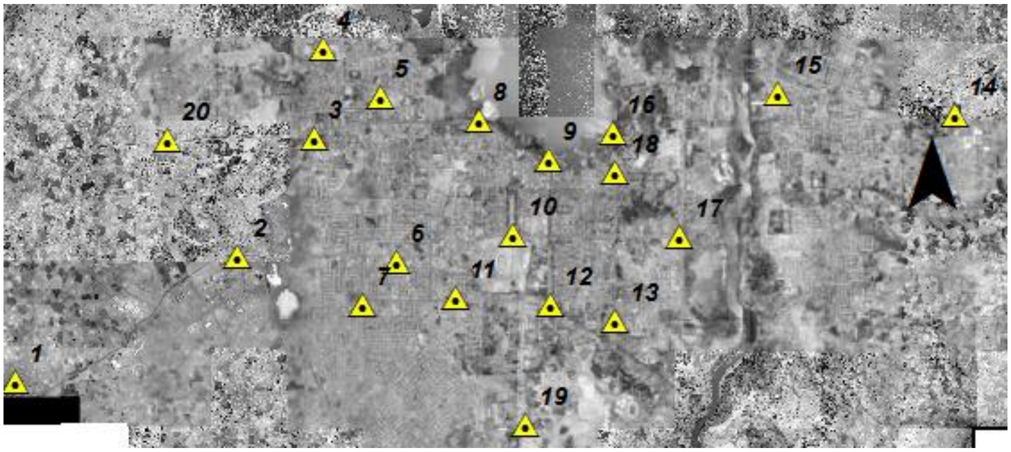
This study is based on three experimental sites having different topography characteristics and different geographical extent purposely, but all the experimental sites have been < 500 square kilometers. One of the experimental sites is Debre Markos city characterized by undulated terrain, situated at an altitude range of 1,933 m to 2,852 meters above mean see level (MSL), and having 192.3 km^2 area coverage. The second city is Bahir Dar, characterized by flat plain, situated at an altitude range of 1650 to 1886 meters above MSL, and having 362 km^2 area coverage. The third city is Harar, characterized by slightly undulating topography, and situated at an altitude range of 1836 - 1926 meters above MSL, and having 334 km^2 area coverage.

2.2. Data Used

The data source for this study is a rectified aerial photograph, secondary Ground Control Points (GCP), and a Digital Elevation Model (DEM) acquired over the whole area of the above listed experimental sites. The rectified aerial photograph and DEM were generated by using the ArcInfo photogrammetric software platform. The photogrammetric surveying was conducted by the Information Network Security Agency (INSA) in 2011/12 with middle frame camera at 1:2,000 scale and 15 cm Ground Sample Distance (GSD). The reference secondary control point coordinates were observed for 12 hours in connection with the primary point (determined in 48 hours of GPS observation) and their data was computed in connection with International GNSS Service (IGS) permanent stations using Leica Geo-office (LGO) and Ashtech solutions software packages by the Ethiopian Mapping Agency (EMA, 2013). All the data sources in this study were geometrically registered to the UTM reference system (zone 37 N) for all experimental sites using the Adindan (Ethiopia) Plane Datum.

2.3. Standards Used for Checkpoint Selection and Error Budget

This study is guided by two newly endorsed test standards: ASPRS (2013) for designing the distribution of checkpoints and FGDC (1998) for determining the sample size. Besides, this study attempts to examine the accuracy assessment from the perspective of Ethiopian standards and directives, e.g., Ministry of Urban Development, Housing and Construction (2015). The selection of check points and their spatial distribution was guided by the 1998 international standard of the U.S. National Standard for Spatial Data Accuracy (NSSDA) authored by the U.S. Federal Geographic Data Committee (FGDC). The FGDC (1998) standard provides excellent guidance on positional accuracy sample design, estimation of sample size and sample selection criteria. Furthermore, in the Ethiopian context the accuracy requirement of the horizontal position according to the National Mapping Agency (EMA) is ±30 cm at the scale of 1:2,000, which is the recommended scale for urban areas (urban legal cadastral standard No.-03/2015, page 22). This corresponds to two pixels at a Ground Sample Density (GSD) of 15 cm, regardless of the method; however, the positional accuracy of the final output should not exceed 40 cm at scale of 1:2,000. The accuracy of the vertical position is ±45 cm, likewise corresponding to three pixels.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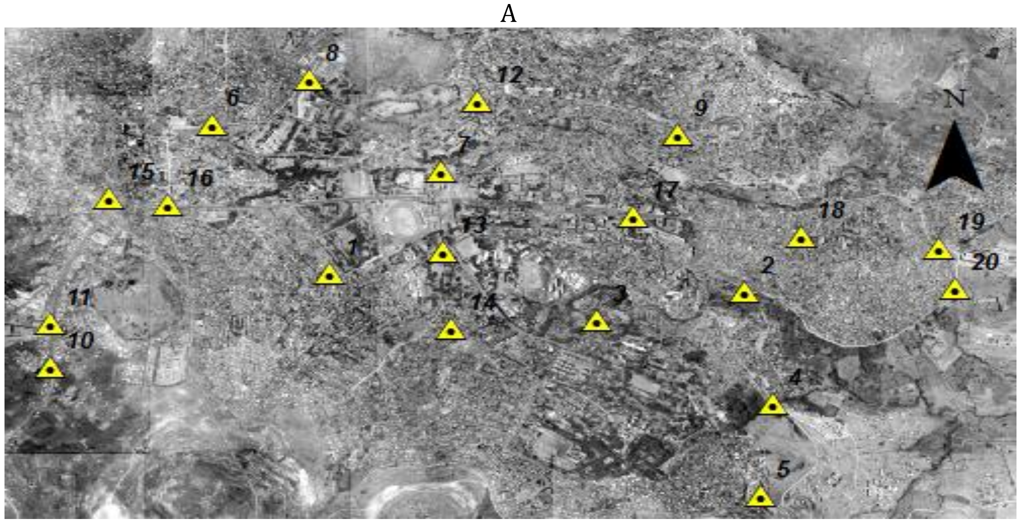
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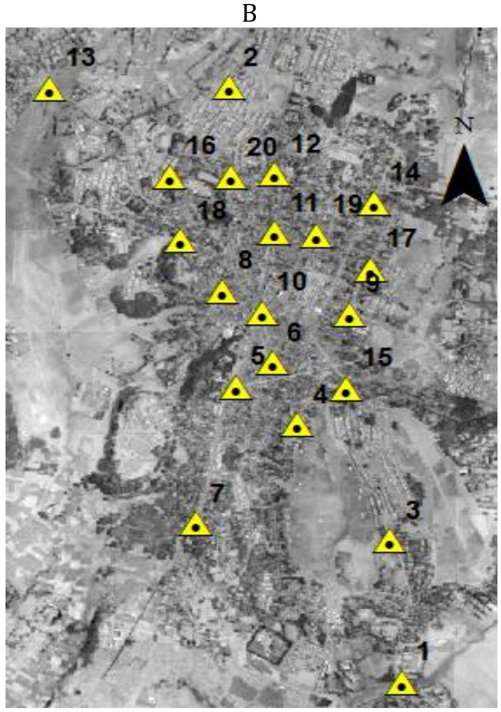
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***Figure** 1. Checkpoint location symbolized by yellow triangles in (A): Bahir Dar, (B): Harar and (C): Debre Markos at canal corners, road junctions, water points, culvert edges, centers of utilities, bridge corners, and swimming pool edges*

2.4. Scenario Development

In order to determine the optimum sample size for orthophoto positional verification, the study has developed three scenarios based on the number of sampling checkpoints, their spatial distribution and topographic undulation characteristics for each experimental site. In this context, the first, the second and the third scenarios consist of 10, 15 and 20 sampling checkpoints (CPs) respectively for each experimental site. According to ASPRS (2013), the recommended number of checkpoints with the corresponding experimental site area in square kilometers is discussed. The standard explicitly stated that when the experimental site area varied by 250 in square kilometers, checkpoints are also varied by 5 in numbers simultaneously. In this connection, this study has used scenarios having 10, 15 and 20 checkpoints to test what will happen the with positional variation if the number of sampling checkpoints is varied by 5 starting from 10 with varied topography as well.

2.5. Measurement, Processing and Analysis

A minimum of one hour of GPS observations has been collected in static mode for each checkpoint and processed using LGO by using verified secondary GCPs for the reference station with less than 3 km base line distance, i.e., within each city. During the measurements, from 8 to 12 satellites, both GPS and GLONASS were in the sky, and GDOP varied between 1.2 and 2.8. In the processing using the LGO software package, the translation parameters in the x, y and z direction were 162, 12 and -206 m, the rotation parameters in x, y and z were also 0, 0 and 0 seconds of arc, the scale factor was 0.9996 and the projection was Universal Transverse Mercator (UTM) 37 N while converting WGS84 geodetic co- ordinates to Adindan geodetic co-ordinates. In this connection, the three scenarios were tested in each three experimental sites and the results were analyzed in terms of RMSE in the x and y directions independently and together based on the Greenwalt and Shultz (1992) formula.

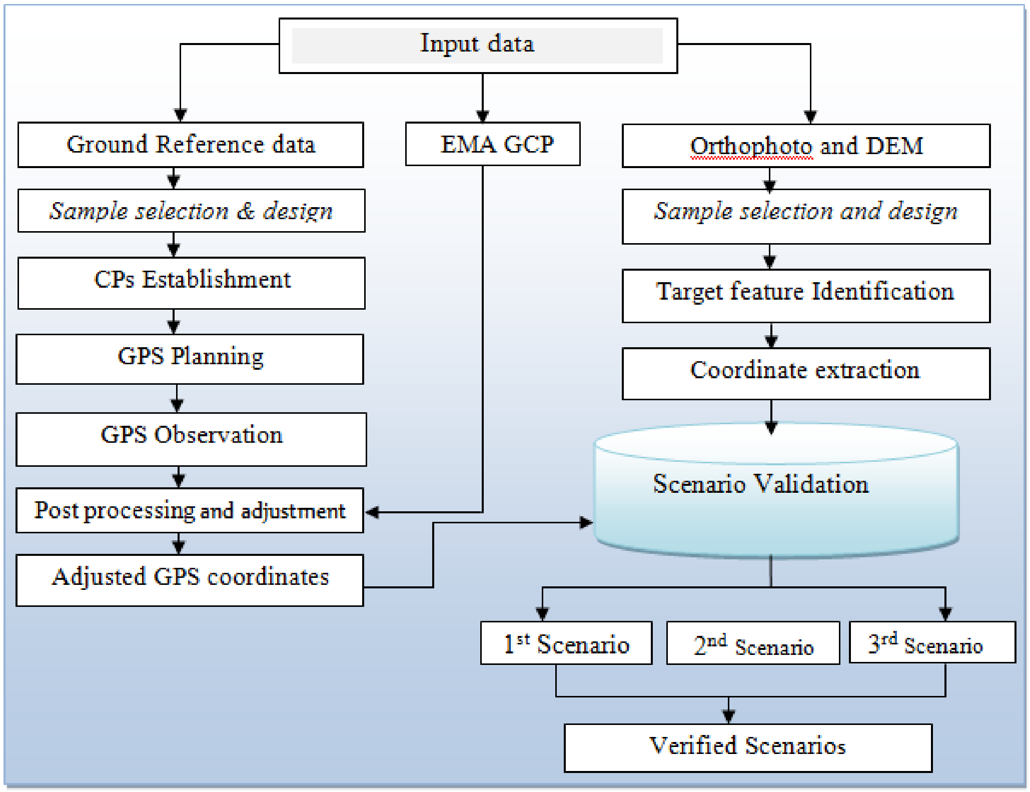

***Figure** 2. Overall methodological framework*

3. Results

3.1. GNSS Processing

Regarding the processing logic, the two GPS instruments were placed at the reference stations (secondary GCPs) and the other two GPS instruments were also placed at each a CP location. In other words, there were two GPS instruments at a time for reference and two GPS instruments at a time for CPs data collection and 10 session and 20 baselines were computed in GNSS processing for all three scenarios. The baseline length between reference stations and the CP location and the distribution across the experimental site were considered for the baseline selection for each scenario. The quality status of the reference stations has 6, 7 and 8 millimeters error on average respectively in terms of 95% confidence level. In this case, the precision of the GNSS processing results obtained with the LGO software on their own is a maximumof 4 mm.

In describing our results, we have used the values obtained with the LGO as representative for all GNSS results. In this case, the agreements between GPS static and orthophoto/DEM derived coordinates were computed in three different experimental sites using three different scenarios. Only differences in easting and northing were computed (See Table 2, 3 and 4), because of the large number of tables to be presented.

For all cities and for all scenarios, the height values were extracted from the DEM which is the input/prior output of the given orthophoto. In this case the deviation between heights from DEM and GPS derived were computed intermesh mean error, standard deviation and RMSE. The heights values from DEM were extracted by using the GIS platform, specifically Arc tool box, for extracting values for a point. In this case, the input point features are candidate checkpoints and the input raster is DEM. As a result, the output features are a point feature dataset containing the extracted raster values.

3.2. First Scenario Positional Point Accuracy

The accuracy of horizontal coordinates of the checkpoints derived from orthophoto was evaluated by comparing it with the corresponding coordinates measured directly from in-situ GPS. In this case, an agreement of orthophoto derived coordinates with GPS static observed coordinates at ten (10) checkpoints locations in easting and northing, a root mean square error ($RMSE_r$), was found of ±37 cm, ±41 cm and ±32 cm for Bahir Dar, Harar and Debre Markos city respectively. The vertical accuracy was obtained as a root mean square error of 112, 78 and 66 cm for Bahir Dar, Harar and Debre Markos city respectively at the same checkpoints location.

Table 2. *Comparison between GPS coordinates and orthophoto/DEM derived coordinates in Adindan UTM, units: meter, centimeter. It is seen that all results are within the specified national error budget across three experimental sites using 10 sampling checkpoints for the horizontal component.*

ID	Bahir Dar			Harar			Debre Markos		
	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)
1	-0.286	0.238	-0.700	0.032	-0.317	0.672	-0.075	0.220	1.101
2	-0.295	-0.285	-1.618	-0.265	0.141	0.816	-0.162	-0.005	0.657
3	-0.335	0.013	-1.297	-0.349	0.175	1.136	-0.414	-0.018	0.395
4	-0.384	-0.084	-1.509	-0.501	0.024	0.947	0.168	0.398	0.417
5	-0.333	0.172	-0.431	-0.325	0.362	0.521	-0.254	0.282	0.513
6	-0.236	0.025	0.596	-0.171	-0.014	1.124	-0.251	0.315	0.281
7	0.201	0.137	1.298	0.136	-0.104	0.474	-0.330	0.161	0.012
8	-0.394	0.159	1.682	0.557	-0.521	0.356	-0.095	0.292	1.104
9	-0.216	-0.356	-0.328	0.039	0.235	-0.581	-0.003	0.167	0.355
10	-0.288	0.276	-0.629	-0.316	-0.214	0.635	0.228	-0.027	0.750
№. of CPs	10								
Sum	-2.564	0.296	-2.937	-1.162	-0.233	6.101	-1.189	1.783	5.582
Mean error (m)	-0.256	0.030	-0.294	-0.116	-0.023	0.610	-0.119	0.178	0.558
Standard dev. (m)	0.171	0.214	1.143	0.312	0.271	0.496	0.207	0.152	0.350
$RMSE_{x,y}$ (m)	0.303	0.206	1.124	0.318	0.258	0.770	0.230	0.229	0.650
$RMSE_r$ (m)	±0.366			±0.409			±0.325		

3.3. Second Scenario Positional Point Accuracy

An agreement of orthophoto derived coordinates with GPS static observed coordinates at fifteen (15) checkpoints location in easting and northing together with a root mean square error ($RMSE_r$) of ±38 cm, ±40 cm and ±33 cm was found for Bahir Dar, Harar and Debre Markos city respectively. On the other hand, a vertical accuracy was found as a root mean square error of 96 cm, 94 cm and 71 cm for Bahir Dar, Harar and Debre Markos city respectively at the same checkpoints location.

Table 3. *Comparison between GPS coordinates and orthophoto/DEM derived coordinates in Adindan UTM, units: meter, centimeter. It is seen that all results are within the specified national error budget across three experimental sites using 15 sampling checkpoints for the horizontal component.*

ID	Bahir Dar			Harar			Debre Markos		
	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)
1	-0.286	0.238	-0.700	0.032	-0.317	0.672	0.227	0.173	0.902
2	-0.295	-0.285	-1.618	-0.425	-0.181	0.114	-0.075	0.220	1.101
3	-0.295	-0.110	-1.138	-0.235	0.019	0.597	-0.162	-0.005	0.657
4	-0.103	-0.337	-1.350	0.096	0.261	1.648	-0.414	-0.018	0.395
5	-0.384	-0.084	-1.509	-0.501	0.024	0.947	-0.140	0.429	0.304
6	-0.443	-0.575	-0.822	-0.619	-0.273	0.619	0.168	0.398	0.417
7	-0.333	0.172	-0.431	-0.325	0.362	0.521	-0.106	-0.034	0.705
8	-0.226	-0.247	-0.684	-0.426	0.102	1.250	-0.218	0.386	0.485
9	-0.145	0.176	-0.359	0.136	-0.104	0.474	-0.061	0.047	0.297
10	0.201	0.137	1.298	0.027	-0.139	0.840	-0.438	-0.331	0.290
11	-0.210	-0.018	1.107	0.357	-0.521	0.356	-0.251	0.315	0.281
12	0.212	0.322	0.721	0.039	0.235	-0.581	-0.090	0.316	1.267
13	0.013	-0.299	0.062	-0.168	-0.137	-1.441	-0.173	0.099	0.828
14	-0.216	-0.356	-0.328	-0.316	-0.214	0.635	-0.095	0.292	1.104
15	-0.288	0.276	-0.629	-0.484	-0.021	1.720	-0.003	0.167	0.355
№. of CPs	15								
Sum	-2.797	-0.989	-6.381	-2.813	-0.903	8.372	-1.831	2.452	9.387
Mean error (m)	-0.186	-0.066	-0.425	-0.188	-0.060	0.558	-0.122	0.163	0.626
Standard dev. (m)	0.195	0.277	0.894	0.287	0.237	0.793	0.178	0.208	0.341
$RMSE_{x,y}$ (m)	0.265	0.275	0.963	0.332	0.230	0.948	0.211	0.259	0.707
$RMSE_r$ (m)	±0.382			±0.404			±0.334		

3.4. Third Scenario Positional Point Accuracy

An agreement of orthophoto derived coordinates with GPS static observed coordinates at twenty (20) checkpoints locations in easting and northing as a root mean square error ($RMSE_r$) of ±39 cm, ±40 cm and ±36 cm were found for Bahir Dar, Harar and Debre Markos city respectively. On the other hand, a vertical accuracy with a root mean square error of 102, 93 and 69 cm was found for Bahir Dar, Harar and Debre Markos city respectively at the same checkpoints location.

Table 4. *Comparison between GPS coordinates and orthophoto/DEM derived coordinates in Adindan UTM, units: meter, centimeter. It is seen that all results are within the specified national error budget across three experimental sites using 20 sampling checkpoints for the horizontal component.*

ID	Bahir Dar			Harar			Debre Markos		
	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)	ΔE (m)	ΔN (m)	ΔH (m)
1	-0.286	0.238	-0.700	0.032	-0.317	0.672	0.227	0.173	0.902
2	-0.295	-0.285	-1.618	-0.122	0.452	0.468	-0.075	0.220	1.101
3	-0.295	-0.110	-1.138	-0.425	-0.181	0.114	-0.162	-0.005	0.657
4	-0.103	-0.337	-1.350	-0.235	0.019	0.597	-0.414	-0.018	0.395
5	-0.335	0.013	-1.297	-0.265	0.141	0.816	-0.140	0.429	0.304
6	-0.285	-0.076	-1.261	-0.349	0.175	1.136	-0.378	0.165	1.091
7	-0.384	-0.084	-1.509	-0.295	-0.124	0.722	0.168	0.398	0.417
8	-0.443	-0.575	-0.822	0.096	0.161	1.648	-0.106	-0.034	0.705
9	-0.439	-0.526	-0.770	-0.501	0.024	0.947	-0.218	0.386	0.485
10	-0.333	0.172	-0.431	-0.619	-0.273	0.619	-0.254	0.282	0.513
11	-0.226	-0.247	-0.684	-0.325	0.362	0.521	-0.295	0.545	0.209
12	-0.145	0.176	-0.359	-0.426	0.102	1.250	-0.061	0.047	0.297
13	-0.236	0.025	0.596	-0.171	-0.014	1.124	-0.438	-0.331	0.290
14	0.201	0.137	1.298	0.136	-0.104	0.474	-0.251	0.315	0.281
15	-0.210	-0.018	1.107	0.027	-0.139	0.840	-0.090	0.316	1.267
16	-0.394	0.159	1.682	0.557	-0.521	0.356	-0.173	0.099	0.828
17	0.212	0.322	0.721	0.039	0.235	-0.581	-0.330	0.161	0.012
18	0.013	-0.299	0.062	-0.168	-0.137	-1.441	-0.095	0.292	1.104
19	-0.216	-0.356	-0.328	-0.316	-0.214	0.635	-0.003	0.167	0.355
20	-0.288	0.276	-0.629	-0.484	-0.021	1.720	0.228	-0.027	0.750
№. of CPs	20								
Sum	-4.485	-1.394	-7.430	-3.815	-0.373	12.638	-2.861	3.576	11.961
Mean error (m)	-0.224	-0.070	-0.372	-0.191	-0.019	0.632	-0.143	0.179	0.598
Standard dev. (m)	0.184	0.266	0.978	0.277	0.236	0.706	0.194	0.205	0.356
$RMSE_{x,y}$ (m)	0.287	0.269	1.024	0.330	0.231	0.934	0.237	0.268	0.691
RMSEr (m)	±0.393			±0.403			±0.358		

4. Discussion and Conclusion

Orthophoto mapping integrating with ground survey has been recently planned to be used for both urban and rural cadastral mapping application in Ethiopia. This paper uses national and international standards and scientific methods of photogrammetric science for a positional point accuracy test in urban orthophoto mapping. In this paper, we used the cities of Bahir Dar, Harar and Debre Markos, which have a varied topography, as a test case, using varied scenarios for validating point location accuracies achieved in orthophoto mapping. A set of carefully selected test points were measured using static GNSS, and processed using Leica Geo-Office (LGO) software package.

As seen above and in Table 2 (first scenario), Table 3 (second scenario) and Table 4 (third scenario) positional accuracy results do not vary significantly when the checkpoints are varied in numbers and spatial distribution. The positional accuracy acquired in terms of RMSE in easting and northing together were ±36, ±40 and ±32, ±38, ±40 and ±33, and ±39, ±40and ±35 cm while using 10 sampling checkpoints, 15 sampling checkpoints and 20 sampling checkpoints in Bahir Dar, Harar and Debre Markoscity respectively. In this case we can conclude that in all scenarios within the same city the maximum point positional accuracy difference is 3 cm and minimum 0.5 cm. Furthermore we can conclude that in all scenarios across three different cities the maximum point positional accuracy difference is 8.9 cm and minimum 0.9 cm in terms of $RMSE_r$ in easting and northing together as shown in the table 5 below.

Table 5. Summary of $RMSE_r$ difference across cities with the same scenario and RMSEr difference cross scenario with the same city.

Scenarios	Cities with their $RMSE_r$			Differences across cities, but the same scenario		Differences across scenarios, the same city	
	Bahir Dar	Harar	Debre Markos	Differences Max.	Differences Min.	Differences Max.	Differences Min.
1 (10 CPs)	36 cm	40.9 cm	32 cm	8.9 cm	4 cm	3 cm	1 cm
2 (15 CPs)	38 cm	40.4 cm	33 cm	7.4 cm	2.4 cm	0.6 cm	0.1 cm
3 (20 CPs)	39 cm	40.3 cm	35 cm	5.3 cm	1.3 cm	3 cm	1 cm

For instance, in Debre Markos city specifically in scenario 1 the $RMSE_r$ is 32 cm, which is minimum and in Harar city the $RMSE_r$ is 40.9 cm, which is maximum, the difference being 8.9 cm. The result indicates that the maximum point positional accuracy difference is achieved in different cities having varied topography, but the same city having different sample size.

All the positional accuracy results obtained from all three scenarios in all three experimental sites, approximately meet the requirement set in sub-section 2.3, as indicated in Urban Legal Cadastral Standard No.-03/2015, of the maximum allowable error budget, ±40 cm horizontally for a map scale 1:2,000 in urban areas. The coordinate disagreement between orthophoto and GPS static derived in easting, northing and height at each sampling location looks like a systematic shift as seen above in Tables 2, 3 and 4. In this case, the numbers of checkpoints aren't as such the decisive factor to acquire the optimum results. In contrary, appropriate location such as sharp or visible corners of manmade features and addressing the topographic variations in each experimental site are important.

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