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Comparison of Orthometric Heights Obtained Using Total Station and Differential Global Positioning Systems (DGPS) With Precise Levels Instruments

Isaac A. Idoko.[1] Anthony, A. Sam[2] Mitchell A. Eboigbe[3].

Abstract— This project focuses on the comparison of Orthometric heights obtained using Total Station and Differential Global Positioning System (DGPS) with precise Levels. The Surveys executed were on existing second-order controls established along Durbar – Akinnmoorin road, Oyo, Oyo State. The obtained Easting, Northing, and height (Ellipsoidal) coordinates of the points were from the observation of the Trimble Dual Frequency GPS receivers. Trigonometric heighting was by the Leica TS02 Total station while the reduced levels of those points were by the Leica Sprinter Digital level in a geodetic-mode. The transformation of the Ellipsoidal heights obtained through DGPs to orthometric heights is by selecting the EGM 96 option in the processing software. Comparison is then made between the heights obtained using the total station and the differential GPS using the precise level as the reference height. Also compared, are their root mean square errors. The roots mean square error of GPS heights was + 0.0649 while the root mean square error of total station height was + 0.0674. This research shows that GPS levelling is more accurate than the total station (trigonometric) levelling over a long distance. The recommendation is for the use of differential GPS when long distances are involved, and the use of the total station for short distances and small areas.

Index Terms— Orthometric Heights, Global Positioning Systems (GPS), Total Stations.

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1 Introduction

In scientific studies and engineering works, it is required to determine height differences between points or the height of points itself in those applications such as measurements of national or local networks, vertical applications of the bridge, dam and infrastructures, maintenance and control measurements, determination of vertical crustal movements, motorway, railway, sewerage, and pipeline measurements. Precise height determination is also required for photogrammetric and remote sensing purposes (Ayhan et al, 2005). Height determinations are geometric levelling, trigonometric levelling, and GPS/Levelling depending on the instrumentation or methodology. While each of these methods has its advantages and disadvantages, the particular survey work accuracy determines their use.

This study analyses the trigonometric levelling with using a total station, which is capable of high accuracy observing vertical angles and distances, geometric levelling with using the digital level, and GPS/Levelling with using GPS observations. Vertical surveying (levelling) is the process of determining elevations above a chosen datum, Mean Sea Level. In geodetic surveys, a geodetic position (y, x) refers to an ellipsoid, and the elevations of those positions referenced to the geoid. Precise geodetic levelling surveys will establish the basic network of vertical control points (Wang and Soler, 2015). The mean sea level surface used as reference (vertical datum) is determined by averaging the hourly water heights for a specified period at specified tide gauges. The purpose of levelling is to establish a series of national or municipal benchmarks along certain routes for developmental purposes (Ndlovu, 2015). National benchmarks are along most national roads, while municipal benchmarks are mainly in large cities and towns along with the road networks. The three levelling techniques are DGPS, Trigonometric, and differential levelling.

DGPS Levelling is the most recent and advanced method in the determination of heights. The GPS in the geocentric Cartesian coordinate system generates the three-dimensional coordinate differences while the transformation of the Cartesian coordinates into geodetic latitude, geodetic longitude, and ellipsoidal heights are in reference to the adopted reference ellipsoid, i.e. WGS84. Practical surveying such as in engineering do not directly adopt the ellipsoidal heights obtained by GPS (Wang & Soler, 2015). The ellipsoidal height has to be transformed to orthometric height, which is the distance measured along the plumb line between the geoid and a point on the Earth's surface and taken positive upward from the geoid (Ayhan et al,2005).

Trigonometric levelling uses the total station instrument's slope distance and zenith angle for the mathematical determination of a point's elevation using trigonometric formulae. To achieve accuracies similar to the differential levelling would require appropriate procedures, such as adjustment for the

- *Isaac, A. Idoko is in the Department of Surveying and Geoinformatics, federal School of Surveying, Oyo, Nigeria.*
- *Anthony, A. Sam is in the Department of Hydrography, Maritime Academy of Nigeria, Oron.*
- *Mitchell, A. Eboigbe is in the Department of Surveying and Geoinformatics, Edo State Polytechnic, Usen, Nigeria.*
- *Corresponding Authour: Mitchell A. Eboigbe florencetius@gmail.com*

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curvature of the earth and the refraction of light. Trigonometric levelling embraces all types of heights determination by the use of vertical angles, distances, and trigonometric functions. We find out the vertical distance between points by taking the vertical angular observations and the known distances. The known distances are either assumed horizontal or the geodetic length at the mean sea level.

Spirit levelling is the most important type of levelling and with the most accurate results. The instrument used for this method varies from simple handheld levels to highly accurate and precise levels, but with all having the sole purpose of measuring height differences between two points at close range. The most commonly used procedure is the spirit level instrument that consists of a telescope with a crosshair. It also has a tube level used by carpenters and rigidly connected. The bubble at the tube level must be at the centre for the telescope's line of sight to be truly horizontal. The accuracies depend on the corrections applied to eliminate errors such as collimation error and placing the level instrument equidistance between the two points whose heights are been determined. This will eliminate curvature and refraction errors. One cannot emphasis enough the importance and role of the human error. The observer needs to take precautions when levelling to eliminate any errors from arising (Ndlovu, 2015).

1.1 Review of Existing Literature

THE usage of GPS RTK method for surveying, staking out and monitoring was in many cases limited by system accuracy, especially in the vertical component. The highest achievable accuracy is at the centimetre level. Classical height determination methods allow the highest accuracy. By trigonometric levelling using an electronic tacheometer, it is possible to achieve sub centimetre accuracy. Differential levelling (using level with parallel plate micrometer) also enables the achievement of submillimetre accuracy. Paar et al, (2014) and Saghravanietal (2009) compared the accuracy of RTK – GPS and Automatic Level in the determination of heights over a 16-hectare research area using 12 points whose minimum distances between them were 50m and the maximum being 130m. Ayhan et al (2005) Opined that Height determination can be categorize as geometric levelling, trigonometric levelling and GPS/Levelling depending on used instruments or the methods applied. Hirtettal (2010) presented geometric-astronomical leveling as a suited technique for the validation of GNSS (Global Navigation Satellite System) heights. Žarko et al (2014) expressed that the main difference between the trigonometric and spirit-levelling method for height difference determination is in the construction of geodetic instruments used for them, in the measurement methods and in the influences, which affects the accuracy. Marín et al (2008) found that the vertical errors using a handheld GPS are greater than 100 meters. Marín et al. (2005) conducted a study to determine the precision on the vertical axis using the DGPS.

Geodetic surveys use the GPS for precise structural monitoring such as crustal deformation, and plate tectonics (Cabral–Cano, 2007). Geodetic surveys typically will require permanent stations or use long occupation times unlike engineering surveys with very short occupation times. Existing literature does not give a direct comparison of the different surveying methods in the determination of precise heighting in terms of accuracy and cost (Lambrou, 2014; Schloderer, 2011 and Marín et al, 2008).

1.2 Aim of the Study

This research aims to compare the Orthometric heights obtained using a total station and differential global positioning systems with the heights obtained using the precise Level instrument.

1.3 Study Location

The project site is located in Oyo town. It began from Durbar junction off Oyo–Ogbomoso express road to the left to Akinmoorin junction. The geographic coordinates of the beginning and ends are (07º 49′ 55.″75N, 03º 55′ 31.″2E) and (07º 46′ 20.″665N, 03º 55′ 11.″11E). The total straight line distance covered is about 6km.

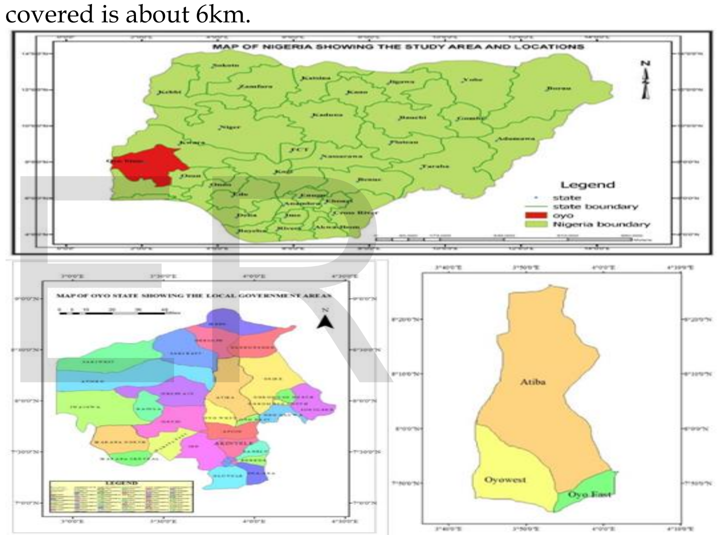

Fig. 1 Study Area

2. METHODOLOGY

TABLE 1: CONTROLS AS SECONDARY DATA FROM FSS OYO PRACTICAL UNIT

Station	Eastings(m)	Northings(m)	Height(m)
XSN07	604755.781	866879.146	309.972
FSS1/10	603355.720	866138.560	316.541
FSS1/11	603074.368	865927.570	316.091
FSS1/24	601944.769	858841.655	271.011
FSS1/25	601332.104	857819.060	278.322

The five (5) existing first order controls used for this project are XSN07, FSS1/10, FSS1/11, FSS1/24, and FSS1/25. The GPS were used to carry out observation on each of the controls so as to compare the given coordinates values with that of the observed coordinates values of the control points. The observation were carried out by setting up the base on XSN 07 and rover on FSS1/10, FSS1/11, FSS1/24, FSS1/25 respectively with a minimum observation time of 50 minutes spent on each rover point.

2.1.2 Geodetic Levelling Operation

The survey team executed the levelling operation using the Leica Sprinter Digital level and two bar coded staves. This study adopted the geodetic levelling method in order to satisfy the accuracy and specifications for the survey. Collimation error was determined from the two-peg test prior to the field observations. The instrument configuration was in the BFFB mode meaning, the order of observation was backsight, foresight, foresight and finally foresight to complete a section of observation at each instrument set-up.

2.2 GPS Observation

The R8 series of Trimble dual frequency with model no. 94443-66 was used in rapid static mode. The base receiver was set up and properly levelled on control with identification number FSS1/10 located in front of Methodist Secondary School Apaara – Oyo town. The height of the base receiver was measured with a 7.5m steel tape and booked. The date of observation was also noted. The base receiver was switched on and allowed sometime to acquire enough satellite signals then the start time was recorded. The rover receiver was moved to the points whose positions were to be determined and the above procedure was repeated. Since the observation was in the rapid static mode on a 25 minutes minimum stay time on the rover station before moving to the next point. Every other point was occupied in similar manner while the base receiver.

TABLE 2: EXTRACT OF GPS PROCESSED RESULT

STATION	Distance(m)	NORTHING(m)	EASTING(m)	HEIGHTS(m)
FSS/1/94	0.000	866080.8009	603309.5993	323.822
FSS/1/2016	339.038	865770.5159	603446.2367	329.298
FSS/2/2016	1539.962	864675.9774	603940.4068	315.777
FSS/3/2016	1934.594	864284.6581	603991.4337	332.077
FSS/4/2016	2164.465	864076.3976	604088.7386	331.551
FSS/47/94	5098.446	861167.3511	604470.4351	306.624
FSS/48/49	5372.074	861440.9577	604473.8336	307.659
FSS/49/94	5649.495	861717.2800	604449.1648	309.931
FSS/55/94	8937.617	864948.2397	603838.7185	318.261
FSS/6/2016	11445.950	862481.7857	604295.1623	318.174
FSS/7/2016	12903.394	861029.5423	604418.1793	306.458

3. PRESENTATION AND DISCUSSION OF RESULTS

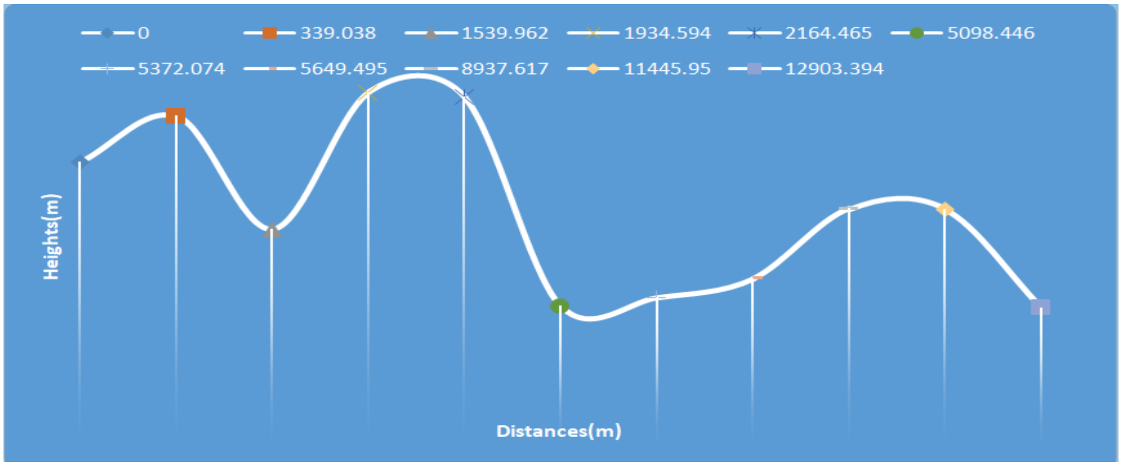

Fig. 2 Graph of GPS Heights against Distance

TABLE 3: EXTRACT OF TRIGONOMETRIC HEIGHTING (TOTAL STATION) PROCESSED RESULT

STATION	Distance(m)	NORTHING(m)	EASTING(m)	HEIGTHS(m)
FSS/1/94	0.000	866080.790	603309.599	323.814
FSS/1/2016	339.038	865770.520	603446.236	329.262
FSS/2/2016	1539.962	864676.000	603940.399	315.801
FSS/3/2016	1934.594	864284.634	603991.443	332.072
FSS/4/2016	2164.465	864076.410	604088.752	331.508
FSS/47/94	5098.446	861167.381	604470.419	306.534
FSS/48/49	5372.074	861440.960	604473.828	307.766
FSS/49/94	5649.495	861717.287	604449.159	309.921
FSS/55/94	8937.617	864948.217	603838.709	318.225
FSS/6/2016	11445.950	862481.799	604295.159	318.163
FSS/7/2016	12903.394	861029.535	604418.193	306.438

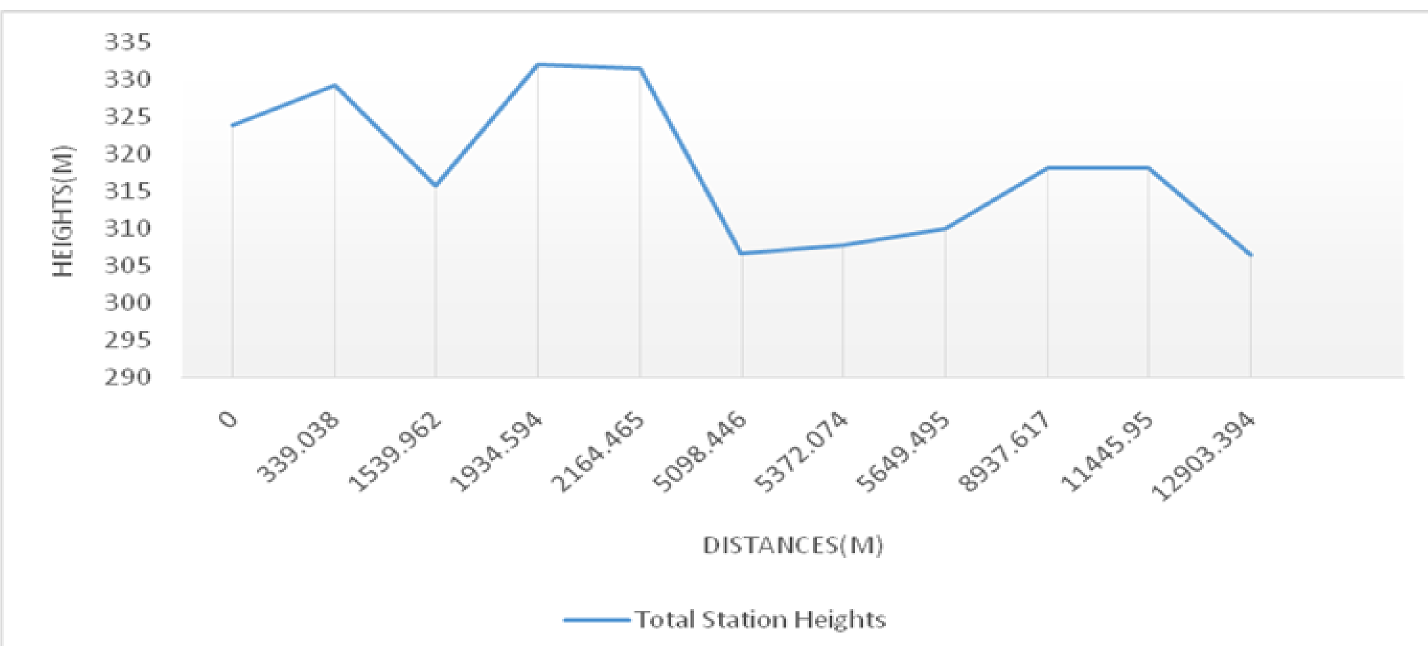

Fig. 3 Graph of Total Station Heights against Distance

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TABLE 4: EXTRACT OF PRECISE LEVELLING PROCESSED RESULT

STATION	Distance(m)	REFERENCED HEIGHTS(m)
FSS/1/94	0.000	323.826
FSS/1/2016	339.038	329.282
FSS/2/2016	1539.962	315.911
FSS/3/2016	1934.594	332.102
FSS/4/2016	2164.465	331.533
FSS/47/94	5098.446	306.657
FSS/48/49	5372.074	307.774
FSS/49/94	5649.495	309.939
FSS/55/94	8937.617	318.246
FSS/6/2016	11445.950	318.199
FSS/7/2016	12903.394	306.568

Fig. 4 Graph of Precise Level Heights

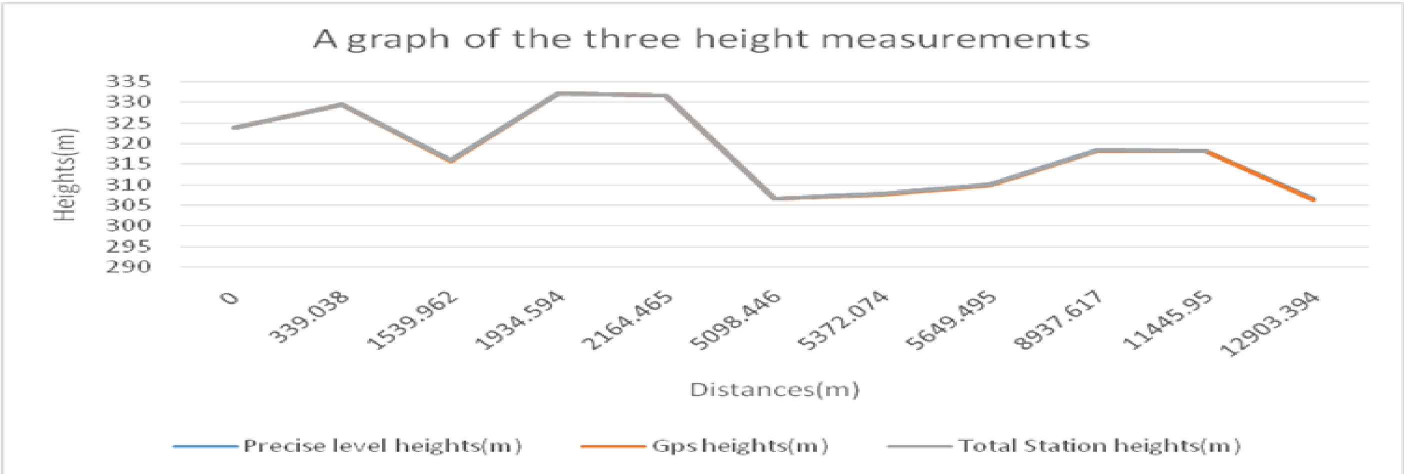

Fig. 5 Graph showing the three Height Measurements

The result obtained from precise digital levelling was used as a reference height (mode 1) because of its assumed accuracy derived from its geodetic mode of observations. The other height measurements with the GPS and Total Station equipment also referred to as modes 2 and 3 respectively are Compared with mode 1.

TABLE 5: REFERENCE HEIGHTS AND DIFFERENCES FROM THE TWO OTHER METHODS

Station	Cumulative Distance(m)	Height by precise level (Ref. height)-mode 1	Height by Differential GPS Levelling-mode 2		Height by Total Station-mode 3	
			H(m)	Δh	H(m)	Δh
FSS/1/94	0.000	323.826	323.822	0.004	323.814	0.012
FSS/1/2016	339.038	329.282	329.298	-0.016	329.262	0.020
FSS/2/2016	1539.962	315.911	315.777	0.134	315.801	0.110
FSS/3/2016	1934.594	332.102	332.077	0.025	332.072	0.030
FSS/4/2016	2164.465	331.533	331.551	-0.018	331.508	0.025
FSS/47/94	5098.446	306.657	306.624	0.033	306.534	0.123
FSS/48/49	5372.074	307.774	307.659	0.115	307.766	0.008
FSS/49/94	5649.495	309.939	309.931	0.008	309.921	0.018
FSS/55/94	8937.617	318.246	318.261	-0.015	318.225	0.021
FSS/6/2016	11445.950	318.199	318.174	0.0025	318.163	0.036
FSS/7/2016	12903.394	306.568	306.458	0.110	306.438	0.130

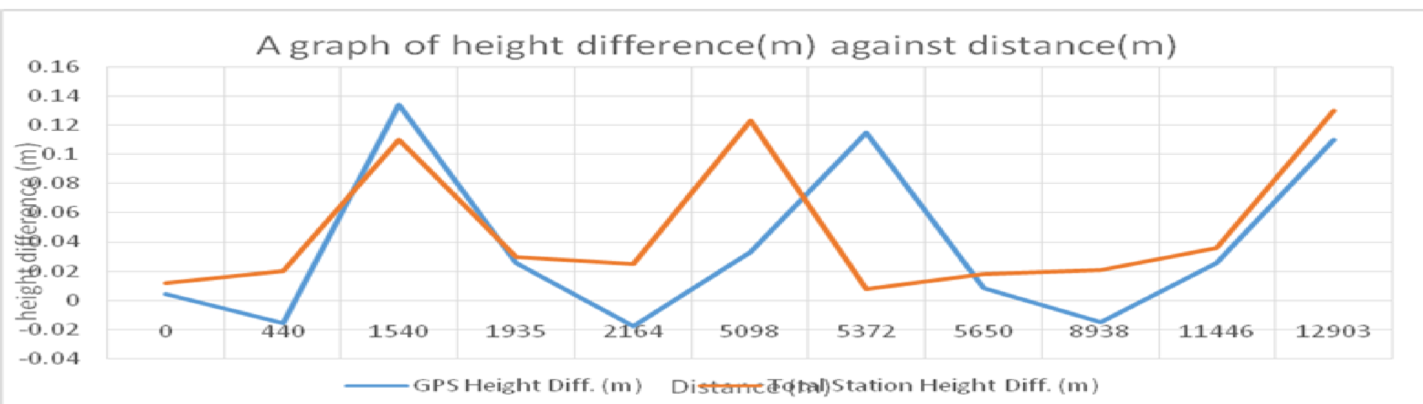

Fig. 6 Graph of Height Difference (m) against Distance (m)

4. DISCUSSION OF RESULTS

4.1 Assessment of Accuracies of the Differential GPS, Levelling and Total Station Trigonometrical Levelling

The accuracy of an observation is the measure of the departure of the observation from the true value, but since the true value of any observed quantity cannot be ascertained due to errors, most probable values are usually computed.

This gives rise to root mean square error computed as a measure of measurements of accuracy of a set of observations.

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Therefore, root mean square error is given as:

$$\sqrt{\{\sum (Href - Hi)^2/n-1\}}$$

Where: Href is the reference height, Hi is the observed height of each point and n is the number of observations.

TABLE 6: GPS ACCURACY COMPUTATION

STATION	REFERENCE HEIGHT (Href)	OBSERVED HEIGHT (Hi)	Href– Hi	(Href – Hi)2
FSS/1/94	323.826	323.822	0.004	0.000016
FSS/1/2016	329.282	329.298	-0.0016	0.000256
FSS/2/2016	315.911	315.777	0.134	0.017956
FSS/3/2016	332.102	332.077	0.025	0.000625
FSS/4/2016	331.533	331.551	-0.018	0.000324
FSS/47/94	306.657	306.624	0.033	0.001089
FSS/48/49	307.774	307.659	0.115	0.013225
FSS/49/94	309.939	309.931	0.008	0.000064
FSS/55/94	318.246	318.261	-0.015	0.000225
FSS/6/2016	318.199	318.174	0.025	0.000625
FSS/7/2016	306.568	306.458	0.110	0.0121

The root mean square error (accuracy) = $\sqrt{\{\sum (Href- Hi)^2/n-1\}}$ = ±0.0649

TABLE 7: TOTAL STATION TRIGONOMETRIC LEVELLING ACCURACY COMPUTATION

STATION	REFERENCE HEIGHT (Href)	OBSERVED HEIGHT (Hi)	Href – Hi	(Href – Hi)2
FSS/1/94	323.826	323.814	0.0120	0.000144
FSS/1/2016	329.282	329.262	0.020	0.0004
FSS/2/2016	315.911	315.801	0.110	0.0121
FSS/3/2016	332.102	332.072	0.030	0.0009
FSS/4/2016	331.533	331.508	0.025	0.000625
FSS/47/94	306.657	306.534	0.123	0.015129
FSS/48/49	307.774	307.766	0.008	0.0000064
FSS/49/94	309.939	309.921	0.018	0.000324
FSS/55/94	318.246	318.225	0.021	0.000441
FSS/6/2016	318.199	318.163	0.036	0.001296
FSS/7/2016	306.568	306.438	0.136	0.0121

The root mean square error (accuracy) = $\sqrt{\{\sum (Href - Hi)^2/n-1\}}$ = ±0.0674

Comparing the results obtained from differential GPS levelling and trigonometric heighting by total station to that of the precise spirit levelling, the differential levelling seems to be more accurate judging from the values of their root mean square errors as computed.

Each type of surveying (GPS or traditional levelling) has its advantages and disadvantages. Traditional levelling provides greater accuracy than GPS. Therefore, it is the method-of-choice in projects requiring height determinations at the sub 2 cm level. In addition, traditional levelling is more cost efficient than GPS in small distance projects where vertical control is very close together, such as along beaches in coastal monitoring.

5. CONCLUSION AND RECOMMENDATION

The three methods considered in this project are relatively accurate although the orthometric height obtained using the precise level is more accurate for smaller areas with a relatively flat topography. The scope of the project, desired accuracy and the cost of execution influence the choice of equipment.

In contrast, GPS has cost effectiveness for large distance projects because the GPS cost remains constant with distance. Levelling operation is relative to distance change. Therefore once a project size increases beyond the small project size classification (~1 km), GPS is then cheaper to use compared with the Traditional levelling. Furthermore, this cost savings increases with project distance. Another advantage of the GPS compared over the traditional levelling, is that it is not constrained by the terrain topography. This terrain independence means that there is no difference in GPS surveying whether the baseline is level or extends into mountains. Whereas, levelling costs increase significantly in hilly or mountainous terrain and cheaper on flat terrain. In review, both GPS and traditional levelling have their advantages and disadvantages with regard to accuracy, cost efficiency, and terrain independence. More precisely, these advantages and disadvantages are project specific.

Apart from the horizontal positioning to be determined, the heights of points have to be determined in geodetic studies. Before initiating any survey procedure, considerations must first be on the cost of equipment, production velocity, and terrain topography. If there is geoid information at levelling in rural area were point density is so low and for which shadow areas are also limited due to trees, etc., the GPS levelling method must be chosen. On the contrary, the preference could be the geometric levelling method with digital level or the trigonometric levelling method with total station. It is appropriate to choose the geometric levelling with digital level or the trigonometric levelling with total station for levelling surveys in urban area or semi-urban area where point density is high. For deformation surveys in bigger structures such as bridge and dams, the GPS receivers may be used for observations on condition that they are not far from the reference points. In addition, the precision levelling method should be chosen by using digital level with invar rods or optic-mechanic level in type of these deformation surveys. In construction projects such as highway, railway, smoothing area, the GPS/levelling, the trigonometric levelling with total station, the geometric levelling with digital level may be chosen respectively.

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