Preventing Forest Loss, Promoting Restoration, and Integrating Sustainability into Ethiopia's Coffee Value Chains and Food Systems (FOLUR)

Validation of GPS-Enabled Smart Phones for Geo-locating Smallholder Coffee Farm Plots in Ethiopia

Authors

Mulugeta Worku[1], Berhan Gessesse (PhD)[2], and Eyasu Leta[3]

September 2024

Addis Ababa, Ethiopia

[1] Project Manager, FOLUR Ethiopia, MoPD; Email: m.w.ayele@gmail.com

[2] GIS and Remote Sensing Lead, SSGSI; Email: berhanavu@gmail.com

[3] Geodesy Lead, SSGSI; Email: letaeyasu@gmail.com

Table of Contents

1. Problem background and objectives

The Preventing Forest Loss, Promoting Restoration, and Integrating Sustainability into Ethiopia's Coffee Value Chains and Food Systems (FOLUR Ethiopia) project, implemented by the Ministry of Planning and Development (MoPD) and its partners, aims to support transformation towards deforestation-free coffee value chains and food systems in Oromia, Southwest Ethiopia, Sidama, and South Ethiopia regions. Accordingly, the project supports the Ethiopia Coffee and Tea Authority (ECTA) in meeting its sectoral goals and compliance demands particularly the European Union's Deforestation Regulation (EUDR) in the Ethiopian coffee value chain.

Meeting the EUDR requirements necessitates ensuring the traceability of individual coffee farm plots, which involves geographical indication of those smallholder coffee plots. This process necessitated use of geo-location recording devices and high-performance computing facilities to collect, analyze, map and dynamically manage geo-located information.

Hand-held Global Positioning System (GPS) devices (such as Garmin variants) are commonly used to record geo-location data in local contexts. Yet, these devices are relatively costly, importantly when large numbers of them are sought to collect data covering the entire country. Accordingly, the ECTA requested MoPD to support national efforts in meeting EUDR (EU's 2023/1115) regulation requirements through procurement of GPS-enabled smartphones, high-performance laptop computers, and tablets for geo-location data management. In response, the FOLUR project management unit (PMU) at MoPD presented ECTA's request to FOLUR Ethiopia's Steering Committee (PSC) and the same was approved on the 24th of June 2024.

It was learned that different smart phone brands are equipped with different chip sets. Hence, their GPS receivers exhibit different levels of accuracy (Bauer, 2013). This necessitated the proposed smart phones to undergo validation processes before bulk procurement.

The main objective of the validation action was to assess whether GPS-enabled smart phones can capture reliable geo-located data on individual coffee farm plots. It was also intended to ensure that the smartphone-based geo-location data collection is aligned with other activities relevant to creating a comprehensive coffee plots geo-location database, including training, deployment of data collectors, attribute data collection (including, farm boundaries detection and mapping, farm size, owner of the farm and history of the farm plots), analysis, and mapping.

2. Methodology

2.1. General methodological framework

This work started by defining *validation* as assessing the extent to which a specific measurement device measures what it is intended to measure (Scholtes et al., 2011). It is operationalized in the context of this work as the processes of checking reliability of GPS-enabled smart phones to generate geo-located data at the required level of accuracy (within the range of 10 meters). The validation process has thus combined ensuring whether the GPS-enabled smartphones can meet geo-location data collection requirements plus the findings are valid to guide decisions regarding choice of proposed smartphone brands.

The validation work was grounded on the principle that the proposed smartphone brands need to be *compared against precision device measurements* so that subsequent actions of tracing coffee plots' geo-location will be pursued using robust and reliable approaches.

The overall processes for GPS-enabled smart phones validation and geo-locating coffee plots involved sets of assessment questions and steps including selection of devices to eventual production of geo-location maps of smallholder coffee plots as illustrated in Figure 1. This report only addresses the first four steps, while the remaining ones including training of data collectors, actual farm-level data collection, and production of geo-location maps of smallholder coffee plots are yet to come.

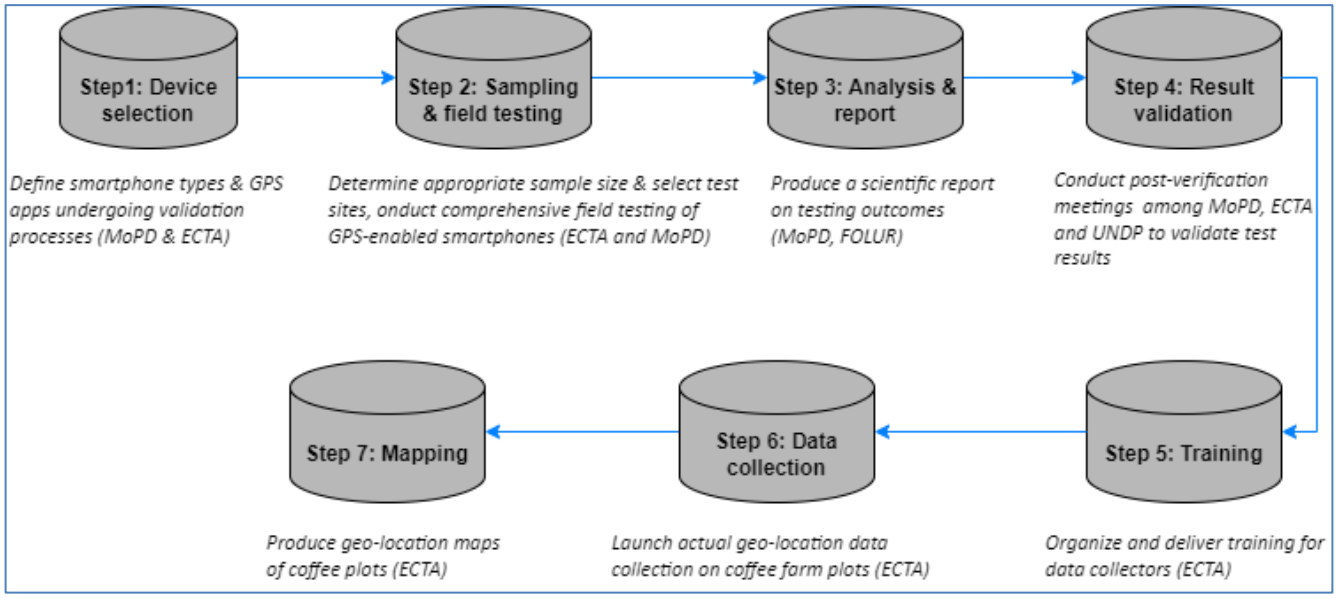

Figure 1: Generalized methodological framework for device validation for smartphone-based geo-location mapping

2.2. Specific methods

2.2.1. Smartphone brands for geo-location data collection

For the purpose of this study, the smartphone brand specified by ECTA (Samsung Galaxy A55 and Samsung Galaxy A35) have been used to collect geographic coordinate values of a point location and eventually validated on whether they can accurately capture geo-location data.

2.2.2. GPS devices, GPS Apps and online – offline considerations

Differential GPS (Leica GS18) was accessed from the Ethiopia Space Science and Geo-spatial Institute (SSGI) and used as a precision device. Besides, Garmin etrex 30x hand-held GPS device was also used, as it is claimed to exhibit less than 4 meters of planimetric accuracy (Fator & Zomrawi, 2015). It is also one of the most widely used GPS devices worldwide and in Ethiopia. Besides, two open-source GPS Apps (including the default Google Earth Map) have been installed onto both Samsung A55 and Samsung A35 smartphones for geo-location data collection.

It is critical to note that most smallholder coffee farm plots are located in remote locations without access to internet and cellular communication networks. Therefore, selection of GPS apps installed

onto smartphones was on the basis of their offline capability. That is, digital apps that perform in the absence of internet and cellular networks were employed. Based on recommendations from different web-based navigation knowledge sharing platforms, 2 GPS apps that are proved to have offline functionalities were applied (Table 1).

Table 1: GPS Apps installed onto Android Smartphones

#	GPS App Options	Description
1	Tracklia	Is a free app for android devices With Tracklia, you can record your own GPS tracks, import tracks, routes, and waypoints from GPX, KML, and KMZ files, and view elevation graphs, distance, and ascent/descent of imported tracks and routes.
2	My GPS Coordinates	Is a free and an easy-to-use, accurate GPS app for sharing your location via email, text message, or social media. With a simple, clean user interface, you can find your current location on maps with one click, and it works even without an Internet connection. My GPS Coordinates are based on the **WGS84** standard.

In addition to the above GPS apps, Google Maps App (that is normally comes as one of the default apps in Smartphones) was used[4].

2.2.3. Setting reference (expected) values

It is made clear at the outset that this work is intended to validate GPS-enabled smart phones on whether they can serve the purpose of collecting reliable geo-located data on individual coffee farm plots. That is, how precise are the records in locating an object or a point location being tracked on the earth's surface. The fundamental question that was primarily answered was 'what represents the true (expected) coordinate value of a specific site against which point values (recorded using GPS-enabled smart phones) will be compared. Coordinate values recoded using Global Navigation System (GNSS) receiving device, importantly the widely known Differential Global Positioning System (***DGPS)*** have served as expected (reference) values.

2.2.4. Visibility and timing of recording

Although GPS-enabled smartphones are claimed to have ***accuracy level*** of 5m radius under open sky, their accuracy is argued to degrade near buildings, bridges, and trees. Large objects such as buildings, mountains, or big tree canopies disrupt radio frequencies. That is, they will force satellite signals to bounce off from these structures and result in inaccurate calculation of the signal's timing, eventually leading to the wrong location of the GPS device. Accordingly, geo-location data acquisition was done in a way the effects of large objects is avoided.

[4] It is recommended to download the offline version of Google Maps App in the presence of strong internet connectivity in advance so that it can be applied for data collection in the absence of communication network signals.

Atmospheric phenomena including water vapor reduce the strength of radio signals reaching ground objects and hence compromise the accuracy of coordinate values (Ali, 2020). Therefore, recording was carried out during relatively clear skies.

2.2.5. Number of satellites

Although the GPS consists of a network of 24 medium earth orbit (MEO) satellites constellations stationed at an altitude of about 20,200 KMs, a maximum number of GPS satellites accessed by a hand-held GPS receiver (a hand-held Garmin GPS in this case) are known to be 12 on average. Subsequently, in order to obtain reasonably precise geo-located data and to show precise coordinate values of a point position on the earth's surface, a minimum of four satellites are required. The more the number of satellites accessed by a GPS receiver, the more accurate will be the geo-location data (coordinate). Interestingly, GPS-enabled smart phones were able to receive signals from a minimum of 16 satellites and a maximum of 40 satellites due to their in-built functionality to receive from different satellites that make up the global navigation satellite systems (GNSS). In contrast, Garmin etrex 30 hand-held GPS device received signals only from a maximum of 12 and a minimum of 8 satellites.

2.2.6. Sample size

One of important considerations in the validation process was having good enough data records for better extrapolation. A test site based on recommendations from SSGI experts was purposively selected and total of 33 data points at 30 to 50 meters interval in both North-South and East-West Directions have been identified to collect sample geo-location data.

2.2.7. Datum and coordinate units of measurement

According to NOAA, a geodetic datum refers to an abstract coordinate system with a reference surface that serves to provide known locations to begin surveys and create maps. There are several reference coordinate reference systems (datum) employed for different locations in the globe. Yet, the common and universally applied datum is the 'World Geodetic System 1984 (WGS 1984)' and this has been applied in this study. Experts in the field of GIS recommend use of the Adindan Clarke 1880 datum as the local datum for Ethiopia and Eritrea. Notwithstanding, google map employs the WGS 1984 standard and use of the Adindan Clarke 1880 datum in this study was thought to create data inconsistencies and complicate validation processes.

Within is the frame of the WGS 1984 datum, two types of coordinate measurement units can be applied to record latitude and longitude values. These are the geographic coordinate system units (often involving decimal degrees or degrees-minutes-seconds (DMS) units of measurement) and the projected coordinate system units (often employing meter as a unit of measurement). In the latter case, the Universal Transverse Mercator (UTM) is the most commonly used projected coordinate system in Ethiopia and the Tropics at large. Measurement accuracy levels of GPS receiving devices (hand-held Garmin GPS and **smartphones** in this case) are often calculated in meters. Hence, the UTM approach (in meters) was used for this validation work to simplify data analysis using linear units (Senanayake & Jayawardena, 2018).

2.2.8. Data recording

Two different recording sheet categories (one for general information and the other for geo-location data recording) were employed for this wok. The general information sheet was common to all devices,

but the geo-location data and associated features sheets vary depending on the devices employed as presented under the Annex section.

2.2.9. Validation approach

The Root Mean Square Error (RMSE) and the Mean Absolute Deviation (MAD) methods were employed to measure the degree of fitness between observed and expected values. These methods were selected due to their universality and simplicity while comparing actual and predicted values.

A brief technical consultative meeting was held among the FOLUR Ethiopia team, ECTA, and UNDP to review the methodology and agreed on the threshold to accept or reject the final test results (deviation greater than 10 meters in North – South and East – West directions). The team has also emphasized on the need to make sure the approaches and methodologies are aligned to broader geo-location database management platforms and requirements.

3. Results

Root Mean Square Error (RMSE) and Mean Absolute Deviation (MAD) values computed from sample data sets proved that both GPS enabled smartphones (Samsung A55 & Samsung A35) can reliably help geo-location data collection within less than 3.1 meters planimetric accuracy (Table 2).

Table 2: Summary of Geo-location data values recorded using various GPS devices and computed deviations against precision instrument

#	GPS App	Validity Parameter Values Against Precision Device (DGPS LeicaGS18)			
		RMSE		Mean Absolute Deviation	
		Easting	Northing	Easting	Northing
1	Garmin etrex 30 (hand-held GPS)	1.829	3.079	1.184	2.947
2	A55 with Tracklia App	2.043	1.054	1.676	0.804
3	A55 with MyGPS Coordinate App	1.523	1.830	1.1867	1.2332
4	Samsung A55 with Google Maps App	1.965	1.738	1.641	1.474
5	Samsung A35 with Tracklia App	1.607	1.326	1.126	0.902
6	Samsung A35 with Google Maps App	7.011	15.391	5.116	9.467

- Both devices with Tracklia GPS app proved to collect geo-location data with deviations not going beyond 2.05 meters in both North – South and East – West Directions.
- Samsung A35 performed better than Samsung A55 while using Tracklia GPS App (<1.61 meters).
- Small deviations (<1.83 meters) have also been noted while using Samsung A55 with MyGPS Coordinate App installed on it.
- An exception finding (in the range of 5 to 15.4 meters) is the deviation observed in Samsung A35 with Google Maps App and this requires further exploration of the reasons.

4. Conclusions and recommendations

The processes of validating GPS-enabled smartphones pursued good enough sets of approaches and instrument combinations. The findings generally indicated better reliability of Samsung A55 and Samsung A35 smartphones for collecting geo-location data when compared to hand-held Garmin etrex 30. The two Samsung smartphones have shown slight differences in measurement accuracy levels while using different GPS Apps.

Findings suggest that stakeholders involved in geo-location data collection activities in smallholder coffee farm plots have the freedom to choose either of the Samsung smartphone brands. Yet, it's worth considering cost elements before procurement decisions. Both Tracklia or MyGPS Coordinate Apps performed well and are recommended for use.

5. References

Ali, M. E. (2020). *Global Positioning System (GPS): Definition, Principles, Errors, Applications & DGPS*.

Bauer, C. (2013). On the (In-)Accuracy of GPS Measures of Smartphones: A Study of Running Tracking Applications. *Proceedings of International Conference on Advances in Mobile Computing & Multimedia - MoMM '13*, 335–341. https://doi.org/10.1145/2536853.2536893

Fator, M., & Zomrawi, N. (2015). Etrex Garmin GPS Receiver Accuracy Testing. *International Journal on Recent and Innovation Trends in Computing and Communication*, *3*(5).

Scholtes, V. A., Terwee, C. B., & Poolman, R. W. (2011). What makes a measurement instrument valid and reliable? *Injury*, *42*(3), 236–240. https://doi.org/10.1016/j.injury.2010.11.042

Senanayake, I. P., & Jayawardena, C. L. (2018). *Accuracy of Smartphone Location Services for Geo-tagged Data Collection: A Field Study*.

6. Annex

Annex A: Geo-location data values recorded using various GPS devices and computed deviations against precision instrument

Annex A1: Geo-location data values using Garmin etrex 30 (hand-held GPS) and computed deviations

Data point codes	Garmin Coordinate Values		DGPS LeicaGS18 Coordinate Values		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478600	1006864	478599.191	1006860.735	0.809	3.265	0.654	10.660	0.809	3.265
A02	478590	1006928	478597.681	1006925.545	-7.681	2.455	58.996	6.027	7.681	2.455
A03	478651	1006901	478650.739	1006897.877	0.261	3.123	0.068	9.753	0.261	3.123
A04	478688	1006929	478688.660	1006926.216	-0.660	2.784	0.436	7.751	0.660	2.784
A05	478727	1006958	478726.919	1006953.880	0.081	4.120	0.007	16.974	0.081	4.120
A06	478717	1006884	478719.066	1006881.491	-2.066	2.509	4.267	6.295	2.066	2.509
A07	478718	1006835	478719.930	1006831.913	-1.930	3.087	3.723	9.530	1.930	3.087
A08	478723	1006752	478724.840	1006749.129	-1.840	2.871	3.384	8.243	1.840	2.871
A09	478636	1006756	478637.656	1006753.954	-1.656	2.046	2.741	4.186	1.656	2.046
A010	478520	1006745	478523.048	1006742.851	-3.048	2.149	9.292	4.618	3.048	2.149
A011	478487	1006795	478489.190	1006798.398	-2.190	-3.398	4.796	11.546	2.190	3.398
A012	478473	1006847	478474.016	1006849.487	-1.016	-2.487	1.033	6.185	1.016	2.487
A013	478457	1006908	478457.072	1006911.152	-0.072	-3.152	0.005	9.935	0.072	3.152
A014	478402	1006932	478401.527	1006932.505	0.473	-0.505	0.223	0.255	0.473	0.505
A015	478351	1006928	478351.141	1006929.828	-0.141	-1.828	0.020	3.342	0.141	1.828
A016	478295	1006915	478292.375	1006917.137	2.625	-2.137	6.891	4.567	2.625	2.137
A017	478241	1006880	478240.894	1006884.649	0.106	-4.649	0.011	21.613	0.106	4.649
A018	478205	1006859	478204.798	1006861.752	0.202	-2.752	0.041	7.574	0.202	2.752
A019	478172	1006827	478173.270	1006829.784	-1.270	-2.784	1.613	7.751	1.270	2.784
A020	478130	1006796	478130.600	1006799.452	-0.600	-3.452	0.360	11.916	0.600	3.452
A021	478076	1006769	478077.089	1006772.859	-1.089	-3.859	1.186	14.892	1.089	3.859
A022	478009	1006729	478009.577	1006733.854	-0.577	-4.854	0.333	23.561	0.577	4.854
A023	478003	1006699	478003.952	1006702.239	-0.952	-3.239	0.906	10.491	0.952	3.239
A024	478043	1006704	478043.925	1006707.043	-0.925	-3.043	0.856	9.260	0.925	3.043
A025	478105	1006711	478105.926	1006713.775	-0.926	-2.775	0.858	7.701	0.926	2.775
A026	478167	1006717	478167.309	1006720.716	-0.309	-3.716	0.096	13.809	0.309	3.716
A027	478227	1006723	478229.014	1006727.159	-2.014	-4.159	4.054	17.297	2.014	4.159
A028	478290	1006730	478291.122	1006732.892	-1.122	-2.892	1.258	8.364	1.122	2.892
A029	478352	1006736	478353.202	1006737.802	-1.202	-1.802	1.446	3.247	1.202	1.802
A030	478373	1006774	478372.888	1006777.681	0.112	-3.681	0.013	13.550	0.112	3.681
A031	478433	1006772	478432.107	1006775.175	0.893	-3.175	0.798	10.081	0.893	3.175
A032	478482	1006740	478482.155	1006741.306	-0.155	-1.306	0.024	1.706	0.155	1.306
A033	478464	1006699	478464.064	1006702.194	-0.064	-3.194	0.004	10.202	0.064	3.194
Average							**3.345**	**9.481**		
Root Mean Square Error (RMSE)							**1.829**	**3.079**		
Mean Absolute Deviation									**1.184**	**2.947**

Annex A2: Geo-location data values using Samsung A55 with Tracklia App and computed deviations

Data point codes	A55_Tracklia Coordinate Values		DGPS LeicaGS18 Coordinate Values		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478599.770	1006862.770	478599.191	1006860.735	0.579	2.035	0.335	4.141	0.579	2.035
A02	478599.510	1006925.450	478597.681	1006925.545	1.829	-0.095	3.346	0.009	1.829	0.095
A03	478651.920	1006898.330	478650.739	1006897.877	1.181	0.453	1.395	0.205	1.181	0.453
A04	478690.650	1006925.290	478688.660	1006926.216	1.990	-0.926	3.960	0.857	1.990	0.926
A05	478729.060	1006953.370	478726.919	1006953.880	2.141	-0.510	4.583	0.260	2.141	0.510
A06	478722.200	1006882.010	478719.066	1006881.491	3.134	0.519	9.824	0.269	3.134	0.519
A07	478721.030	1006831.760	478719.930	1006831.913	1.101	-0.153	1.211	0.023	1.101	0.153
A08	478724.560	1006748.960	478724.840	1006749.129	-0.280	-0.169	0.078	0.029	0.280	0.169
A09	478638.170	1006754.140	478637.656	1006753.954	0.514	0.186	0.265	0.035	0.514	0.186
A010	478523.960	1006743.690	478523.048	1006742.851	0.912	0.839	0.831	0.704	0.912	0.839
A011	478491.160	1006796.930	478489.190	1006798.398	1.970	-1.468	3.881	2.155	1.970	1.468
A012	478477.050	1006848.030	478474.016	1006849.487	3.034	-1.457	9.203	2.123	3.034	1.457
A013	478462.500	1006913.700	478457.072	1006911.152	5.428	2.548	29.462	6.492	5.428	2.548
A014	478403.590	1006933.270	478401.527	1006932.505	2.063	0.765	4.254	0.585	2.063	0.765
A015	478353.710	1006929.130	478351.141	1006929.828	2.569	-0.698	6.601	0.487	2.569	0.698
A016	478296.200	1006918.290	478292.375	1006917.137	3.825	1.153	14.631	1.329	3.825	1.153
A017	478243.240	1006884.540	478240.894	1006884.649	2.346	-0.109	5.502	0.012	2.346	0.109
A018	478203.840	1006862.710	478204.798	1006861.752	-0.958	0.958	0.917	0.918	0.958	0.958
A019	478172.330	1006829.530	478173.270	1006829.784	-0.940	-0.254	0.883	0.065	0.940	0.254
A020	478132.190	1006799.760	478130.600	1006799.452	1.590	0.308	2.529	0.095	1.590	0.308
A021	478078.870	1006770.320	478077.089	1006772.859	1.781	-2.539	3.172	6.447	1.781	2.539
A022	478011.500	1006733.390	478009.577	1006733.854	1.923	-0.464	3.697	0.215	1.923	0.464
A023	478004.630	1006701.590	478003.952	1006702.239	0.678	-0.649	0.460	0.421	0.678	0.649
A024	478044.860	1006706.150	478043.925	1006707.043	0.935	-0.893	0.873	0.797	0.935	0.893
A025	478106.980	1006713.250	478105.926	1006713.775	1.054	-0.525	1.111	0.276	1.054	0.525
A026	478167.660	1006720.350	478167.309	1006720.716	0.351	-0.366	0.123	0.134	0.351	0.366
A027	478229.630	1006727.020	478229.014	1006727.159	0.617	-0.139	0.380	0.019	0.617	0.139
A028	478291.010	1006733.020	478291.122	1006732.892	-0.112	0.128	0.012	0.016	0.112	0.128
A029	478357.030	1006736.020	478353.202	1006737.802	3.828	-1.782	14.651	3.176	3.828	1.782
A030	478372.270	1006776.500	478372.888	1006777.681	-0.618	-1.181	0.381	1.395	0.618	1.181
A031	478431.140	1006775.110	478432.107	1006775.175	-0.967	-0.065	0.935	0.004	0.967	0.065
A032	478480.160	1006739.690	478482.155	1006741.306	-1.995	-1.616	3.978	2.611	1.995	1.616
A033	478466.140	1006702.770	478464.064	1006702.194	2.076	0.576	4.310	0.332	2.076	0.576
Average							**4.175**	**1.110**		
Root Mean Square Error (RMSE)							**2.043**	**1.054**		
Mean Absolute Deviation									**1.676**	**0.804**

Annex A3: Geo-location data values using Samsung A55 with MyGPS Coordinate App and computed deviations

Data point codes	A55 MyGPS Coordinate Values		DGPS LeicaGS18 Coordinate Values		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478601	1006861	478599.191	1006860.735	1.809	0.265	3.272	0.070	1.809	0.265
A02	478597	1006926	478597.681	1006925.545	-0.681	0.455	0.464	0.207	0.681	0.455
A03	478651	1006899	478650.739	1006897.877	0.261	1.123	0.068	1.261	0.261	1.123
A04	478690	1006927	478688.660	1006926.216	1.340	0.784	1.795	0.615	1.340	0.784
A05	478729	1006951	478726.919	1006953.880	2.081	-2.880	4.329	8.294	2.081	2.880
A06	478719	1006881	478719.066	1006881.491	-0.066	-0.491	0.004	0.241	0.066	0.491
A07	478720	1006829	478719.930	1006831.913	0.070	-2.913	0.005	8.486	0.070	2.913
A08	478723	1006749	478724.840	1006749.129	-1.840	-0.129	3.384	0.017	1.840	0.129
A09	478639	1006755	478637.656	1006753.954	1.344	1.046	1.807	1.094	1.344	1.046
A010	478522	1006741	478523.048	1006742.851	-1.048	-1.851	1.099	3.426	1.048	1.851
A011	478490	1006796	478489.190	1006798.398	0.810	-2.398	0.656	5.750	0.810	2.398
A012	478475	1006849	478474.016	1006849.487	0.984	-0.487	0.968	0.237	0.984	0.487
A013	478460	1006910	478457.072	1006911.152	2.928	-1.152	8.573	1.327	2.928	1.152
A014	478401	1006933	478401.527	1006932.505	-0.527	0.495	0.278	0.245	0.527	0.495
A015	478350	1006930	478351.141	1006929.828	-1.141	0.172	1.301	0.030	1.141	0.172
A016	478294	1006910	478292.375	1006917.137	1.625	-7.137	2.641	50.937	1.625	7.137
A017	478241	1006884	478240.894	1006884.649	0.106	-0.649	0.011	0.421	0.106	0.649
A018	478204	1006861	478204.798	1006861.752	-0.798	-0.752	0.636	0.566	0.798	0.752
A019	478173	1006831	478173.270	1006829.784	-0.270	1.216	0.073	1.479	0.270	1.216
A020	478130	1006801	478130.600	1006799.452	-0.600	1.548	0.360	2.396	0.600	1.548
A021	478076	1006774	478077.089	1006772.859	-1.089	1.141	1.186	1.302	1.089	1.141
A022	478010	1006730	478009.577	1006733.854	0.423	-3.854	0.179	14.853	0.423	3.854
A023	478001	1006703	478003.952	1006702.239	-2.952	0.761	8.713	0.579	2.952	0.761
A024	478043	1006708	478043.925	1006707.043	-0.925	0.957	0.856	0.916	0.925	0.957
A025	478103	1006715	478105.926	1006713.775	-2.926	1.225	8.562	1.501	2.926	1.225
A026	478165	1006721	478167.309	1006720.716	-2.309	0.284	5.332	0.081	2.309	0.284
A027	478229	1006728	478229.014	1006727.159	-0.014	0.841	0.000	0.707	0.014	0.841
A028	478291	1006733	478291.122	1006732.892	-0.122	0.108	0.015	0.012	0.122	0.108
A029	478353	1006738	478353.202	1006737.802	-0.202	0.198	0.041	0.039	0.202	0.198
A030	478370	1006778	478372.888	1006777.681	-2.888	0.319	8.338	0.102	2.888	0.319
A031	478433	1006774	478432.107	1006775.175	0.893	-1.175	0.798	1.381	0.893	1.175
A032	478479	1006742	478482.155	1006741.306	-3.155	0.694	9.951	0.482	3.155	0.694
A033	478465	1006701	478464.064	1006702.194	0.936	-1.194	0.876	1.426	0.936	1.194
Mean							**2.320**	**3.348**		
Root Mean Square Error (RMSE)							**1.523**	**1.830**		
Mean Absolute Deviation									**1.1867**	**1.2332**

Annex A4: Geo-location data values and computed deviations for Samsung A55 with Google Maps App

Data point codes	A55 Google Maps Coordinate Values		DGPS LeicaGS18 Coordinate Values (precision device)		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478600.633	1006862.636	478599.191	1006860.735	1.442	1.901	2.079	3.613	1.442	1.901
A02	478597.615	1006927.130	478597.681	1006925.545	-0.065	1.585	0.004	2.512	0.065	1.585
A03	478652.540	1006896.390	478650.739	1006897.877	1.801	-1.487	3.243	2.212	1.801	1.487
A04	478689.183	1006927.081	478688.660	1006926.216	0.523	0.865	0.274	0.748	0.523	0.865
A05	478728.877	1006954.699	478726.919	1006953.880	1.958	0.819	3.835	0.671	1.958	0.819
A06	478722.734	1006880.997	478719.066	1006881.491	3.668	-0.494	13.454	0.244	3.668	0.494
A07	478722.707	1006831.860	478719.930	1006831.913	2.778	-0.053	7.716	0.003	2.778	0.053
A08	478722.665	1006752.012	478724.840	1006749.129	-2.175	2.883	4.731	8.311	2.175	2.883
A09	478637.202	1006755.129	478637.656	1006753.954	-0.453	1.175	0.205	1.380	0.453	1.175
A010	478524.262	1006742.905	478523.048	1006742.851	1.213	0.054	1.472	0.003	1.213	0.054
A011	478490.716	1006798.203	478489.190	1006798.398	1.526	-0.195	2.330	0.038	1.526	0.195
A012	478472.429	1006847.350	478474.016	1006849.487	-1.587	-2.137	2.518	4.568	1.587	2.137
A013	478457.203	1006911.850	478457.072	1006911.152	0.131	0.698	0.017	0.488	0.131	0.698
A014	478399.222	1006933.379	478401.527	1006932.505	-2.306	0.874	5.316	0.764	2.306	0.874
A015	478353.436	1006930.333	478351.141	1006929.828	2.295	0.505	5.269	0.255	2.295	0.505
A016	478292.382	1006915.011	478292.375	1006917.137	0.008	-2.126	0.000	4.520	0.008	2.126
A017	478240.477	1006884.329	478240.894	1006884.649	-0.417	-0.320	0.174	0.103	0.417	0.320
A019	478173.295	1006826.015	478173.270	1006829.784	0.025	-3.769	0.001	14.204	0.025	3.769
A021	478078.644	1006770.788	478077.089	1006772.859	1.555	-2.071	2.419	4.289	1.555	2.071
A022	478008.420	1006730.903	478009.577	1006733.854	-1.157	-2.951	1.339	8.709	1.157	2.951
A023	478005.351	1006700.194	478003.952	1006702.239	1.399	-2.045	1.957	4.183	1.399	2.045
A024	478041.982	1006706.316	478043.925	1006707.043	-1.944	-0.727	3.779	0.529	1.944	0.727
A025	478103.032	1006715.495	478105.926	1006713.775	-2.894	1.720	8.375	2.959	2.894	1.720
A027	478228.181	1006724.640	478229.014	1006727.159	-0.833	-2.519	0.694	6.346	0.833	2.519
A028	478292.282	1006730.747	478291.122	1006732.892	1.160	-2.145	1.346	4.601	1.160	2.145
A029	478356.385	1006739.925	478353.202	1006737.802	3.182	2.123	10.128	4.508	3.182	2.123
A030	478371.668	1006779.841	478372.888	1006777.681	-1.220	2.160	1.488	4.665	1.220	2.160
A031	478435.764	1006776.735	478432.107	1006775.175	3.657	1.560	13.375	2.433	3.657	1.560
A032	478478.476	1006739.859	478482.155	1006741.306	-3.679	-1.447	13.533	2.094	3.679	1.447
A033	478466.247	1006703.013	478464.064	1006702.194	2.183	0.819	4.764	0.670	2.183	0.819
Average							**3.861**	**3.021**		
Root Mean Square Error (RMSE)							**1.965**	**1.738**		
Mean Absolute Deviation									**1.641**	**1.474**

Annex A5: Geo-location data values and computed deviations for Samsung A35 with Tracklia App

Data point codes	A35_Tracklia Coordinate Values		DGPS LeicaGS18 Coordinate Values (precision device)		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478597.000	1006860.000	478599.191	1006860.735	-2.191	-0.735	4.800	0.540	2.191	0.735
A02	478593.300	1006927.100	478597.681	1006925.545	-4.381	1.555	19.192	2.418	4.381	1.555
A03	478650.700	1006898.200	478650.739	1006897.877	-0.039	0.323	0.002	0.104	0.039	0.323
A04	478689.950	1006925.870	478688.660	1006926.216	1.290	-0.346	1.664	0.120	1.290	0.346
A05	478725.780	1006954.330	478726.919	1006953.880	-1.139	0.450	1.298	0.202	1.139	0.450
A06	478718.300	1006882.340	478719.066	1006881.491	-0.766	0.849	0.586	0.721	0.766	0.849
A07	478718.190	1006829.090	478719.930	1006831.913	-1.740	-2.823	3.026	7.969	1.740	2.823
A08	478727.180	1006749.260	478724.840	1006749.129	2.340	0.131	5.477	0.017	2.340	0.131
A09	478639.090	1006754.790	478637.656	1006753.954	1.434	0.836	2.058	0.699	1.434	0.836
A010	478522.450	1006742.190	478523.048	1006742.851	-0.598	-0.661	0.358	0.437	0.598	0.661
A011	478489.100	1006799.100	478489.190	1006798.398	-0.090	0.702	0.008	0.493	0.090	0.702
A012	478473.400	1006849.600	478474.016	1006849.487	-0.616	0.113	0.380	0.013	0.616	0.113
A013	478455.310	1006911.870	478457.072	1006911.152	-1.762	0.718	3.105	0.516	1.762	0.718
A014	478403.000	1006932.180	478401.527	1006932.505	1.473	-0.325	2.169	0.106	1.473	0.325
A015	478351.690	1006931.500	478351.141	1006929.828	0.549	1.672	0.302	2.796	0.549	1.672
A016	478293.470	1006916.830	478292.375	1006917.137	1.095	-0.307	1.199	0.094	1.095	0.307
A017	478240.550	1006884.170	478240.894	1006884.649	-0.344	-0.479	0.119	0.229	0.344	0.479
A018	478205.910	1006863.880	478204.798	1006861.752	1.112	2.128	1.237	4.528	1.112	2.128
A019	478170.690	1006830.440	478173.270	1006829.784	-2.580	0.656	6.656	0.430	2.580	0.656
A020	478130.900	1006804.110	478130.600	1006799.452	0.300	4.658	0.090	21.697	0.300	4.658
A021	478076.690	1006772.340	478077.089	1006772.859	-0.399	-0.519	0.159	0.269	0.399	0.519
A022	478009.620	1006733.900	478009.577	1006733.854	0.043	0.046	0.002	0.002	0.043	0.046
A023	478003.970	1006701.480	478003.952	1006702.239	0.018	-0.759	0.000	0.576	0.018	0.759
A024	478044.830	1006707.200	478043.925	1006707.043	0.905	0.157	0.818	0.025	0.905	0.157
A025	478105.430	1006716.470	478105.926	1006713.775	-0.496	2.695	0.246	7.263	0.496	2.695
A026	478166.260	1006721.600	478167.309	1006720.716	-1.049	0.884	1.101	0.781	1.049	0.884
A027	478227.680	1006727.160	478229.014	1006727.159	-1.334	0.001	1.778	0.000	1.334	0.001
A028	478290.680	1006732.880	478291.122	1006732.892	-0.442	-0.012	0.195	0.000	0.442	0.012
A029	478353.460	1006738.080	478353.202	1006737.802	0.258	0.278	0.066	0.077	0.258	0.278
A030	478373.460	1006776.370	478372.888	1006777.681	0.572	-1.311	0.328	1.719	0.572	1.311
A031	478431.900	1006773.900	478432.107	1006775.175	-0.207	-1.275	0.043	1.626	0.207	1.275
A032	478482.600	1006741.180	478482.155	1006741.306	0.445	-0.126	0.198	0.016	0.445	0.126
A033	478469.220	1006703.430	478464.064	1006702.194	5.156	1.236	26.584	1.528	5.156	1.236
Average							**2.583**	**1.758**		
Root Mean Square Error (RMSE)							**1.607**	**1.326**		
Mean Absolute Deviation									**1.126**	**0.902**

Annex A6: Geo-location data values and computed deviations for A35 with Google Maps App

Data point codes	A35_GoogleMap Coordinate Values		DGPS LeicaGS18 Coordinate Values (precision device)		Deviation (Error)		Squared Deviation		Absolute Deviation	
	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
A01	478600.618	1006834.996	478599.191	1006860.735	1.427	-25.739	2.037	662.486	1.427	25.739
A02	478594.560	1006920.989	478597.681	1006925.545	-3.121	-4.556	9.741	20.753	3.121	4.556
A04	478698.334	1006914.792	478688.660	1006926.216	9.673	-11.424	93.575	130.518	9.673	11.424
A05	478741.088	1006957.764	478726.919	1006953.880	14.169	3.884	200.757	15.083	14.169	3.884
A06	478719.675	1006868.714	478719.066	1006881.491	0.609	-12.777	0.371	163.250	0.609	12.777
A07	478731.862	1006828.784	478719.930	1006831.913	11.933	-3.129	142.394	9.793	11.933	3.129
A08	478719.612	1006752.013	478724.840	1006749.129	-5.227	2.884	27.325	8.320	5.227	2.884
A010	478512.034	1006709.130	478523.048	1006742.851	-11.014	-33.721	121.307	1137.098	11.014	33.721
A011	478484.605	1006785.922	478489.190	1006798.398	-4.585	-12.476	21.020	155.659	4.585	12.476
A012	478472.428	1006844.279	478474.016	1006849.487	-1.589	-5.208	2.523	27.127	1.589	5.208
A014	478396.183	1006957.950	478401.527	1006932.505	-5.345	25.445	28.565	647.424	5.345	25.445
A015	478338.200	1006976.408	478351.141	1006929.828	-12.941	46.580	167.465	2169.650	12.941	46.580
A016	478283.226	1006915.016	478292.375	1006917.137	-9.149	-2.121	83.708	4.498	9.149	2.121
A022	478011.477	1006740.114	478009.577	1006733.854	1.900	6.260	3.611	39.192	1.900	6.260
A025	478106.084	1006715.494	478105.926	1006713.775	0.158	1.719	0.025	2.954	0.158	1.719
A026	478167.132	1006718.531	478167.309	1006720.716	-0.177	-2.185	0.031	4.774	0.177	2.185
A027	478228.181	1006724.640	478229.014	1006727.159	-0.833	-2.519	0.694	6.346	0.833	2.519
A028	478292.284	1006733.818	478291.122	1006732.892	1.162	0.926	1.350	0.857	1.162	0.926
A029	478353.331	1006736.856	478353.202	1006737.802	0.128	-0.946	0.017	0.895	0.128	0.946
A031	478444.919	1006773.659	478432.107	1006775.175	12.812	-1.516	164.155	2.299	12.812	1.516
A032	478484.580	1006739.856	478482.155	1006741.306	2.426	-1.450	5.885	2.104	2.426	1.450
A033	478466.247	1006703.013	478464.064	1006702.194	2.183	0.819	4.764	0.670	2.183	0.819
Average							**49.151**	**236.898**		
Root Mean Square Error (RMSE)							**7.011**	**15.391**		
Mean Absolute Deviation									**5.116**	**9.467**