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Research Article

Assessment of Ground Control Points Positional Shift and Management Practices: Evidences from Assosa Town, Western Ethiopia

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Abstract

This study assesses the positional shift of existing control points and management practices found in and around Assosa town. The static GPS measurement technique was used as an independent source and a point wise method were used to assess the positional shift and accuracy level evaluation. Due to unavailability of local CORS station, two first order GCPs were used as a reference during static GPS measurement. After measurement was conducted depending on the baseline length between control point marks, the STC desktop software and online CSRS-PPP post processing technique was used. Thus, the positional accuracy of selected GCPs of STC Post processing technique has a mean error of 0.324 m and whereas the GCPs of CSRS-PPP has a mean error of 0.571 m. Horizontal distance error obtained with the STC differential technique is ranging from 0 to 0.83 m which is inconsistent relative to the range 0.437 m to 0.815 m obtained from online CSRS-PPP solution. The positional accuracy of GCPs was also assessed using horizontal distance error of both processed techniques. The positional accuracy of GCPs at 95% confidence level is between -0.117 m and 0.765 m with STC and between 0.395 m and 0.747 m in online CSRS-PPP solution. Based on the result, the accuracy level of existing GCPs found in Assosa town, does not meet the FGDC accuracy. This was mainly associated with perception of communities on ground control point management activities. The study revealed almost low communities practice and control point management responsiveness. Finally, study suggested that there should be participatory guidance to establish and manage the ground control points.

Keywords

Control Points, Static GNSS Measurement, Positional Shift, Positional Accuracy, Management Practice

1. Introduction

Land is the source of all economic, political and social activities of humankind. Therefore, using the land in a proper way is very important [1]. In order to study the condition and proper uses of natural resource including land, especially in urban areas where land is highly a scarce resource needs surveying applications that have an accuracy range between

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a few millimeters and a few centimeters [2]. To conduct an accurate and precise surveying; accurate and dense ground control points are needed, this is because the increasing the distance between the two networked control points causes a decrement in the quality of positions [3].

A ground control point is a survey monument usually established with control survey methods as a reference point with known position in terms of longitude, latitude and height or easting, northing and elevation; serving as a reference frame upon which other survey jobs can be justified [4, 5]. These control points are used as a reference for accurate planning and mapping projects in urban areas, since land use planning and its implementation without accurate control surveying is said to be incomplete. On the historical development of control point's establishment method (Wolf, 2012, p. 529) states that:

"Traditionally, there have been two general types of control surveys: horizontal and vertical. .... Horizontal control [point] establishment have traditionally been the ground methods of triangulation, precise traversing, trilateration, and combinations of these basic approaches. In addition, astronomical observations were made to determine azimuths, latitudes, and longitudes. Rigorous photogrammetric techniques have also been used to densify the control point in areas".

Today Global Navigation Satellite System (GNSS) technology plays a very important role, for surveyors and geodesist especially for engineering works, mapping, and several geodetic applications in urban areas. Points made with traditional method in Ethiopia dates more than 50 years back in time and have a poor accuracy, compared to the accuracy that can be achieved with modern technology [6].

The Global Navigation Satellite System (GNSS) generally provides two techniques, absolute (precise point positioning) and differential (relative) positioning. Highly accurate results can be obtained using differential GNSS (DGNSS). However, there are some limitations in relative GPS technique: two or more receivers are required to be available and the true coordinate of the reference station should be known. Moreover, increasing the distance between the two receivers causes a decrement in the quality of positions [7]. Due to this fact many studies show that to densify ground control points a new technique in GNSS positioning known as precise point positioning (PPP), a user with a single receiver can attain a positioning accuracy of sub-centimeter and centimeter level in static mode, as compared to differential technique [8-10].

Precise point positioning technique is preferable whereby, there are no existing ITRF based networks like CORS stations and processing software is unavailable or not suitable [11, 12], based on online processing services, which derive ITRF coordinates or positions, if sufficient RINEX data has been submitted for processing. RINEX, which is an acronym for Receiver Independent Exchange, format. GNSS survey work often has many stations with numerous receiver and antenna combinations from several manufacturers. One of the easiest approaches is to work with the data in a common format [2]. According to the same fact sheet, PPP provides positioning without the need for a reference station using a single GNSS receiver by using precise satellite orbit and clock corrections.

Establishment of permanent GNSS ground control points and GNSS networks observations as references for other surveying applications should perform with high accuracy [13, 14]. To achieve this high accuracy different countries have their own measurement techniques. The most common technique used worldwide is static measurement technique. Which is two or more receivers tracking the same satellite ephemeris simultaneously. The static measurement technique has to be needed baseline post processing, whether in post processing to solve a baseline error between a known reference and unknown station positions differentially or with an online processing technique. The baseline computation is often carried out in the 'World Geodetic System 1984' (WGS84) which is a global coordinate system that has to be transformed into local coordinate systems.

There are many web based processing service provider companies worldwide. Among these, this study chooses Canadian Spatial Reference System Precise Point Positioning Service (CSRS-PPP) operated by the Geodetic Survey Division of Natural Resources Canada (NRCan). The researcher chooses this technique; Due to the fact, observational files can be uploaded from the website or through the PPP-Direct desktop software. Additionally, the capability of CSRS-PPP in processing observational data is from 20 minutes to several hours.

Moreover, this research uses an average of a 35-minute observation data (depending on the baseline length), whereas other online processing services need observational data measured at least for 2 hours and above. After post processing, the user receives not only the coordinates and their sigma in the ITRF or NAD83 system, but also diagrams of the visibility of satellites, the temporal convergence of coordinates, the estimated tropospheric delay and clock offset as well as detailed observational data from each measurement epoch. This new method of control point establishment is needed for the countries like Ethiopia, which has sparse geodetic control networks and CORS stations. Especially, in Assosa a town where there are no geodetic networks and the available first order control points accuracy is in doubt.

1.1. Statement of the Problem

In Ethiopia, the greater part of geodetic network was created using conventional triangulation traversing. The points made with a method dates more than 50 years back in time and have a poor accuracy, compared to the accuracy that can be achieved with modern technology [6]. The first order controls points exist around Assosa town were established by

Ethiopian mapping agency dates more than 29 years ago. Whereas, the second order Ground control points (GCPs) found in Assosa town were established by the Ethiopian Civil Service University 9 years ago by using the first order control points as a reference. Ground control points have accuracy problems in there establishment. The main reason for this is that the method of establishment applied, the equipment used, the quality of reference points has poor accuracy. The reference points that uses to adjust the other established lower order points are not accurate enough, systematic error in the adjusted coordinates would occur. In an increasing urbanization and other competing issues, the control points are reference marks for any infrastructural development in 21th century. Thus, the need of accurate and precise ground control points and management activates is indispensable. Therefore, to establishment of an accurate and well-distributed control network, comparing the positional shift of existing ground control points with static GNSS measurement technique and assessing management perception is the prerequisite and the determinant stage for conducting effective and accurate surveying work. The primary purpose of this research was therefore to assess the positional shift of existing control points and management practices by determining the current positional value of existing control points with static GNSS techniques and rigorously adjust the baseline error in two post-processing techniques. The post processing was performed with south total control (STC) software developed by south survey &mapping instrument CO.LTD (www.southinstrument.com or www.southsurvey.com) and alternatively uses new a technique that is CSRS-PPP online processing service. A comparison between these processing techniques was performed, and the positional difference (coordinate difference between the existing and newly determined coordinate values) of each control point was computed. This study may important for decision makers and surveyors to select the alternative methods and appropriate procedures in the ongoing control point establishment and management endeavors.

1.2. Objectives

The main objective of this research is to assess the positional shift in existing ground control points and management practices in and around Assosa town.

The specific objectives of the study are:

(1). To determine the current positions of ground control points in and around Assosa Town.

(2). To evaluate positional shift by processing first order Known GCPs and online Precise Point Positioning (PPP) in the study area.

(3). To identify communities perceptions to managing control points in Assosa Town.

1.3. Research Questions

1. How many ground control points found in and around Assosa town?
2. Do the ground control points have positional shift (discrepancies) in the study area?
3. How communities perceive on ground control management in the study area?

1.4. Significance of the Study

Assosa town is considered, as one of the fastest growing town in Ethiopia, which is expanding in different directions. This growth and expansion of the city has to be guided with up to date land use plan. Land use planning creates the preconditions required to achieve a type of land use that is environmentally sustainable, socially just and desirable and economically sound. To achieve this, establishing accurate horizontal control networks is a prerequisite to prepare an up-to-date urban plan as well as to implement it. All real state and properties can only be located or staked to the ground based on the survey control points. Although urban land value is increasing time to time, the reliable, up-to-date, complete information about it and other structures are heavily demanding. Therefore, the outcome of this study used as insight for researchers and policy and decision makers. Further, this study used as benchmark for planners and surveyors, and communities to improve their understanding to manage control points.

2. Research Methods and Materials

2.1. Description of the Study Area

Assosa town is the capital of Benishangul Gumuz Regional State (BGRS), which is one of the nine regional states comprising the Ethiopian federal structure. According to information obtained from the municipality of the town, the town was founded in 1984. It is located in the Southwestern part of the country geographically located between 10°00' and 10°03' north and between 34°35' to 34°39' east and lies in an area of about 982.5 hectares. In addition, it found 678 km away from Addis Ababa, the capital city of Ethiopia and 90 km away from the Ethio-Sudanese border. We chose Assosa City as a study area because of high demand of land given that the City is the political and economic center of the region; the recorded high rate of urbanization and urban population growth; high level of informal land developments in the peripheries; access to information from government institutions and households has been relatively easy and the possibility to generalize the findings.

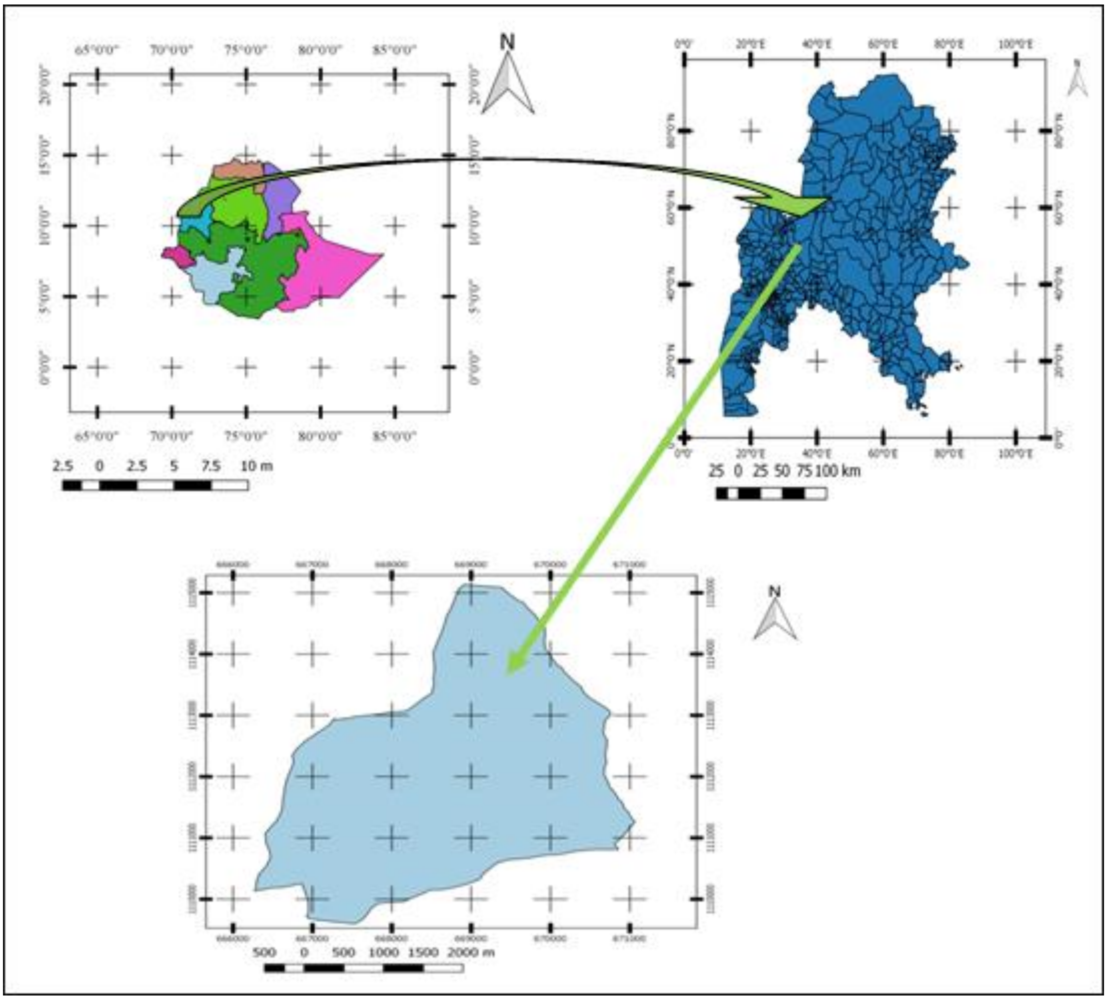

Figure 1. *Location Map of the Study Area.*

2.2. Research Methods

This study was carried out to assess the positional shift in existing control points with static GNSS measurement techniques and management practices in Assosa town. For this study, the researcher applied mixed research design data collection methods. Quantitative data are the data related to the coordinates of GCPs while qualitative data are the data regarding to the management practice of control points.

To achieve the objectives of the study relevant data was collected through a review of literatures and individual interviews from household’s lives around the control points and interviewing key informants, to gather data about the inventory and management of the ground control points found in and around Assosa town. The interview was conducted based on the designed open-ended and closed-ended questions. In addition, data related to the positions of the control points was first obtained from the regional urban development bureau and then GNSS measurement was conducted in static sense with south GNSS receiver, since it was the only available equipment in the study area and finally, the observational data were processed. The processed spreadsheet data and are presented in tables and graphs for comparison. Finally, the data collected from key informant interviews about the management control points were analyzed using descriptive statistics.

2.3. Data Source

To fulfill the aims of the study, the researcher used both primary and secondary data sources. Primary quantitative data sources are the positions of control points (X, Y, Z) of each ground control point, which was collected with static GPS measurement technique and Google earth satellite image of Assosa town. The qualitative data are the data related to the management of control points collected through interviews, key informant interviews and field trips. Secondary data sources data was collected via reading books, reviewing related literatures, standards, manuals and journals. Quantitative data, such as existing ground control point coordinates were obtained from Benishangul Gumuz Region urban development Bureau. Whereas the shape file of Assosa town was obtained from central statistics agency (CSA) data respectively.

2.4. Sampling Technique and Sample Size

In this work, the selected interviewee and key informants were residents near the control points and municipal surveying experts (surveyors) respectively. Purposive non-probability sampling technique was used to select the target sample unit. Given the limited resources, 21 households were purposively selected that GCPs were established near to their fence. Thus, one interviewee in each ground control points was selected for interview. One surveyor at municipal level and one surveyor and an urban planner expert at regional bureau level having knowledge of surveying and planning were selected purposively.

Selections of the measured ground control points were based on the distribution of points through the town. The guidelines of the FGDC, (1998) indicated that "to evaluate the accuracy of control points, at least a minimum of 20 independent ground points shall be examined". Similarly, American Society for Photogrammetry and Remote Sensing (ASPRS, 2013) developed new Geo-location accuracy standards for digital geospatial data recommends 20 clearly defined checkpoints for a project area of $\leq 500\ km^2$. Accordingly, among 29 GCPs found in the study area, 21 GCPs were selected. In addition, the study uses two first order known control points (namely, "ASOS" and "GCP 4") out of the town as a reference point. Due to this, the sample GCP points are all 23 available points found in and around the town and their positions were determined using static GNSS post processing techniques for positional shift analysis.

3. Result and Discussion

3.1. Inventory of Ground Control Points in and Around Assosa Town

Based on the data found from the urban development bureau, the inventory of the existing control points found in the study area were a total number of 29 established by the Ethiopian Civil Service University as a consultant Figure A1. Despite 29-ground control points were established 2 years ago, 8 GCPs that accounts 28% of the total do not physically exist now. Four GCPs in the town and another four GCPs out of the plan boundary of the town are not found in their previous station. Ground control points may destructed by different means. According to the socioeconomic data collected from the key informants, Ground Control Point found in Assosa were destructed by the construction of roads, buildings and fences. They also reveal that:

".... Among eight-destructed GCPs 5 of the GCP, accounts 62.5% of the total were destroyed during the construction of in town road while 1 GCPs which accounts 13% was destructed by the means of building construction. The remaining 2 GCP 25% of the total destructed during fence construction".

Most of interviewee also emphasized especially on the coordination of different sectors to protect the control points were less. They added that independent institution to take full responsibilities to protect and maintain the control points is not found. As far as the knowledge and observation of the researcher, independent organizational structure is not found to run the surveying and mapping framework at the municipal and regional level. In addition, the site selection during control point establishment was inappropriate. Most of the control points are placed at lots and Block corners of private and public property, on not yet constructed walkways, near to residential house fences and the center of not yet constructed road intersections. Regarding to the protection of control points from destruction, other countries' experience show that, for example, in Seattle city responsibility was assigned to the local jurisdiction to protect the control points by enacting a code of conduct, which states that:

".....Anyone performing construction, maintenance, or other work in Seattle is responsible for protecting all survey [control points] within the area of work. If it is necessary to disturb a survey monument, a permit must be requested in advance from the Department of Natural Resources. The developer must pay the cost of repairing or replacing the survey monument and is responsible for all contractors working for them".

Surprisingly in Canada, "There is a large guard Dog watching over survey monuments in Canada. No matter how remote the monuments may be, this brave dog guards them day and night, ready to snarl at anyone who threatens to harm them and bite anyone who does. This fierce, all-seeing beast is sometimes called by its nickname 'the Criminal Code". The study found two (2) E.G.I.A first order GCPs located at the Peak of Enzi Mountain (point named 'ASSOS') and Abrahamo (GCP 4) (indicated with red triangle). The remaining 25-second order GCPs were found in Assosa town. Among 25 GCPs, 4 of them (green star) do not exist physically. The remaining 21 GCPs (indicated by a yellow circle) are available and used for assessment. Gcp11 and GCP 26 are shown out of the map; this is because of the shape file of the town is not included the place they are found since the GCPs are found in the town's expansion areas. As shown in Figure 2.

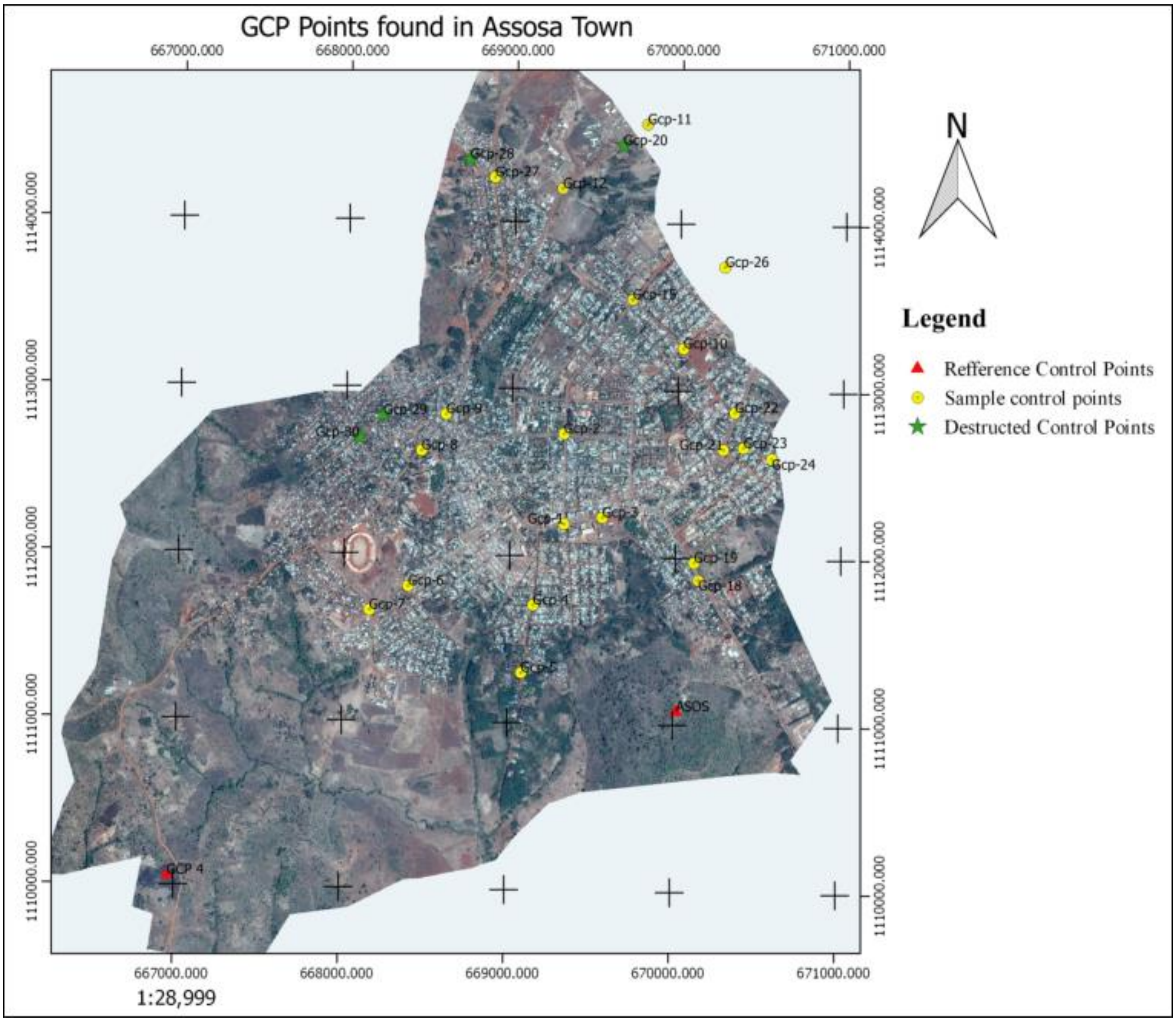

Figure 2. *GCPs in and around Assosa town (Source: researchers).*

From these experiences, one can argue that protecting survey control points are a series issue since control points are an asset for both the government and local communities.

3.2. Results of Static GNSS Measurement

3.2.1. Post Processed Results from STC Software

Points named as "ASOS" and "GCP 4" is known control point that used for adjusting the remaining three GCP baselines. All processing solution type is fixed which mean that the baseline is adjusted differentially, the minimum and maximum horizontal root mean square of the network is 0.004, and 0.007 m respectively, that indicates the baseline network adjustment had highly precise (Table A1).

3.2.2. Results from Online CSRS-PPP Post Processing Technique

The online CSRS-PPP processed results for point ASOS were received via email as a PDF file with a summary. The coordinates after the online post process are expressed in ITRF14 UTM zone 36. To transform these Cartesian coordinates to the Ethiopian national reference system, transformation parameters are used. The transformation from ITRF14 coordinate reference system to ADINDAN UTM ZONE 36N Ethiopian coordinate system had been done with the help of Eye4 Software Hydro-magic Coordinate Calculator. After transformation, there is a difference magnitude of approximately 78 and 206 in x and y position respectively between the two-coordinate systems (Table A1).

3.3. Positional Shift of Points in Both Processing Methods

A positive and negative sign of numbers shown in (Table A2), illustrates the magnitude of coordinate shift with respect to easting and noting position. Comparison is made for both methods with respect to deviations in easting and northing component (in meters). The coordinate discrepancy and horizontal distance error results of ASOSA and GCP 4 obtained from STC processed coordinate with respect to existing coordinates shows a zero value. This is because these points are first order GCPs in the study was identified as known control points to adjust other control point positions. Therefore, their coordinate shift and horizontal distance error processing with STC software is also zero that means no adjustment was made for those two points. However, based on online CSRS-PPP processing technique, minimum coordinates discrepancy of 0.207 m, and 0.322 m in x and y position for GCP 7 and ASOS achieved respectively. The maximum discrepancies was archived as 0.609 m and 0.542 m in x and y position for GCP 4. As previously described the first order points were established 29 years back and the researcher could observed that the existing coordinates of this point is equivalent to the coordinates that can be determine with handheld GPS.

3.4. Statistical Analysis of Results Obtained From STC Software

As shown in Figure A2, research used 23 ground control points for the statistical analysis using south total control software. The horizontal distance error (eh) is expressing the square root of the difference between the coordinate values of the adjusted static GNSS measurement result and existing coordinate values of the same ground control points. The number of GCP points having a horizontal error deviation less than 1 cm are two, the corresponding proportion is 8.7%. Which means that Which means that 21 control points have a deviation exceeding 1 cm: four ground control points have a deviation approximately 0.2 m, which is 17.4% of the total and 12 GCPs has an approximate deviation of 0.4 m that accounts 52.2% and the rest 5 ground control points (21.7%) have a deviation greater than 0.5 m (Figure 3).

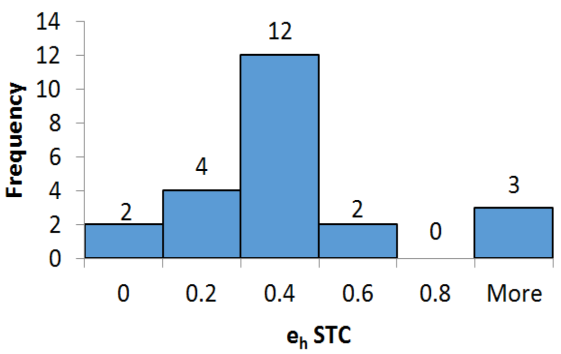

Figure 3. *Distribution of horizontal error across the GCP points.*

The horizontal root mean square error (RMSEh) value of GCPs was 1.00 m with root mean square error in X (RMSEx) and Y (RMSEy)) dimension value of 0.403 m and 0.415 m respectively. As illustrated in Appendix-2, the mean value of the horizontal distance error (eh) is 0.571 m, the median value is 0.569 m the difference between the mean and the median is 0.002 m, which indicates the distribution of the data is approximately statistically symmetrical. The standard deviation of the horizontal distance error is 0.090 m that shows the coordinates obtained from online CSRS-PP adjustment is somewhat precise. The range of horizontal error is 0.719 m, which is slightly near to the minimum value. The lowest deviation value of horizontal error is 0.437 m.

The skewness is determined to 1.110, which indicates the sample is approximately normally distributed. If an error is normally distributed and independently in each the x- and y-component and error, the factor 1.96 is used to compute horizontal accuracy at the 95% confidence level (section 3.8, equation 9). $Mean\ horizontal\ distance\ error\ \pm\sigma h * 1.96$ = 0.571 ± 0.090 * 1.96 = 0.571 ± 0.176, which results in a range from 0.395 m to 0.747 m, which is 95% of the horizontal positional uncertainty of the ground control points would fall between 3.95 decimeter to 7.47 decimeter.

3.5. Perception of Households on Managements Status of Control Points

Semi structured questions and a reconnaissance trip were conducted using predetermined open ended and close ended research questions to assess the status and management of existing control points. The interviewee asked questions about information they had on control points, their participation during control point establishment in their respected localities, and about the responsible to protect the control points. As demonstrated in Table 1, about 90.5% of the total, have no information or awareness about the control points those established in their neighborhood. Only 9.5% of respondents acquired the information from surveyors during establishment by asking surveyors "What are you doing here?" Tried to clarify what they are working along at that place. In again, none of the respondent was taken part during the control point's establishment work, which clearly indicates that the control point's establishment work was not participatory. That in turns the households living near to GCPs has less role in the protection of ground control points.

Most of the respondents (57.2%) think that the responsibilities to manage ground control point left for the government only, while 28.6% of respondent expects the local community holds a duty to protect those control points (Table 1).

Table 1. *Households Perception on the management of control stations.*

No.	Question	Response	Frequency	Percentage
1	Awareness on GCPS	Have awareness	4	9.5
		Haven't awareness	17	90.5
	Total		21	100
2	Participation during GCP establishment	Participated	0	0
		Not Participated	21	100
	Total		21	100
3	Responsible body to manage survey control stations	The Government	12	57.1
		Local Communities	6	28.6
		Every individual	3	14.3
	Total		21	100

Further, the research also observed a situation that the household has heaped woods over the control points, which might break, loosen its paint and labels of control marks constructed with concerts. On the other hand, most of the GCPs were established at inappropriate sites like road centers, close to big fence walls, under large trees etc., which makes them subject to destruction during the construction of different infrastructures. From this, one can argue that it is important that the public be enlightened on the importance of survey control points prior to establishment.

According to the data gathered from key informants reveals that: "The control points found in Assosa town are not sufficiently managed to conduct surveys with total station and other EDM measurement tools, especially in the expansion area, where subdivision survey is needed. Currently we use traditional surveying method by using north direction as a reference and this method is less accurate related to accuracies achieved with using control points as a reference". Finally, they proved lack of awareness and less community derived counts almost all challenges for control point management.

4. Conclusion

The aim of the study was to conduct assessment on the positional shift of existing ground control points and management practice. Thus, interrelated issues such as inventory, management's status of corresponding ground control points were assessed. The result shows that the permanency and sustainability of existing ground control points found in Assosa are subject to destruction, since among 29-ground control points, eight GCPs are destroyed within 2 years during the construction of roads, buildings and fences.

The statistical analysis positional shift shows that positional shift of each GCP is ranging from 0 to 0.828 meters in differential processing technique and 0.437 m to 0.815 m in online CSRS-PPP solution. Whereas its level of Accuracy at the 95% confidence level has identified between - 0.117 m to 0.765 m and 0.395 m to 0.747 m in STC and online CSRS-PPP processing techniques respectively. The horizontal accuracies obtained by both processing techniques does not meet the standards set by different departments across the world for the establishment of second order horizontal control points. Accuracy level set by FDGC (1998) at 95% confidence level is 0.046 meter. In addition, (CALTRANS, 2015) also specify 0.02-meter accuracy for second order GCP points which are better than the accuracy range obtained in both processing techniques.

Finally, the study found that there is weak community and concerned body control point management and controlling perceptions. Following this, the study suggests as follows:

1. Ground control points should be considered as an asset of the government and the local community. Therefore, an immediate action should be taken to protect control points found in Asosa town by enacting bylaws, code of conduct.
2. Control point establishment activities should be participatory to the better management of ground control points from destruction.
3. The municipal should update the positions of existing control points prior to using them for future construction survey.
4. There should be good interaction between different users of GCPs jointly for various surveying applications.

Abbreviations

EGIA	Ethiopian Geospatial Information Agency
GCPs	Ground Control Points
RMSE	Root Mean Square Error
CSRS-PPP	Canadian Spatial Reference System Precise Point Positioning Service

CSA	Central Statistics Agency
STC	South Total Control
GNSS	Global Navigation Satellite System
CORS	Continuously Operating Reference Stations
DGNSS	Differential Global Navigation Satellite System
FGDC	Federal Geographic Data Committee
EDM	Electronic Distance Measurement
ITRFS	International Terrestrial Reference System
NAD83	North American Datum of 1983

Author Contributions

Mihret Fentahun Yeneneh: Conceptualization, Resources, Project administration, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing

Gizachew Kassa Addis: Conceptualization, Resources, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft

Teha Romanu Benti: Funding acquisition, Investigation, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

NO.	Pid	X	Y	Z
1	ASOS	670020.700	1111082.270	1665.680
2	GCP 4	666962.750	1110054.440	1564.250
3	Gcp-1	669323.725	1112194.558	1568.833
4	Gcp-2	669315.858	1112734.017	1566.331
5	Gcp-3	669554.517	1112236.083	1570.156
6	Gcp-4	669145.190	1111706.105	1541.665
7	Gcp-5	669079.342	1111300.785	1535.059
8	Gcp-6	668388.758	1111808.589	1858.892
9	Gcp-7	668156.239	1111662.346	1564.718
10	Gcp-8	668456.974	1112621.338	1561.352
11	Gcp-9	668602.135	1112841.431	1553.680
12	Gcp-10	670028.556	1113254.821	1574.507
13	Gcp-11	669789.369	1114592.533	1551.797
14	Gcp-12	669282.650	1114201.008	1538.790
15	Gcp-15	669716.795	1113543.216	1558.020
16	Gcp-18	670141.387	1111869.297	1576.997
17	Gcp-19	670113.649	1111974.132	1579.720
18	Gcp-20	669644.921	1114463.513	1546.793
19	Gcp-21	670278.789	1112652.366	1579.025
20	Gcp-22	670344.750	1112875.106	1570.344
21	Gcp-23	670400.435	1112665.133	1573.634
22	Gcp-24	670572.980	1112601.841	1569.479
23	Gcp-26	670271.595	1113745.951	1563.502
24	Gcp-27	668872.807	1114262.527	1548.429
25	Gcp-28	668720.891	1114367.372	1547.291
26	Gcp-29	668223.104	1112828.283	1550.920
27	Gcp-30	668080.584	1112691.736	1554.963

Figure A1. *Existing Survey Control Station Coordinates.*

NO.	Point Name	Existing GCP Coordinates X_e	Existing GCP Coordinates Y_e	STC Drived Coordinates Easting (X_m)	STC Drived Coordinates Northing(Y_m)	Delta x	Delta y	$(DeltaX)^2$	$(DeltaY)^2$	Delta (X^2+Y^2)	Horizontal Distance Errors	e_h-s	$(e_h\text{-}s)^2$
1	ASSOSA	670020.700	1111082.270	670020.700	1111082.270	0.000	0.000	0.000	0.000	0.000	0.00	-0.320	0.102
2	GCP 4	666962.750	1110054.000	666962.750	1110054.000	0.000	0.000	0.000	0.000	0.000	0.00	-0.320	0.102
3	GCP 1	669323.725	1112194.558	669323.628	1112194.730	-0.097	0.172	0.009	0.030	0.039	0.20	-0.122	0.015
4	GCP 2	669315.858	1112734.017	669316.174	1112734.081	0.316	0.064	0.100	0.004	0.104	0.32	0.002	0.000
5	GCP 3	669554.517	1112236.083	669554.435	1112236.293	-0.083	0.210	0.007	0.044	0.051	0.23	-0.095	0.009
6	GCP 4(1)	669145.190	1111706.105	669145.007	1111706.211	-0.183	0.106	0.034	0.011	0.045	0.21	-0.108	0.012
7	GCP 5	669079.342	1111300.785	669079.264	1111300.862	-0.078	0.077	0.006	0.006	0.012	0.11	-0.211	0.044
8	GCP 6	668388.758	1111808.589	668388.589	1111808.689	-0.169	0.100	0.029	0.010	0.039	0.20	-0.124	0.015
9	GCP 7	668156.239	1111662.346	668156.022	1111662.430	-0.217	0.084	0.047	0.007	0.054	0.23	-0.087	0.008
10	GCP 8	668456.974	1112621.338	668456.831	1112621.569	-0.143	0.231	0.021	0.053	0.074	0.27	-0.049	0.002
11	GCP 9	668602.135	1112841.431	668601.945	1112841.646	-0.190	0.215	0.036	0.046	0.082	0.29	-0.033	0.001
12	GCP 10	670028.556	1113254.821	670028.508	1113255.141	-0.048	0.320	0.002	0.103	0.105	0.32	0.004	0.000
13	GCP 11	669789.369	1114592.533	669789.213	1114592.930	-0.156	0.397	0.024	0.158	0.182	0.43	0.107	0.011
14	GCP 12	669282.650	1114201.008	669282.892	1114201.800	0.242	0.792	0.058	0.627	0.686	0.83	0.508	0.258
15	GCP 15	669716.795	1113543.216	669716.695	1113543.570	-0.100	0.354	0.010	0.125	0.135	0.37	0.048	0.002
16	GCP 18	670141.387	1111869.297	670140.626	1111869.601	-0.761	0.304	0.580	0.092	0.672	0.82	0.500	0.250
17	GCP 19	670113.649	1111974.132	670113.636	1111974.321	-0.013	0.189	0.000	0.036	0.036	0.19	-0.131	0.017
18	GCP 21	670278.789	1112652.366	670278.760	1112652.623	-0.029	0.257	0.001	0.066	0.067	0.26	-0.061	0.004
19	GCP 22	670344.750	1112875.106	670344.727	1112875.393	-0.023	0.287	0.001	0.082	0.083	0.29	-0.032	0.001
20	GCP 23	670400.435	1112665.133	670400.429	1112665.406	-0.006	0.273	0.000	0.075	0.075	0.27	-0.047	0.002
21	GCP 24	670572.980	1112601.841	670572.264	1112601.460	-0.716	-0.381	0.513	0.145	0.658	0.81	0.491	0.241
22	GCP 26	670271.595	1113745.951	670271.513	1113746.324	-0.082	0.373	0.007	0.139	0.146	0.38	0.062	0.004
23	GCP 27	668872.807	1114262.527	668872.594	1114262.891	-0.214	0.364	0.046	0.132	0.178	0.42	0.102	0.010
						Total No. of GCP poi		23	23	23	23	23	23
						sum		**1.530**	**1.991**	**3.521**	**7.443**	**0.083**	**1.112**
						$RMSE_X$		**0.258**		0.067			
						RMSEx2		**0.067**					
						$RMSE_Y$			**0.294**	0.087			
						RMSEy2			**0.087**				
						$RMSE_r$				**0.391**			
						Accuracy				**0.677**			
						Range					0.354		
						Mean					**0.324**		
						Median					**0.271**		
						$(e_h-\mu)^2/n$							0.048
						Standard Devation							0.220

Figure A2. *Coordinates Derived from STC Software and Statistical Results.*

NO.	Point Name	Existing GCP coordinates eaating (Xe)	Existing GCP coordinates Northing(Ye)	CSRS- PPP drived Coordinates Easting(x_m)	CSRS- PPP drived Coordinates Northing(y_m)	Delta x	Delta y	Delta x^2	Delta y^2	Delta(x^2+y^2)	Horizontal Distance Error(e_h)	e_h-s	$(e_h\text{-}s)^2$
1	ASSOSA	670020.700	1111082.270	670021.060	1111082.592	0.360	0.322	0.130	0.104	0.233	0.483	-0.088	0.01
2	GCP 4	666962.750	1110054.000	666963.359	1110054.542	0.609	0.542	0.371	0.294	0.665	0.815	0.244	0.06
3	GCP 1	669323.725	1112194.558	669324.139	1112194.992	0.414	0.434	0.171	0.188	0.360	0.600	0.029	0.00
4	GCP 2	669315.858	1112734.017	669316.202	1112734.442	0.344	0.425	0.118	0.181	0.299	0.547	-0.024	0.00
5	GCP 3	669554.517	1112236.083	669554.759	1112236.492	0.242	0.409	0.059	0.167	0.226	0.475	-0.096	0.01
6	GCP 4(1)	669145.190	1111706.105	669145.635	1111706.460	0.445	0.355	0.198	0.126	0.324	0.569	-0.002	0.00
7	GCP 5	669079.342	1111300.785	669079.742	1111301.201	0.400	0.416	0.160	0.173	0.333	0.577	0.006	0.00
8	GCP 6	668388.758	1111808.589	668389.169	1111808.985	0.411	0.396	0.169	0.157	0.326	0.571	0.000	0.00
9	GCP 7	668156.239	1111662.346	668156.446	1111662.798	0.207	0.452	0.043	0.204	0.247	0.497	-0.074	0.01
10	GCP 8	668456.974	1112621.338	668457.438	1112621.685	0.464	0.347	0.215	0.120	0.336	0.579	0.008	0.00
11	GCP 9	668602.135	1112841.431	668602.633	1112841.832	0.498	0.401	0.248	0.161	0.409	0.639	0.068	0.00
12	GCP 10	670028.556	1113254.821	670028.794	1113255.187	0.238	0.366	0.057	0.134	0.191	0.437	-0.134	0.02
13	GCP 11	669789.369	1114592.533	669789.733	1114592.923	0.364	0.390	0.132	0.152	0.285	0.533	-0.038	0.00
14	GCP 12	669282.650	1114201.008	669283.004	1114201.450	0.354	0.442	0.125	0.195	0.321	0.566	-0.005	0.00
15	GCP 15	669716.795	1113543.216	669717.250	1113543.653	0.455	0.437	0.207	0.191	0.398	0.631	0.060	0.00
16	GCP 18	670141.387	1111869.297	670141.801	1111869.761	0.414	0.464	0.171	0.215	0.387	0.622	0.051	0.00
17	GCP 19	670113.649	1111974.132	670114.042	1111974.502	0.393	0.370	0.154	0.137	0.291	0.540	-0.031	0.00
18	GCP 21	670278.789	1112652.366	670279.211	1112652.774	0.422	0.408	0.178	0.166	0.345	0.587	0.016	0.00
19	GCP 22	670344.750	1112875.106	670345.076	1112875.499	0.326	0.393	0.106	0.154	0.261	0.511	-0.060	0.00
20	GCP 23	670400.435	1112665.133	670400.653	1112665.588	0.218	0.455	0.048	0.207	0.255	0.505	-0.066	0.00
21	GCP 24	670572.980	1112601.841	670573.455	1112602.258	0.475	0.417	0.226	0.174	0.400	0.632	0.061	0.00
22	GCP 26	670271.595	1113745.951	670271.877	1113746.306	0.282	0.355	0.080	0.126	0.206	0.453	-0.118	0.01
23	GCP 27	668872.807	1114262.527	668873.407	1114263.008	0.600	0.481	0.360	0.231	0.591	0.769	0.198	0.04
					Total No. of GCP points	23	23	23	23	23	23	23	23
					Sum	8.935	9.477	**3.726**	**3.959**	7.685	13.138		0.18
						$RMSE_x$		**0.403**					
						$(RMSE_x)^2$		0.162					
						$RMSE_y$			**0.415**				
						$(RMSE_y)^2$			0.172				
						$RMSE_h$				**0.578**			
						$Accuracy_h$				**1.000**			
						Mean e_h					**0.571**		
						∑(eh-mean eh)2/n							0.008
						Standard deviation							**0.088**

Figure A3. *Coordinates Derived from CSRS-PPP and Statistical Results.*

Table A1. *Processed GNSS Data in Both Techniques.*

NO.	Point Name	Coordinates From STC Software		Coordinates From Online CSRS-PPP	
		Easting	Northing	Easting	Northing
1	ASSOSA	670020.700	1111082.270	670021.060	1111082.592
2	GCP 4	666962.750	1110054.000	666963.359	1110054.542
3	GCP 1	669323.628	1112194.730	669324.139	1112194.992
4	GCP 2	669316.174	1112734.081	669316.202	1112734.442
5	GCP 3	669554.435	1112236.293	669554.759	1112236.492
6	GCP 4(1)	669145.007	1111706.211	669145.635	1111706.460
7	GCP 5	669079.264	1111300.862	669079.742	1111301.201
8	GCP 6	668388.589	1111808.689	668389.169	1111808.985
9	GCP 7	668156.022	1111662.430	668156.446	1111662.798
10	GCP 8	668456.831	1112621.569	668457.438	1112621.685
11	GCP 9	668601.945	1112841.646	668602.633	1112841.832
12	GCP 10	670028.508	1113255.141	670028.794	1113255.187
13	GCP 11	669789.213	1114592.930	669789.733	1114592.923
14	GCP 12	669282.892	1114201.800	669283.004	1114201.450
15	GCP 15	669716.695	1113543.570	669717.250	1113543.653
16	GCP 18	670140.626	1111869.601	670141.801	1111869.761
17	GCP 19	670113.636	1111974.321	670114.042	1111974.502
18	GCP 21	670278.760	1112652.623	670279.211	1112652.774
19	GCP 22	670344.727	1112875.393	670345.076	1112875.499
20	GCP 23	670400.429	1112665.406	670400.653	1112665.588
21	GCP 24	670572.264	1112601.460	670573.455	1112602.258
22	GCP 26	670271.513	1113746.324	670271.877	1113746.306
23	GCP 27	668872.594	1114262.891	668873.407	1114263.008

Table A2. *Positional Shift of Points in Both Processing Methods.*

NO.	Point Name	CRCS-ppp		STC		$eh_{crcs\text{-}ppp}$	eh_{stc}
		Delta X	Delta Y	$deltax_e$	$deltay_e$		
1	ASSOSA	0.360	0.322	0.000	0.000	0.483	0.000
2	GCP 4	0.609	0.542	0.000	0.000	0.815	0.000
3	GCP 1	0.414	0.434	-0.097	0.172	0.600	0.198
4	GCP 2	0.344	0.425	0.316	0.064	0.547	0.322
5	GCP 3	0.242	0.409	-0.083	0.210	0.475	0.225
6	GCP 4(1)	0.445	0.355	-0.183	0.106	0.569	0.212
7	GCP 5	0.400	0.416	-0.078	0.077	0.577	0.109

NO.	Point Name	CRCS-ppp		STC		$eh_{crcs-ppp}$	eh_{stc}
		Delta X	Delta Y	$deltax_e$	$deltay_e$		
8	GCP 6	0.411	0.396	-0.169	0.100	0.571	0.196
9	GCP 7	0.207	0.452	-0.217	0.084	0.497	0.233
10	GCP 8	0.464	0.347	-0.143	0.231	0.579	0.271
11	GCP 9	0.498	0.401	-0.190	0.215	0.639	0.287
12	GCP 10	0.238	0.366	-0.048	0.320	0.437	0.324
13	GCP 11	0.364	0.39	-0.156	0.397	0.533	0.427
14	GCP 12	0.354	0.442	0.242	0.792	0.566	0.828
15	GCP 15	0.455	0.437	-0.100	0.354	0.631	0.368
16	GCP 18	0.414	0.464	-0.761	0.304	0.622	0.820
17	GCP 19	0.393	0.37	-0.013	0.189	0.540	0.189
18	GCP 21	0.422	0.408	-0.029	0.257	0.587	0.259
19	GCP 22	0.326	0.393	-0.023	0.287	0.511	0.288
20	GCP 23	0.218	0.455	-0.006	0.273	0.505	0.273
21	GCP 24	0.475	0.417	-0.716	-0.381	0.632	0.811
22	GCP 26	0.282	0.355	-0.082	0.373	0.453	0.382
23	GCP 27	0.600	0.481	-0.214	0.364	0.769	0.422

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