ASSESSMENT OF HAND-HELD GPS SURVEYING IN LAND ADJUDICATION: A CASE STUDY OF NGOLIBA SETTLEMENT SCHEME IN KENYA

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Abstract
Land adjudication is the process through which existing rights in a particular parcel of land are ascertained. Land ownership in Kenya is largely achieved through a land adjudication process, especially in the rural areas. The Preliminary Index Diagrams (PIDs) are the official map documents that together with adjudication records constitute the adjudication register required for determination and registration of interests and rights over land. The PIDs are produced from enlarged, marked and un-rectified aerial photographs; hence they contain distortions. This paper assesses the application of hand-held GPS surveying to determine plot boundaries in an adjudication area in Kenya. The study was conducted in Ngoliba Settlement schemes. Areas of 12 plots of similar sizes were obtained by three methods - PIDs, traditional ground based surveying using a station-theodolite and EDM (total station) and using a hand-held single GPS (in point positioning mode). Plot areas obtained from PIDs and GPS were compared against those determined from total station measurements, which are taken as the standard in this study. We also compared the coordinates and side lengths derived from total station and hand-held GPS measurements. Results show that hand-held GPS can recover 98.1% of the combined area of the 12 plots compared to PIDs which can only recover 77.5%. Results from coordinates and side lengths differences show that hand-held GPS can determine side lengths and coordinates that are approximately close to the ones obtained by total station. Hence Hand-held GPS would significantly improve the accuracy of parcel areas for land adjudication when compared to those obtained from PIDs only.

Key words: land adjudication, hand-held GPS, total station, aerial photograph, PIDs, Ngoliba

1.0 Introduction

The last few decades have seen a sharp rise in the demand for better land records in all parts of the world. This demand has been drawn by two factors, the transition to a market economy in many countries, and the need to establish land information system for better resource and environmental management. Consequently, many countries have been implementing land titling programmes as part of attempts to improve the performance of their economies (e.g., Angus-Leppan and Williamson, 1985; Angus –Leppan, 1989; McLaughlin and de Soto, 1994).

Land is categorized in three territorial domains in Kenya, namely government, private and trust land. Government land comprises 10%; Private land 20% and Trust land 70% of the total land area (Mwenda, 2001). Interests in land are broadly classified into three groups. These include customary rights (governed by customary law), statutory or formal rights (governed by statutory law) and informal or non-formal rights (under informal tenure arrangements). Formal land ownership information consists of boundary definitions and cadastral maps that support registration of land parcels. Land parcel boundary in Kenya is normally obtained as fixed or general.

Fixed boundaries utilize high precision surveying methods and are mostly found in urban areas, they are marked by accurately positioned concrete beacons at turning points. The outputs from such surveys are survey plans that are geo-referenced and often referenced to the national geodetic reference system. General boundaries were introduced along with the land reforms for individualization of land tenure. The aim was to speed-up the issuance of individual title to land proprietors and to realize as much cadastral coverage as possible in the former colonial native reserves in Kenya. These general boundaries are described by physical features (e.g. hedges, rivers, cliffs, etc) and surveyed using relaxed survey methods, hence inaccurate and unreliable for precise parcel boundary delineation.

The resulting maps for general boundary areas in Kenya are referred to as Preliminary Index Diagrams (PIDs) and Registry Index Maps (RIMs) which are not geo-referenced and generally of low accuracy. Generally, the uncertainty in PID area is about ±20% of the actual area (Ondulo et al., 2015). Several researchers have investigated the problem of general boundaries and the cadastral system in Kenya (Wayumba, 2013; Myles et al., 2009; Mwenda, 2001; Adams 1969). The concept of general boundaries was originally introduced in Kenya in 1959 through the use of registry index map (GoK, 1966). Land ownership in the vast Kenyan Trust land (designated as adjudication areas) is through the process of land adjudication of which the Preliminary Index Diagram (PID) is the official map document that together with adjudication record constitute the adjudication register that forms the basis for determination and registration of interests and rights over land and the subsequent issuance of titles.

In this paper, we assess application of hand-held GPS in improving the accuracy of preliminary index diagram areas in adjudication areas in order to improve effectiveness in land administration in Kenya. This is also consistent with the new Land Registration Act 2012, Sec.15 (2) which makes a case for more accurate parcel boundary delineation (Land Registration Act, 2012). A comparative analysis of the conventional surveying using theodolite and EDM (total station) as well as with single hand-held GPS is also conducted. To facilitate the comparisons, 12 plots in Ngoliba Settlement schemes (under general boundary) in Thika District are surveyed by both total station and hand-held GPS. The coordinates were determined at 33 plot corners. Comparisons of areas, coordinates and side lengths are then carried out and presented in the paper. The area of study including the individual plots is shown in Figure 1. The study area covers parts of Ingoliba settlement scheme in Thika District along Garissa–Kitui road.

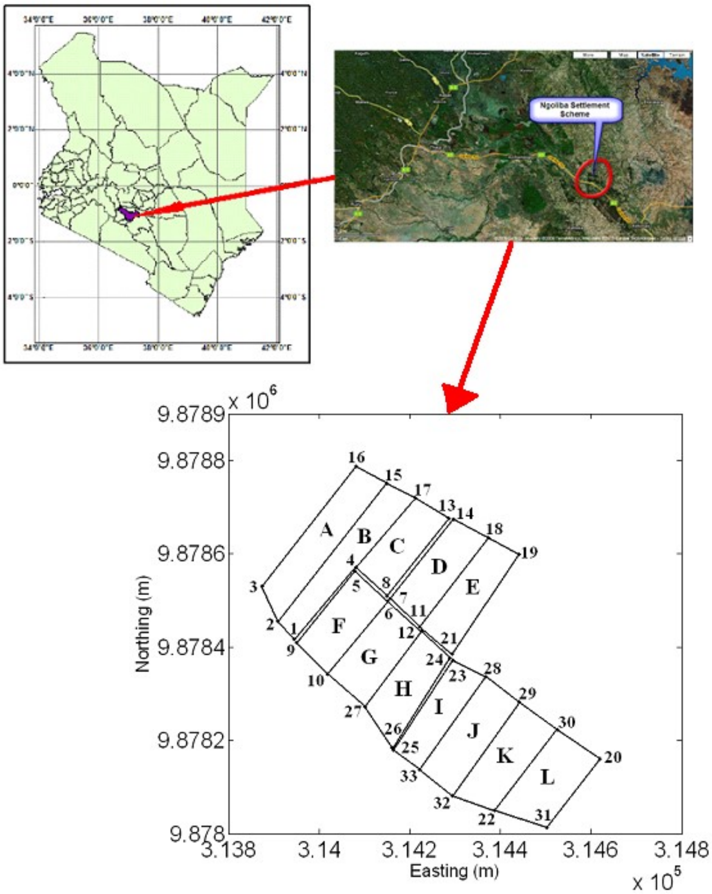

Figure 1: Area of study

2.0 Materials and Methods

2.1 Area determination from Aerial Photography Technique (PIDs)

Aerial photo covering the area of interest at a scale of 1:50,000 is enlarged to a scale of 1:12,500 to facilitate identification of land parcel boundary. The enlarged photo is then marked using green marker pencil, to highlight the required parcel boundaries as illustrated in Figure 2. We have used an aerial photograph covering Jomo Kenyatta University of Agriculture and Technology for illustration only (see Figure 2). We have used a photograph for a different area for illustration because we could not trace the photograph for the study area at Survey of Kenya. The marked boundaries are then traced manually on to a transparent plastic material called dura-film. Two area measurements are then performed for each parcel using the manual planimeter and the average of the measured areas of individual land parcel is adopted.

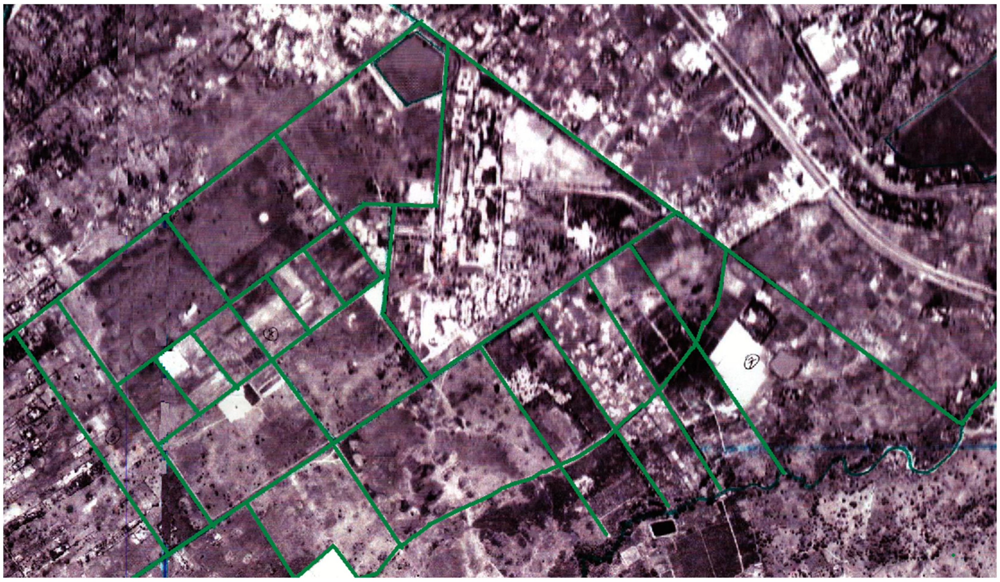

Figure 2: Marked, enlarged aerial photo

In Kenya the use of PIDs was necessitated by very high demand for land titles especially immediately after independence. The details of this use and underlying policies are well documented (e.g., Ratzeburg, 1970; Dale and McLaughlin, 1998; Mulaku and McLaughlin, 1996). Due to photogrammetric and cartographic distortions, PIDs are only suitable for identifying land parcel on the ground and indexing registered land. The effects of inaccurate PID areas are manifested in the general dissatisfaction of PID users since financial institutions are only prepared to advance 40 percent of the land value registered on the basis of PIDs as opposed to 90 percent of the land value registered using more accurate area calculation methods (e.g., Mulaku and McLaughlin, 1996). Accurate parcel area can be obtained by accurate ground surveying techniques such as total station and GPS, among others.

2.2 Area Determination from Total Station

Surveying with total station is a well-established surveying procedure where both angular and linear measurements are obtained from one instrument (combined EDM and theodolite). This technique of measurement has been applied in topographic mapping, land surveying, deformation monitoring and construction works among others (e.g., Kizil and Tisor, 2011; Lin, 2004; Lane and Chandler, 2003, Khalil, 2013). The normal procedure of traversing and double polars was followed to determine the adjusted positions of the plot corner points. The total station (TS) coordinates are based on the local geodetic datum (Arc-Datum 1960) determined by classical techniques. The final co-ordinates were used to compute side lengths and areas of the land parcels.

2.3 Area Determination from Hand-held GPS

We used the Garmin eTrex Vista hand-held GPS (HGPS) to determine the coordinates of plot corners. This provides point positioning using correction data obtained from the Wide Area Augmentation System (WAAS). WAAS is a system of satellites and ground stations that provide GPS signal corrections to enhance point positioning accuracy. Once in the field HGPS was used to collect data using the Arc 1960 coordinate reference system and UTM/UPS projection. As before, plot corners were surveyed (Figure 1) to determine plane coordinates. The coordinates obtained were then used to determine side lengths and plot areas. The kind of positioning referred to here is purely point positioning without post processing.

3.0 Results and Discussion

3.1 Comparison of Areas from Ground Surveys and PIDs

Individual and cumulative parcel areas generated from total station (TS), Garmin eTrex Vista - hand-held GPS (HGPS) and aerial photography (PIDs) for the 12 parcels are shown in Table 1. Beginning with the combined area of all the plots, and considering total station areas as the “true” areas, then the combined area obtained from HGPS is more than the TS area by 1.9% while the combined area obtained from PIDs is 22.5% more than the TS total area. This indicates that if the total area of the 12 parcels is considered then hand-held GPS can recover 98.1% of the TS area compared to PIDs which can only recover 77.5% of the TS area. This observation is limited to the area of study and cannot be generalized for any other area with different topographical undulations. A study of such samples covering the whole country would give a more correct comparative analysis but again generalized. HGPS would improve the current PID areas. This would improve land titles data accuracy.

Individual parcel areas were also compared as shown in Table 2. The differences between total station areas and HGPS areas vary from -16.4% to 7.4%. Similarly for PIDs, the differences vary from -43.2% to -1.1%. There is a larger standard deviation (SD) for the PID areas (±0.23 ha) than hand-held GPS areas (±0.14 ha). Figure 3 shows a plot of individual parcel area differences with respect to the actual areas. The linear fits indicate that, generally larger differences in areas occur in larger areas than smaller areas. However, the rate of increase in area error with respect to the actual area (total station area) is higher in PIDs than hand-held GPS areas.

Table 1: Individual and cumulative parcel areas

Parcel No.	Area (ha)		
	TS	**HGPS**	**PID**
A	2.70	2.50	2.73
B	2.36	2.59	2.86
C	1.81	1.82	2.30
D	1.96	2.06	2.35
E	2.16	2.11	2.40
F	1.97	2.00	2.57
G	2.10	2.15	2.33
H	1.99	2.02	2.70
I	1.83	2.13	2.62
J	2.25	2.42	2.97
K	2.32	2.20	2.96
L	2.30	2.25	2.75
Total	25.75	26.25	31.54
Diff.		-0.50	-5.79
% Diff.		-1.94	-22.49

Table 2: Comparison of individual parcel areas

Parcel No.	Area (ha)			Area Difference (ha)			
	TS	**HGPS**	**PID**	**TS-HGPS**		**TS-PID**	
				Diff.	**% Diff.**	**Diff.**	**% Diff.**
A	2.70	2.50	2.73	0.20	7.41	-0.03	-1.11
B	2.36	2.59	2.86	-0.23	-9.75	-0.50	-21.19
C	1.81	1.82	2.30	-0.01	-0.55	-0.49	-27.07
D	1.96	2.06	2.35	-0.10	-5.10	-0.39	-19.90
E	2.16	2.11	2.40	0.05	2.31	-0.24	-11.11
F	1.97	2.00	2.57	-0.03	-1.52	-0.60	-30.46
G	2.10	2.15	2.33	-0.05	-2.38	-0.23	-10.95
H	1.99	2.02	2.70	-0.03	-1.51	-0.71	-35.68
I	1.83	2.13	2.62	-0.30	-16.39	-0.79	-43.17
J	2.25	2.42	2.97	-0.17	-7.56	-0.72	-32.00

K	2.32	2.20	2.96	0.12	5.17	-0.64	-27.59
L	2.30	2.25	2.75	0.05	2.17	-0.45	-19.57
Mean				-0.04	-2.31	-0.48	-23.32
SD				0.14	6.64	0.23	11.80

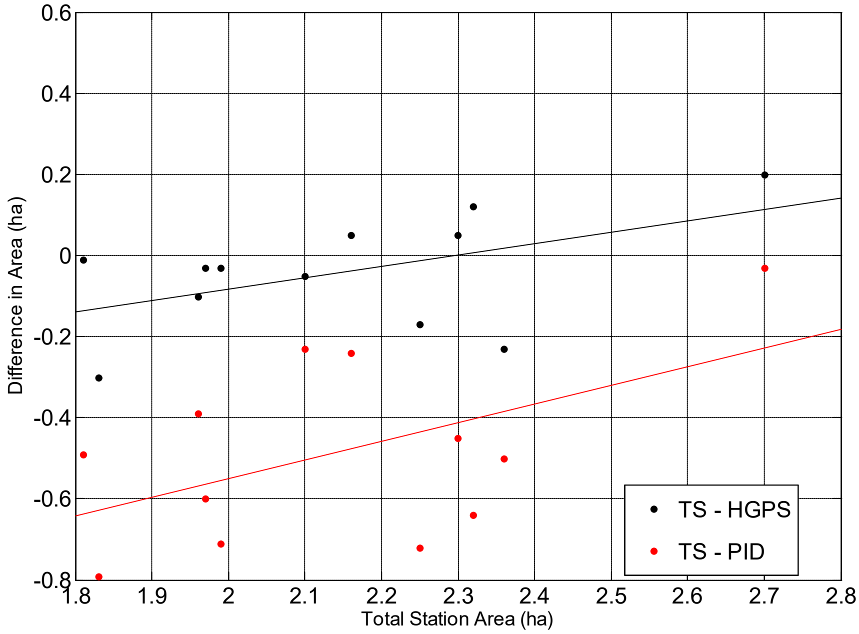

Figure 3: Parcel area differences of hand-held GPS and PID areas with respect to the actual area

3.2 Comparison of Coordinates from Hand-held GPS and Total Station

The coordinates obtained by TS and HGPS together with the differences are given in Table 3. Larger differences were observed in the Northings than Eastings. The standard deviation of the northing differences is ±8.40 m while the standard deviation of the Easting differences is ±4.96 m. We suspect that the significant shifts in North and East are partly due to the use of generalized transformation parameters between Arc-Datum 1960 and WGS84 in HGPS. The other contribution is from the usual errors associated with GPS single point positioning.

The linear point differences between total station and HGPS coordinates are also shown in Figure 4. The standard deviation of the linear point differences is ±6.27 m. The standard deviation of point linear differences reduces to ±5.58 m after removing one point (point 15), which seems to be an outlier. The plot corners and boundary lines obtained by total station and hand held GPS are also plotted (see Figure 5) to facilitate visual interpretation. We note a general shift between the points obtained by the two techniques although positions and shapes of the plots are largely maintained. This effect may be partly a result of the use of generalized transformation parameters between Arc-Datum 1960 and WGS84. A localized set of transformation parameters may reduce the shifts in Northing and Easting coordinates. We note this observation for our future research.

Table 3: Comparison of coordinates from hand-held GPS and total station (units are in m)

Point	$N_{(TS)}$	$E_{(TS)}$	$N_{(HGPS)}$	$E_{(HGPS)}$	$N_{(TS)}$ $-N_{(HGPS)}$	$E_{(TS)}$ $-E_{(HGPS)}$	Linear point difference
1	9878417.50	313945.66	9878422.00	313946.00	-4.50	-0.34	4.51
2	9878455.40	313909.25	9878459.00	313908.00	-3.60	1.25	3.81
3	9878530.95	313873.84	9878537.00	313872.00	-6.05	1.84	6.32
4	9878570.88	314080.77	9878583.00	314076.00	-12.12	4.77	13.02
5	9878562.90	314077.61	9878580.00	314078.00	-17.10	-0.39	17.10
6	9878498.27	314152.00	9878509.00	314157.00	-10.73	-5.00	11.84
7	9878503.69	314156.97	9878517.00	314155.00	-13.31	1.97	13.45
8	9878508.68	314150.31	9878523.00	314149.00	-14.32	1.31	14.38
9	9878409.84	313949.48	9878421.00	313953.00	-11.16	-3.52	11.70
10	9878342.36	314018.83	9878360.00	314023.00	-17.64	-4.17	18.13
11	9878443.30	314221.32	9878455.00	314221.00	-11.70	0.32	11.70
12	9878434.05	314224.56	9878451.00	314230.00	-16.95	-5.44	17.80
13	9878676.00	314286.85	9878695.00	314282.00	-19.00	4.85	19.61
14	9878673.69	314296.70	9878690.00	314295.00	-16.31	1.70	16.40
15	9878751.31	314150.02	9878780.00	314143.00	-28.69	7.02	29.54
16	9878788.03	314080.95	9878806.00	314089.00	-17.97	-8.05	19.69
17	9878719.56	314212.52	9878732.00	314208.00	-12.44	4.52	13.24

18	9878634.23	314374.19	9878650.00	314372.00	-15.77	2.19	15.92
19	9878597.67	314440.59	9878613.00	314436.00	-15.33	4.59	16.00
20	9878160.27	314618.64	9878166.00	314619.00	-5.73	-0.36	5.74
21	9878385.75	314294.24	9878396.00	314293.00	-10.25	1.24	10.32
22	9878050.41	314387.00	9878061.00	314400.00	-10.59	-13.00	16.77
23	9878371.58	314294.88	9878387.00	314291.00	-15.42	3.88	15.90
24	9878376.80	314287.64	9878398.00	314283.00	-21.20	4.64	21.70
25	9878179.50	314163.31	9878195.00	314163.00	-15.50	0.31	15.50
26	9878184.17	314159.96	9878193.00	314157.00	-8.83	2.96	9.31
27	9878271.52	314101.44	9878272.00	314091.00	-0.48	10.44	10.45
28	9878335.70	314366.57	9878338.00	314366.00	-2.30	0.57	2.37
29	9878282.90	314441.51	9878285.00	314438.00	-2.10	3.51	4.09
30	9878223.29	314525.82	9878227.00	314521.00	-3.71	4.82	6.08
31	9878013.80	314502.82	9878014.00	314505.00	-0.21	-2.18	2.19
32	9878081.07	314293.33	9878076.00	314299.00	5.07	-5.67	7.61
33	9878136.44	314222.65	9878122.00	314212.00	14.44	10.65	17.94
Mean					-10.35	0.95	12.73
SD					8.40	4.96	6.27

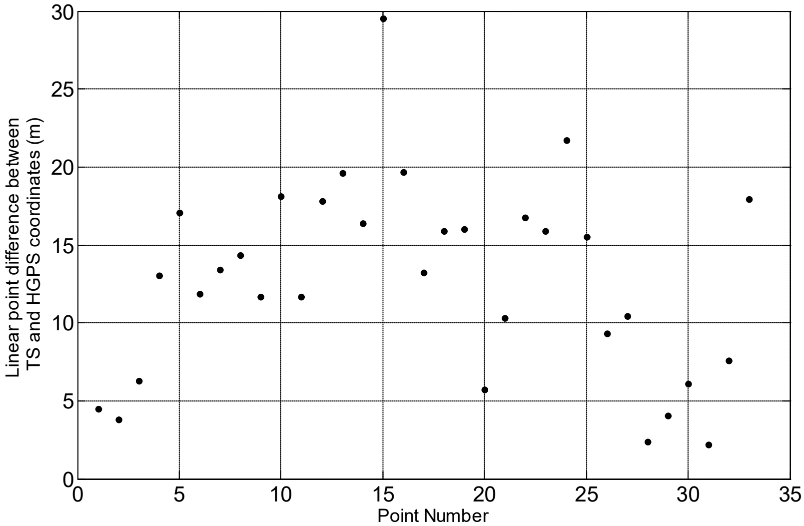

Figure 4: Linear point differences between total station and hand-held GPS positions

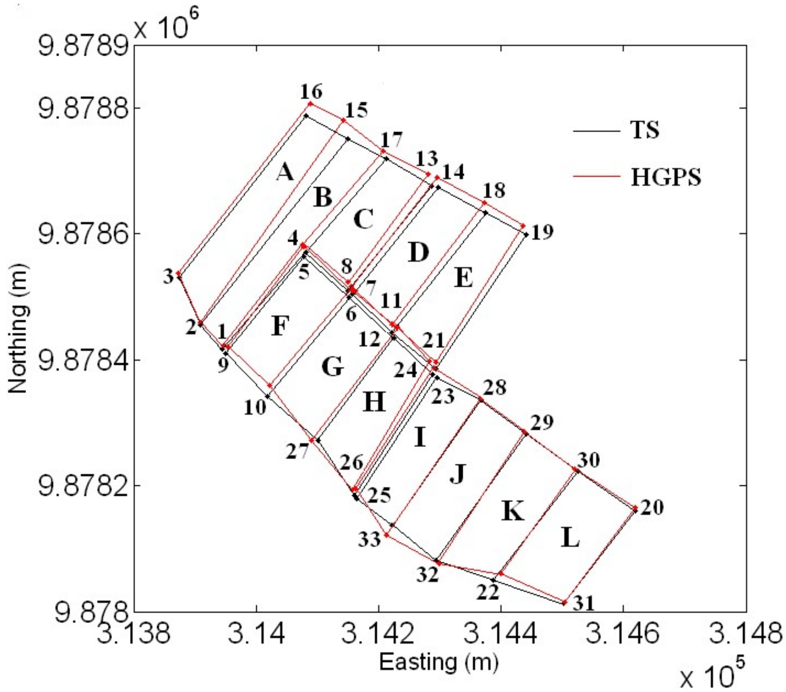

Figure 5: Overlay of total station and hand-held GPS corner points and land parcel boundaries

3.3 Comparison of Side Lengths from Hand-held GPS and Total Station

We compared side lengths obtained by HGPS and total station. Forty one side lengths were computed from coordinates obtained using HGPS and total station (Figure 5). The side lengths derived from total station and GPS observations together with the differences are given in Table 4. The differences between total station and GPS side lengths are also shown in Figure 6. The standard deviation of the side lengths differences is ±8.74 m. From Figure 6 it can be seen that side length differences that are more than 15 m and less than -15 m are outliers, hence removing lines 1,2,6,9,11 and 37, the standard deviation of the remaining 35 lines is 5.90 m with a mean of -1.44 m.

Table 4: Comparison of side lengths from total station and hand-held GPS (units are in m)

Line	***End Points***	***TS***	***HGPS***	***TS-HGPS***
1	3–16	330.13	345.61	-15.48
2	2–15	381.49	397.83	-16.34
3	1–4	212.33	206.93	5.40
4	9–5	199.61	202.25	-2.64
5	10–6	205.04	200.39	4.65
6	27–12	203.90	226.63	-22.73
7	26–24	227.15	240.63	-13.48
8	25–23	232.82	230.76	2.06
9	33–28	245.80	265.28	-19.48
10	32–29	250.39	251.00	-0.61
11	22–30	221.72	205.42	16.30
12	31–20	186.73	190.00	-3.27
13	4–17	190.73	199.06	-8.33
14	8–13	215.96	217.42	-1.46
15	7–14	220.06	222.55	-2.49
16	11–18	244.29	246.63	-2.34
17	21–19	257.54	259.88	-2.34
18	3–2	83.44	85.91	-2.47
19	2–1	52.56	53.04	-0.48
20	9–10	96.76	92.85	3.91
21	10–27	108.82	111.21	-2.39
22	27–26	105.14	102.94	2.20
23	25–33	73.32	87.92	-14.6
24	33–32	89.79	98.41	-8.62
25	32–22	98.56	102.11	-3.55
26	22–31	121.47	115.04	6.43
27	5–6	98.54	106.22	-7.68
28	6–12	96.90	93.24	3.66
29	12–24	85.19	74.95	10.24
30	23–28	80.17	89.59	-9.42

31	28–29	91.67	89.40	2.27
32	29–30	103.26	101.26	2.00
33	30–20	112.19	115.43	-3.24
34	4–8	93.67	94.49	-0.82
35	7–11	83.96	90.55	-6.59
36	11–21	97.17	88.50	8.67
37	16–15	78.22	59.93	18.29
38	15–17	70.10	80.80	-10.70
39	17–13	86.15	82.74	3.41
40	14–18	86.96	86.77	0.19
41	18–19	75.80	73.93	1.87
Mean				-2.20
SD				8.74

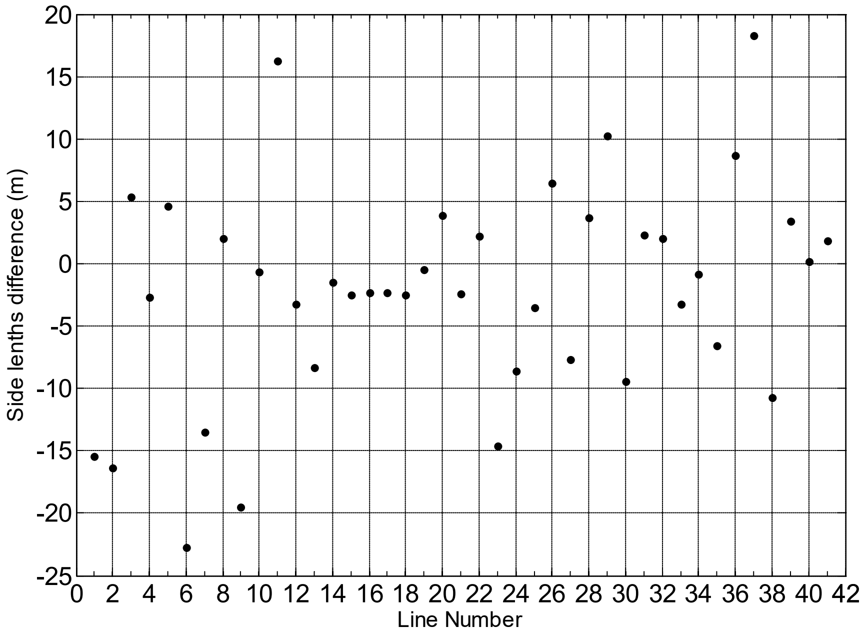

Figure 6: Differences between total station and hand-held GPS side lengths

4.0 Conclusions

We have assessed hand-held GPS surveying in land adjudication. Hand-held GPS was used to determine coordinates of parcel corners. The same points were surveyed using total station. Boundary lengths and coordinates obtained by Hand-held GPS and total station have been compared. We have also compared areas obtained from Hand-held GPS, total station and un-rectified aerial photographs (from which PIDs are derived). The total station areas, coordinates and side lengths are taken as the references against which the PIDs and hand-held GPS results are compared. Twelve land parcels of similar sizes (approx. 2ha) have been used.

From the results obtained, it is clear that hand-held GPS can improve the computed areas for land adjudication in Kenya. PIDs areas are found to be in error by -22.5% while hand-held GPS areas are in error by only -1.9% when the combined area of the 12 plots in the study area is considered. When the 12 plots are compared individually, the differences between total station and hand-held GPS areas vary from -16.4% to 7.4% while the differences between total station and PID areas vary from -43.2% to -1.1%. We would like to note that the stated variations are only specific to this study but indicate the general level of inaccuracy of PIDs in Kenya and the possible improvement through using HGPS.

The results from coordinates and side lengths differences show that hand-held GPS can determine side lengths and coordinates that are close to the ones obtained by total station. Although larger errors are observed in the Northing coordinates than the Easting coordinates. Apart from more accurate areas obtainable by hand-held GPS, coordinates obtained make boundary plotting easier. Plotting parcel boundaries from coordinates ensures geo-referencing which is missing in the current PIDs. This can facilitate development of a land information system (which requires boundary coordinates) for better land management.

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References

Adams L.P. (1969). *The Computation of Aerial Triangulation for the Control of Cadastral Mapping in High Density Agricultural Areas*. PhD. Thesis, University of Nairobi, Jomo Kenyatta Library, Catalogue no TA/613/A3.

Angus-Leppan P.V. and Williamson I.P. (1985). A Project for Upgrading the Cadastral System in Thailand. *Survey Review,* **28**, pp. 63–73.

Angus-Leppan P.V. (1989). The Thailand Land Titling Project: First Steps in a Parcel Based LIS. *Geographical Information Systems,* **3**, pp. 59–68.

Dale P.F. and McLaughlin J.D. (1998). *Land Information Management: An introduction with special references to cadastral problems in Third World Countries.* Clarendon Press, Oxford.

Government of Kenya (1966). Report on the Mission on Land Consolidation and Registration in Kenya. *The Lawrence Mission Report.*

Khalil R. (2013). The accuracy of GIS tools for transforming assumed total station surveys to real world coordinates. *Journal of Geographic Information Systems,* **5**, pp. 486–491.

Kizil U. and Tisor L. (2011). Evaluation of RTK-GPS and total station for applications in land Surveying. *Journal of Earth System Science,* **120**, pp. 215–221.

Land Registration Act (2012). *National Council for Law Reporting*, No.3.

Lane S.N. and Chandler J.H. (2003). Editorial: The generation of high quality topographic data for hydrology and geomorphology: new data sources, new applications and new problems. *Earth surface processes and landforms,* **28**, pp. 229–230.

Lin L-S. (2004). Application of GPS RTK and total station system on dynamic monitoring land use. *Presented at the 20th ISPRS Congress*, July 2004, Istanbul, pp. 12–23.

McLaughlin J.D. and de Soto H. (1994). Property formalization: the proform solution. *Geomatica,* **48**, pp. 307–314.

Mulaku G.C. and McLaughlin J.D. (1996). Concepts for improving property mapping in Kenya. *South African Journal of Surveying and Mapping,* **23**, pp. 211–216.

Mwenda J.N. (2001). Spatial Information in Land Tenure Reform with Special Reference to Kenya. *Proceedings of the International Conference on Spatial Information for Sustainable Development*, October 2-5, 2001, Nairobi, Kenya.

Myles A. and Bwire-Lund K. (2009). Improving Land Administration in Kenya. *Ministry of Lands, Version Publication*.

Ondulo J.D., Wayumba G.O. and Aduol F.W.O. (2015). Accuracy Assessment of Preliminary Index Diagrams (PIDs) from High Resolution Orthoimages in Kenya. *International Journal of Scientific Research and Engineering Studies*, **2**, pp. 38–44.

Ratzeburg F.H. (1970). Cadastral survey and land registration in Kenya. *United Nations Economic and Social Council Seminar on Cadastre, Economic Commission for Africa*, November 2- December 9, 1970, Addis Ababa.

Wayumba G.O. (2013). *An evaluation of the cadastral system in Kenya and a strategy for its modernization.* PhD. Thesis. University of Nairobi.