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Evaluation of the reliability of a permanent low-cost GNSS station for precision positioning: geodetic monitoring of engineering structures in Côte d'Ivoire

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Abstract
The densification of GNSS reference networks is a fundamental challenge for the geodetic monitoring of sensitive infrastructures, particularly engineering structures in sub-Saharan areas.
This study aims to evaluate the reliability and stability of a low-cost GNSS station (INP01) permanently installed in an Ivorian urban environment, and to analyze its impact on the accuracy of differential and absolute positioning.
A low-cost GNSS station based on a ZED-F9P u-blox receiver connected to an Ardusimple AS-ANT2B-CAL antenna is located in Yamoussoukro. It recorded continuous multi-constellation GNSS observations over a period of 90 days. The data were analyzed in static and PPP modes.
The INP01 low-cost GNSS permanent base has demonstrated a planimetric stability of less than ±3 mm and a vertical variation of less than ±5 mm in post-processed static from the permanent station of the IGS network, YKRO located only at 221 m. The permanent station of the IGS network called YKRO, indicated a planimetric stability of ±3 mm and a vertical variation of less than ±5 mm in the same observation period. The horizontal accuracy of INP01 is better than ±10 mm, for distances of less than 10 km. This performance meets the geodetic requirements for local monitoring networks of structures in Côte d'Ivoire.
The data from permanent low-cost GNSS stations, installed in an open environment, powered by a stable current and connected to a high-speed internet network after post-processing with software, provide precise and stable coordinates within a radius of indecision of the order of a millimeter. These results reliably contribute to the accurate determination of reference points with sub-centimeter accuracy for base-rover distances of less than 10 km.

Keywords: low-cost GNSS, permanent station, precision positioning, local reference points, engineering structures

Introduction
Global Navigation Satellite System (GNSS) positioning is now an essential pillar for high-precision geodetic applications, ranging from classical topography to the monitoring of critical infrastructure, such as hydroelectric dams, bridges and dikes [1]. The establishment of permanent GNSS stations plays a central role in providing real-time differential corrections and developing reliable geodetic reference networks. However, in sub-Saharan areas, and particularly in Côte d'Ivoire, the low density of permanent stations, the high cost of professional equipment and the instability of the internet network hinder access to precision positioning solutions [2].
The advent of so-called "low-cost" GNSS receivers, such as the u-blox ZED-F9P and UM980 models, capable of receiving several constellations and frequencies, offers a low-cost alternative for densifying geodetic infrastructures [3]. This equipment has interesting potential for static and dynamic positioning applications, with centimeter accuracies when differential processing methods (RTK or PPP) are implemented [4].
In Côte d'Ivoire, the reliability and stability of these low-cost stations is very crucial for the geodetic monitoring of engineering structures, particularly in areas with high climate variability, such as the lake region and coastal areas [5]. The lack of local scientific data on the performance of these devices poses a major challenge for their use in permanent monitoring networks for the monitoring of engineering structures in accordance with international geodesy standards [6].
Thus, this study aims to evaluate the stability and reliability of a low-cost GNSS station permanently installed in an Ivorian urban environment, and to analyze its impact on the accuracy of differential and absolute positioning.

Materials and Methods
1. Methods
Our study area, mainly centered around Yamoussoukro where our bases (INP01 and YKRO) are located, covers the Autonomous District of the Lakes, within a radius of 30 km, including the villages of Soubiakro, Toumbokro and Kossou where the 3rd hydroelectric dam of Côte d'Ivoire is located. We used data from two permanent GNSS stations and receivers whose descriptions and details are below.

Our methodological approach is
Experimental, because it is based on real observations;
Comparative, because it compares the low-cost solution to the reference geodetic solution;
Qualitative, because it is tested with robust statistical laws (DOPs, standard deviations,
RMS) and allows performance to be interpreted in an operational context.
Thus, in a practical way, we have carried out continuous observations of the permanent low-cost station INP01 over a period of ninety days; The recorded daily data from station INP01 made it possible to evaluate the temporal variations

of the planimetric and altimetry positions of the station. Observations of established landmarks with baseline variation made it possible to evaluate the impact of the said station on static positioning by comparison with the YKRO reference station of the IGS. The recorded data was post-processed using the Leica infinity software and analysed using statistical methods.

Fig 1: visual of the permanent IGS and Low Cost stations

POINTS	BASELINE (Km)	OBSERVATION TIME
P01	1	1 h
P02	5	1 h 30 min
P03=RGIR43	8	2h
P04	20	2h30min
P05	30	3h

Fig 2: Observed landmarks and observation time

Matériels

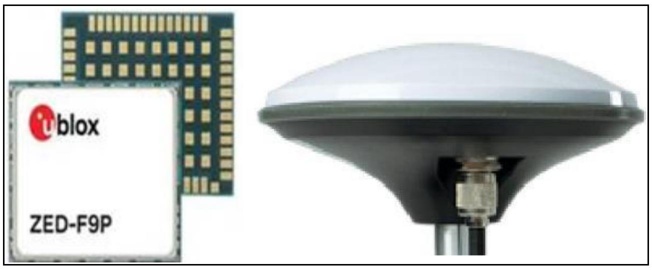


Fig 3: Ublox ZED-F9P GNSS Low Cost

Features

- Multiconstelation, GPS+GLONASS+BEIDOU+GALILEO
- Multi-frequency, L1/L2, E1/E2, B1/B2
- NGS-Calibrated Antenna
- 240 Channels
- Permanent INP01 station installed at INPHB in Yamoussoukro.

And professional receivers of the spectra brand precision and the following characteristics

Fig 4: Spectra SP60 GNSS Professional

The spectra SP60 is a receiver:

- Multi-frequency
- 184 Channels
- Multi-constellation
- Static accuracy:

Horizontal: 3mm+0.1ppm
Vertical: 3.5mm+0.4ppm.

Finally, a reference station YKRO00CIV the IGS network, consisting of a JAVAD TRE_3 DELTA-4.3.00 receiver-firmware; A ASH701945C_M-NONE antenna with a ROBOT antenna calibration and an internal clock.

Fig 5: IGS Ykro GNSS reference

«YKRO00CIV», The Yamoussoukro station is part of NASA's Global GNSS Network (GGN) as well as the IGS network. The GNSS antenna is installed on the RGIR02, the reference point of the Ivorian geodetic network. Since June 2013, a monitoring, evaluation, malfunction prevention and maintenance mechanism has been put in place, which has significantly improved the rate of continuous recording and transfer of measures (24 hours a day). A direct remote connection has been established between the BNETD/CIGN (Abidjan) and the Yamoussoukro site, thus allowing daily monitoring of GNSS data via the server.

Results and Discussion

1. Temporal stability of station INP01

The daily navigation, observation and ephemeris data from INP01 allowed us to follow the temporal evolution of each component of the low-cost station, to see the average of the coordinate deviations, to calculate the standard deviations and the maximum deviation.

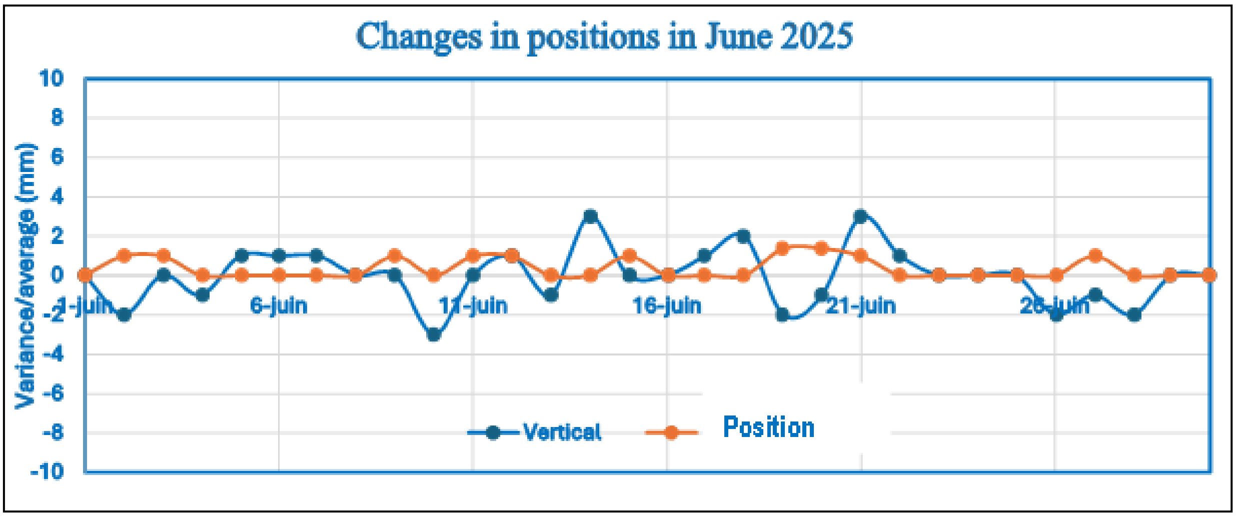
The daily drifts recorded remain mainly between -2mm and +2mm in planimetry, while for the H coordinates, the vertical component, we can see that the variations are higher and between -4mm and +4mm throughout the observation period. The results presented in Table 1 lead to the following conclusions: The time series from the permanent low-cost station INP01 show average deviations of less than one millimetre during the observation period for the three components E, N and H. Very small maximum deviations of the order of a tenth of a millimetre throughout the month of August. This can be explained by the low rainfall in this month.

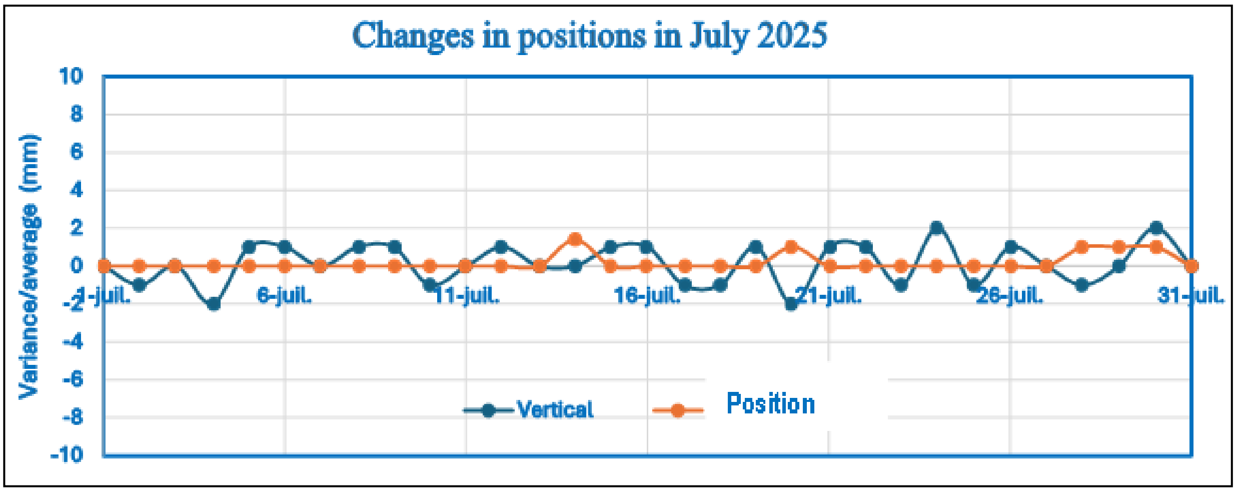
2. Signal quality and sky visibility of the permanent station INP01

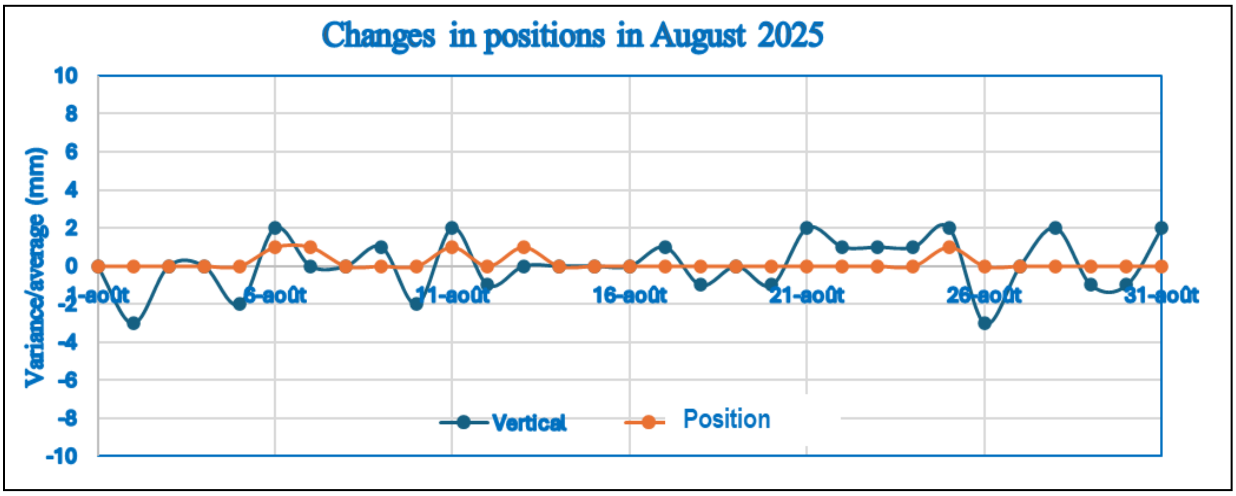
In this part, we have analyzed the quality of the GNSS signals of the permanent station INP01 on a day in June 2025. We have randomly chosen the period from 05 to 06 June.

Table 1: Statistics of the coordinates of INP01 in June, July and August.

Station Low Cost	Parameters (mm)	JUNE 2025			JULY 2025			AUGUST 2025		
		East (mm)	North (mm)	Vertical (mm)	East (mm)	North (mm)	Vertical (mm)	East (mm)	North (mm)	Vertical (mm)
INP01	Average of Variances	-0,043	0,04	-0,003	-0,06	0,03	-0,05	0,001	0,003	0,01
	Standard deviation of deviations	0,33	0,11	2,96	0,18	0,07	1,66	0,002	0,001	0,027
	Maximum Deviation	1,2	0,7	3,4	0,8	0,6	2,5	0,08	0,06	0,34







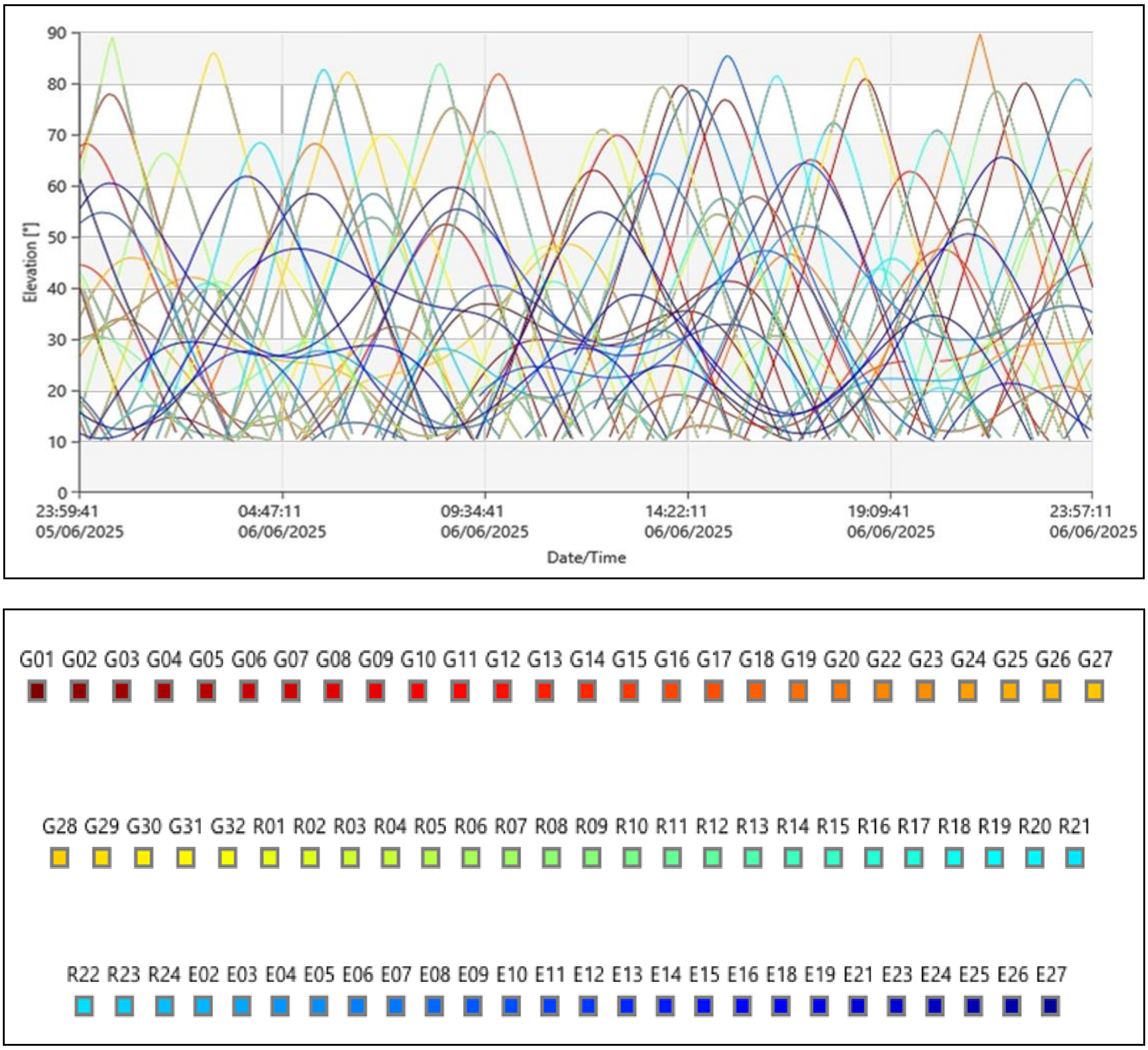


Fig 7: Elevation of the satellites above the permanent low-cost station INP01

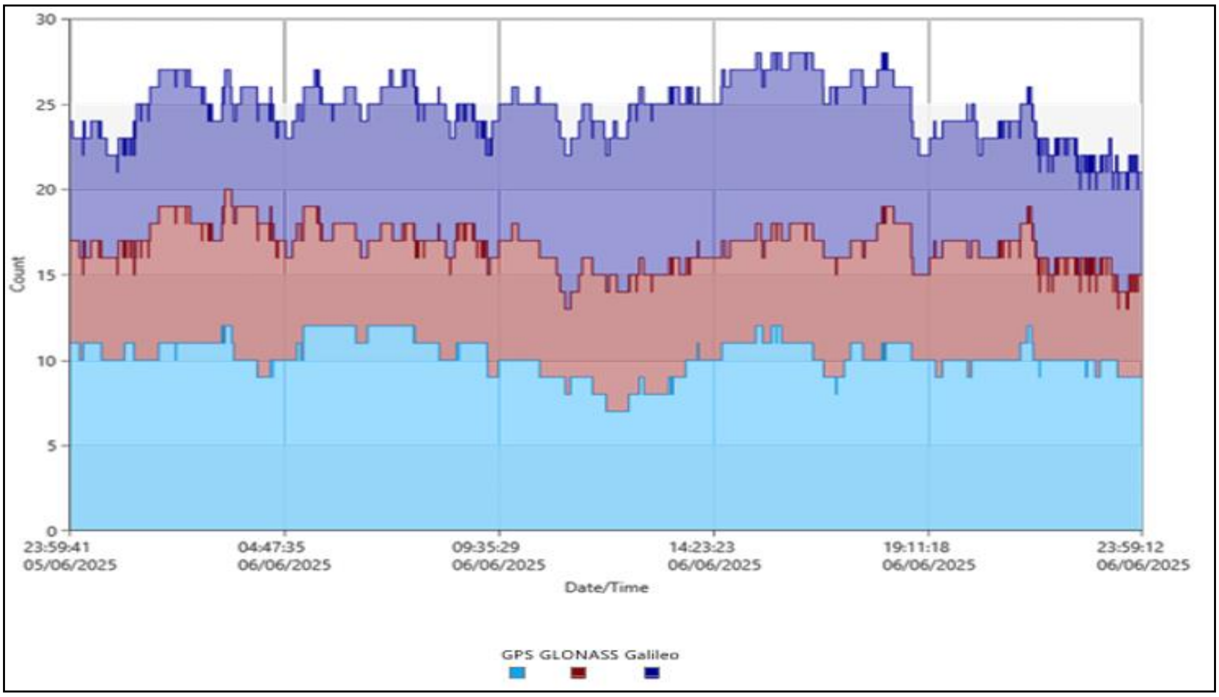


Fig 8: visibility of the satellites above INP01

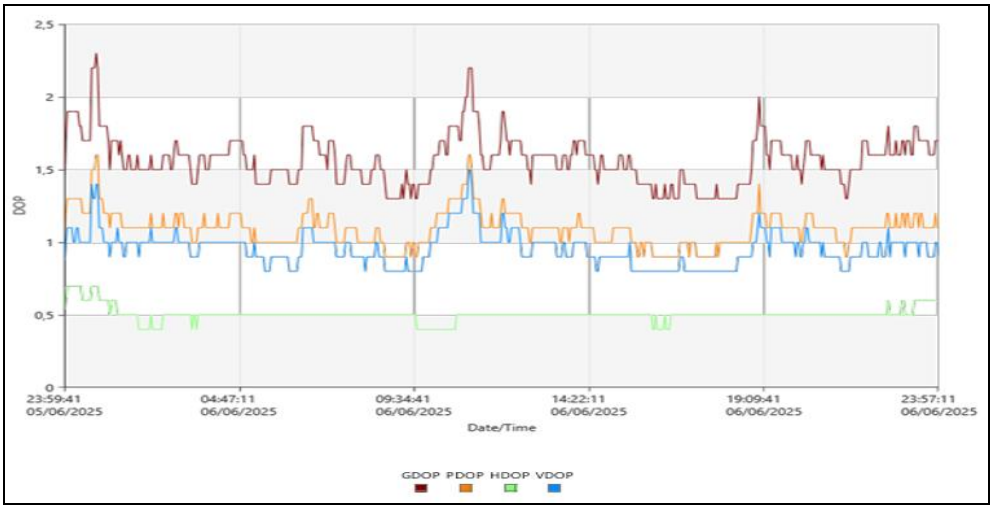


Fig 9: DOPs of the low-cost station's signal

Figs (6, 7 and 8) show that all satellites in all visible constellations have an elevation greater than 10°; the permanent low-cost GNSS station simultaneously picked up signals from more than 25 satellites visible on average during the entire observation period. In addition, there are three visible GNSS constellations. The PDOP of the permanent station signal varies between 0.9 and 1.6 which are values less than 3, so the uncertainty about the position of the station is very negligible, the number of visible satellites is excellent.

3. Differential positioning accuracy

The spectra SP60 receiver is placed respectively on the landmarks located 1km, 5km, 8km, 20km and 30km from our permanent station INP01. Observations are made between 8 a.m. and 12 p.m. each day. One day is dedicated to the observation of a point, so five days are necessary for the observation of all five landmarks. The position of each point is calculated from the two permanent stations YKRO and INP01 using the Leica infinity software. This process allowed us to compare the coordinates of each coordinate system from the professional receiver and to analyze the variations (Table 1, 2 and Fig 5).

Table 2: Differences between station INP01 coordinates and the Reference (YKRO)

		COORDONNEES PLANES - ITRF14.2010.0 - UTM 30N									
		BASE RGIRO2 YKRO			BASE LOW-COST INP01			ΔE (cm)	ΔN(cm)	Δhe (cm)	σp (cm)
MOBILE	POINTS	E (m)	N(m)	he (m)	E (m)	N(m)	he (m)				
SP60	P01	251853.866	759376.545	250.069	251853.868	759376.547	250.063	-0.2	-0.2	0.6	0.3
	P02	249497.845	755937.210	261.926	249497.843	755937.215	261.932	0.2	-0.5	-0.6	0.5
	P03	249776.106	752273.675	266.261	249776.103	752273.681	266.273	0.3	-0.6	-1.2	0.7
	P04	250548.837	739937.750	220.091	250548.843	739937.737	220.074	-0.6	1.3	1.7	1.4
	P05	223508.681	766506.809	191.289	223508.650	766506.785	191.229	3.1	2.4	6.0	3.9

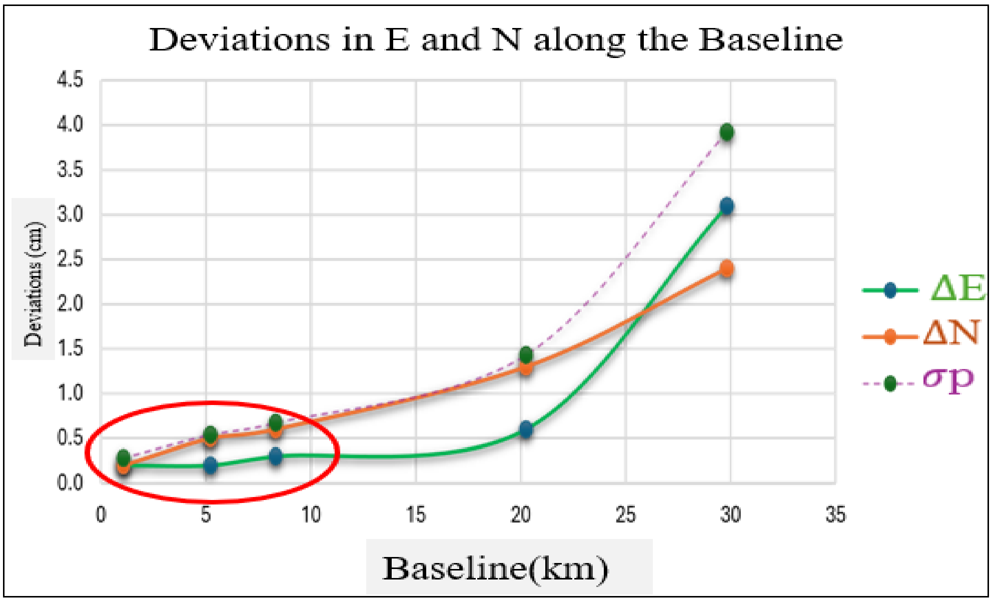


Fig 5: Evolution of coordinate Deviations with Baseline length

Table 3: Accuracy of the GNSS Low-cost INP 01 database according to the baseline

Base/Mobiles	Baseline	Model (Mobile SP60)	
		Vertical	Horizontal
Accuracy (cm) of the base Low-cost INP01	1 km	0.6	0.3
	5 km		0.5
	8 km	1.2	0.7
	20 km	1.7	1.4
	30 km	6.0	3.9

These results (Table 2-3) and Fig 5 show that the differences between the coordinates from the professional SP60 receiver post-processed from the Ykro station of the IGS and those post-processed with the low-cost GNSS station INP01 are less than ±7 mm for a baseline length of less than 10 km. The differences between the coordinates from the professional SP60 receiver post-processed from the YKRO reference station of the IGS and those post-processed with the INP01 station are greater than ±1cm for a baseline length of more than 15km**.**

These results indicate that for high-precision geodetic applications such as the observation of local reference points, a combination of a professional receiver (Mobile) with a permanent low-cost GNSS station is required, for a maximum baseline of 10 km. Observations must be made over a period of at least 2 hours and be calculated using professional or scientific Leica infinity software. These results corroborate the work of Stéphane DURAND *et al* [7]; He processed the data from low-cost GNSS receivers with Leica Infinity and RTKLIB software.

Discussion

The results obtained made it possible to establish an overall picture of the quality of the positioning of the INP01 Low-Cost GNSS station. The permanent low-cost GNSS station INP01 has a maximum plane deviation in absolute value of 1.2 mm and a maximum vertical deviation of 4 mm in absolute value during the entire observation period. The observed performances are consistent with those of the YKRO reference station of the IGS [8]. And the results of the work of Eugenio Realini [9]. No significant systematic drift was detected during the entire observation period at the permanent low-cost GNSS station. The analysis highlights that low-cost GNSS receivers, although not designed for initial geodetic uses, provide usable results when integrated into an optimized observation system. The planimetry precision obtained is sufficient for the detection of slow displacements (> 1 cm/month), so they can be used for the structural auscultation of engineering structures (bridges, dams), the monitoring of landslides or active faults.

The densification of regional or national permanent low-cost GNSS networks is sufficient for precision geodetic applications, georeferencing of local satellite data and the establishment of local reference points for geometric monitoring operations of structures.

Conclusion

The results of this study show that low-cost GNSS receivers have an adequate temporal stability of ± 3 mm horizontally and ± 5 mm vertically when using a permanent low-cost GNSS station combined with a conventional mobile receiver within a 10 km radius of the station.

These results confirm the possibility of using this device in high-precision geodetic applications in Africa and more particularly in sub-Saharan Africa.

These results pave the way for the densification of national geodetic infrastructures in the countries of the sub-Saharan zone, a boon for the space agencies of these developing countries.

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