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Analysis by comparison of the measurements of two different automatic weather stations in Akure, Ondo state Nigeria.

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Abstract- *This paper presents the characterizing measurement of the two automatic weather stations (AWS), Campbell Sci Inc (control) and Trans African Hydro Meteorological Observatory (Tahmo). The paper examined by comparison the relationship between weather parameters (Wind speed, wind direction, Relative humidty, air temperature and solar radiation) observed from the two AWS, which reveals similar variation all through the period. the results of the analysis based on actual sensors (Campbell and Trans African Hydro Meteorological Observatory (Tahmo)) data comparisons in Akure for hundreds of hourly observations clearly illustrate that there is little statistical difference in the measured parameters between the Campbell Sci Inc (control) versus the Tahmo station (measured) as they were found to be significantly correlated in all cases.*

Key words: *Air temperature, Relative humidity, wind speed, wind direction, solar radiation.*

1.0 Introduction

Over a long period of time, researchers have spent abandunt time and efforts towards collecting climate data and evaluating the data quality, especially for the air temperature, precipitation, solar radiation, wind speed and wind direction datasets [1]. The encouragement to do more in large scale is the interest in evaluating climate change at global, regional and local scales [2].

Meteorological data observed by automatic and conventional weather stations shows difference of measurements due to sensor types [3]. The general hypothesis is that mechanical sensors have slower response time than the electronic ones and this could lead to different values of the observed meteorological elements, in particular wind gusts, total daily rainfall and extreme temperatures [4]. One-minute averaged data for wind gusts represents better the real velocity than the peak observed during the same period and shows better correspondence with data collected with mechanical anemographs of standard stations [5].

Campbell Scientific weather stations have become the world-wide standard for meteorological and climatological monitoring. In use on every continent and virtually every country, our weather stations are known for their precision measurement capability, rugged construction, wide operating temperature range, and low power consumption [6]. Campbell Scientific weather stations offer the flexibility to easily change sensor configurations, data processing, and data storage and retrieval options. The flexibility and long-term reliability of our weather stations have resulted in their widespread use in scientific, commercial, and industrial applications [6]. The Trans-African Hydro-Meteorological Observatory (TAHMO), a project supported by Oregon State University and Delft University of Technology (TU Delft, The Netherlands), was selected by The Global Resilience Partnership on September 27th as one of eight global teams that will receive funding to implement transformative resilience solutions to problems that threaten the lives and livelihoods of the most vulnerable populations in Bangladesh, India, Kenya, Mali, Nepal, Niger, Philippines and Uganda [7]. TAHMO participated in the Global Resilience Challenge, a multi-stage design competition that received nearly 500 initial applications to address the most difficult resilience challenges. The organization will now receive up to $1 million to implement its proposed solution in a way that can be scaled and adopted by others in the future [7]. However, it is well known that observed meteorological data are very scarce in the developing and sub -Saharan countries because of lack of measuring equipment. Due to this, most researchers rely on remotely sensed data. Hence it becomes needful to ascertain the reliability and accuracy of the remotely sensed data if they are to replace or compliment the conventional lower measuring equipment.

Rigorous comparison of data from different Automatic weather stations is a fundamental requirement of climate research [8]. This is particularly important for studies that have far-reaching socio-economic implications, such as the quantification of the quality of data measured by different conventional or Automatic weather station in relation to global climate research [9].

In this work we present the results of an analysis characterizing the measurements and performance of two Automatic weather stations (Campbell and Tahmo) sited side by side at a low wind and vegetation area.

2.0 Methodology

Exploratory analysis also suggests that Automatic Weather Station (AWS) sensors are more sensitive to instant fluctuation events than Convectional Weather Station (CWS), mainly for wind gusts . This fluctuation can mainly affect the daily extreme values, increasing the difference between CWS and AWS measures. Automatic weather stations transmit measured and calculated data to a database stored on a server, by internet. Access to the database is done through a Web interface, where users can display all the parameters for different periods with a time step between 1 and 60 minutes. Each measuring point includes a wireless meteorological station and a leaf-soil station. Both stations are communicating with a console, which displays data in real time. Wind speed, wind direction, temperature, relative humidity, solar radiation and soil moisture were collected from Tahmo and Campbell automatic station at Wascal's observatory and analyzed at 10-minutes interval for the period of research. A number of statistical tests were run on the data from both stations. The techniques used can be classified as relative and absolute error indices. The analyzed data were compared to show the characterizing measurement performance of the state of the art of both stations. To test if both the automatic weather stations (AWS) data can be assumed as coming from the same distribution, Kolmogorov-Smirnov test is applied [3]. These two non-parametric tests were applied over original data and over its standardized anomalies, Z, given by [3]:

$$Z = \frac{X_{iy} - \mu_i}{s_i} \qquad (1)$$

where x_{iy} is the ith-day value in a specific year y, μ_i and s_i are, respectively, the AWS historical mean and standard deviation for the ith-day over the years, i.e., the mean and standard deviation value for the subset of AWS data for the n ith -days of the n years in analysis. The purpose was to remove the location and spread influences from the original dataset, which could be significant because of the data seasonality. This can also affect average values calculated from instantaneous measurements such as compensated mean for daily temperature. To mitigate these errors, based on the works done by [3], suggest an alternative method for calculating the AWS wind gust and maximum/minimum temperatures, considering the response time of the mechanical anemometer and of the mercury thermometer as a parameter for comparison with the electronic sensors. For Campinas-SP, the software of the AWS data logger was modified in order to simultaneously calculate "regular" and "smoothed" wind speed and temperature every 10 minutes, and to summarize daily data. Therefore, for smoothed data, instead of considering as extreme daily values the maximum peak collected by the sensors for wind and temperature, it was calculated the one-minute average of the data collected every second. Extreme values of these one-minute averages were used as daily extreme values. A two weeks dataset was collected to compare both datasets using the Wilcoxon Mann-Whitney test. Additionally, three different models to calculate mean daily temperature were generated. Assuming that the real mean temperature would be the average of every one-hour mean temperature, the 24h mean temperature (T_m) was calculated and compared to the average of maximum and minimum temperature (T_{xn}) and to the compensated mean temperature (T_c) given by the formulas;

$$T_{xn} = \frac{T_{max} + T_{min}}{2} \quad (2)$$

$$T_c = \frac{T_{max} + T_{min} + T_9 + 2T_{21}}{5} \quad (3)$$

2.1 Root Mean Square Error (RMSE)

The root means square error (RMSE) also called the root mean square deviation (RMSD)
Is frequently used measure of the difference between the values predicted by a model (Data measured with constructed sensor) and the values actually observed (Data measured using standard sensors). These individual differences are also called residuals, and the RMSE serve to aggregate them into a single measure of predictive power [10].

The RMSE of a model prediction with respect to the estimated variable X_{model} is defined as the square root of the mean square error.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Xc - X_T)}{n}} \quad (4)$$

where:
X_C is data measured from the Campbell station
X_T is data measured from the constructed Tahmo and
n is the total number of data set.

RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of the other predictive models.

3.4 Standard Deviation

Standard deviation and variance are based on how much each observation deviates from a central point represented by the mean. The greater the distances between the individual observation and the mean, the greater the variability of the data set. These measures evaluate how values are spread out or disperse around the mean.

$$\text{SD} = \left(\sqrt{\frac{\sum_{i=1}^{n}(X - \overline{X})^2}{N-1}}\right) \quad (5)$$

X and $\overline{X}$ are each data set and observed means respectively and N is the total number of data set. The standard deviation of a random variable statistical population, data set or probability distribution is the square root of its variance. A low Standard deviation indicates that the data points tend to be very close to the mean also called expected value while a high standard deviation indicates that the data points are spread out over a large range of values [10].

3.0 Results and Discussion

This chapter presents the results of the comparison between the weather parameters observed by the two weather stations (Tahmo and Campbell).

3.1: Comparison between wind speed and direction of Campbell and Tahmo station

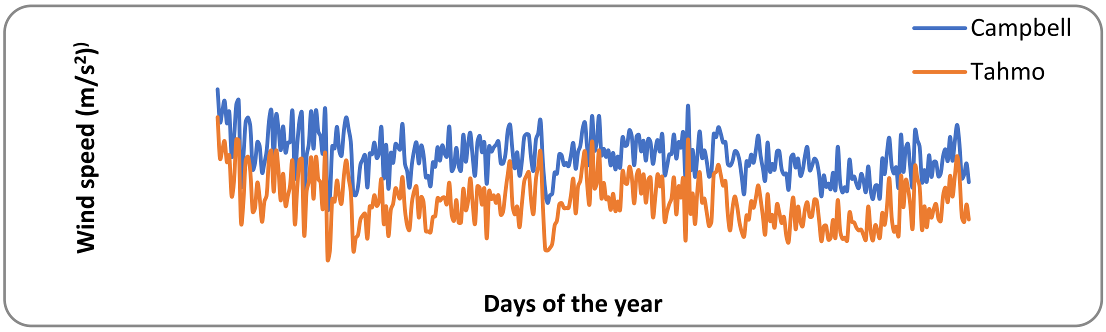

Figure 4.1: Comparison between Campbell and Tahmo station wind speed (m/s)

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Figure 4.1 shows the comparison for wind speed (m/s) for the period of study. The wind speed for both stations reveals similar variation all through the period of research. The wind speed for Campbell station (about 1.6 m/s) was 30% higher than that of Tahmo station (about 1.3 m/s), Campbell appear to be more sensitive to the variation in wind speed (m/s) while Tahmo tends to be slightly lower than Campbell as can be seen in figure 4.1. This variation in the recorded data is not due to location where both stations are sited since both are approximately sited in the same location of relatively low vegetation. Both stations have same resolution towards wind speed but different percentage of accuracy (Percentage of accuracy; Tahmo, ±3% and CampBell, ±2%).

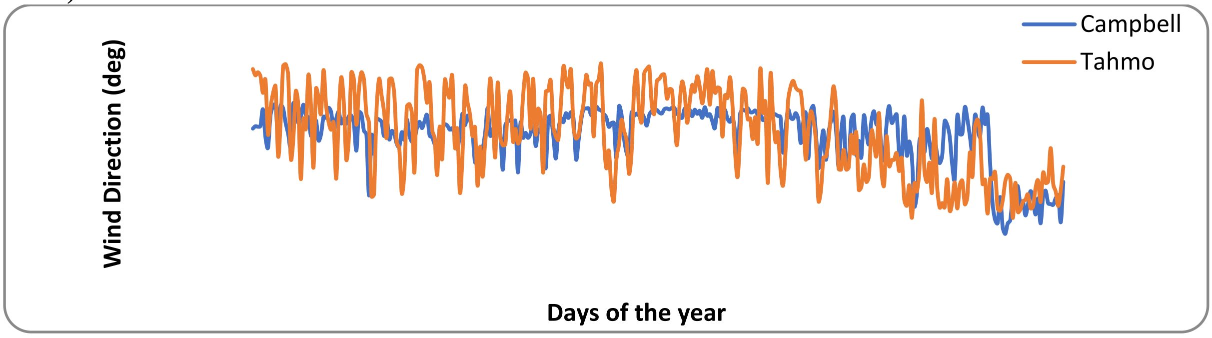

Figure 4.2: Comparison between Campbell and Tahmo station wind direction.

In order to analyze wind direction data correctly, it is important to exclude samples where the wind speed is low, since the associated wind direction may be meaningless. Figure 4.2 shows the comparison for wind direction (deg) for the period of study. It should be noted that the wind direction showed similar variation throughout the period. The wind direction from the North and Eastern directions experiences some obstructions from the nearby tall trees and a thick vegetation around the area where the two AWS were sited. The tall trees and the vegetation obviously obstruct the wind direction sensors from capturing the wind direction correctly. The west and southern directions are somehow free and that's where the two stations agreed as shown in figure. Tahmo station has highest recorded value of 359^0 and the least of 0^0 while Campbell has the highest recorded value of 270^0 and also the least value of 0^0 (Tahmo is 35% higher than Campbell). The directional relationship between the two automatic station mounted side by side as well as their absolute magnitudes was investigated and It was found that the stations recorded difference in the values of data in early hour of the day. Tahmo responded more to this variation even though the flow had no obvious flow effects. Both stations tend to record their respective least values in the month of December. The stations have the same operating resolution of 1 degree. Both Campbell and Tahmo have an operating accuracy of ±3 degree.

3.2: Comparison between Wind Rose of both Campbell and Tahmo station

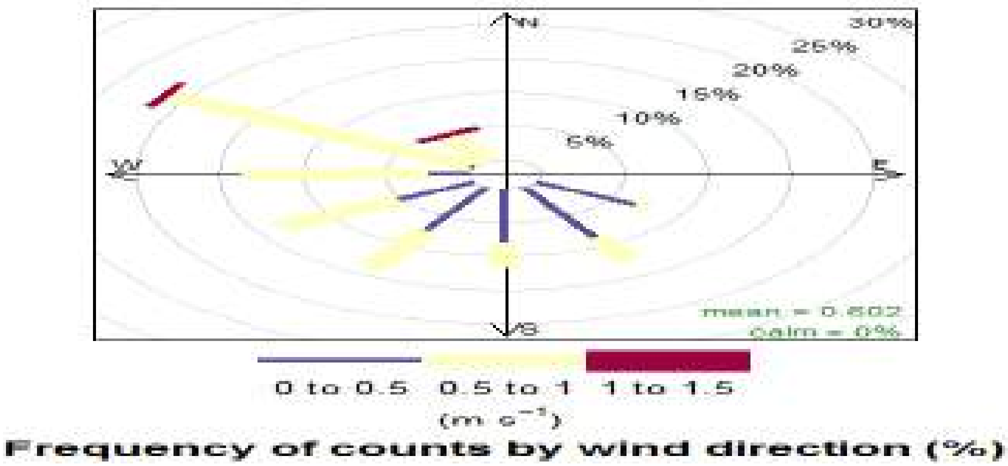

Figure 4.1: Windrose for Tahmo

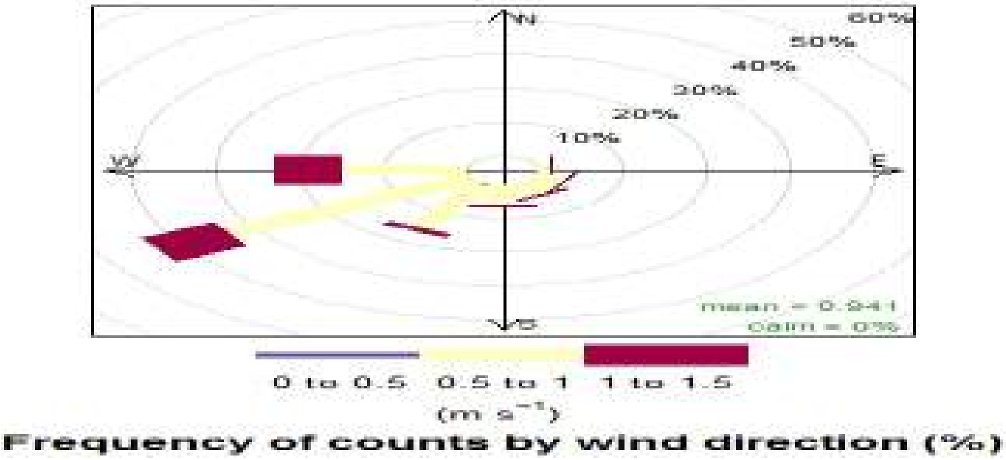

Figure 2.4: Wind rose for Campbell

Figures 4.3 and 4.4 shows the wind rose over the study area and the summary of the occurrence of winds at both the Campbell and Tahmo weather stations; showing their strength, direction and frequency. For Tahmo station (Figure 4.3), the highest frequency was 22% blowing from the North to West direction while the lowest frequency was 5% from the North to the West while at other times, the frequency was between 10 and 15% .The station is approximately calm and has a mean of 60% . While for Campbell station (Figure 4.4), the wind rose shows that the winds blows from the South to west, with the highest frequency of about 43%, which was higher than that of the Tahmo station and the lowest is about 5%. The station is approximately calm and has a mean of about 90%.

3.3 Variation of the ratio of Sonic to cup wind speeds with direction

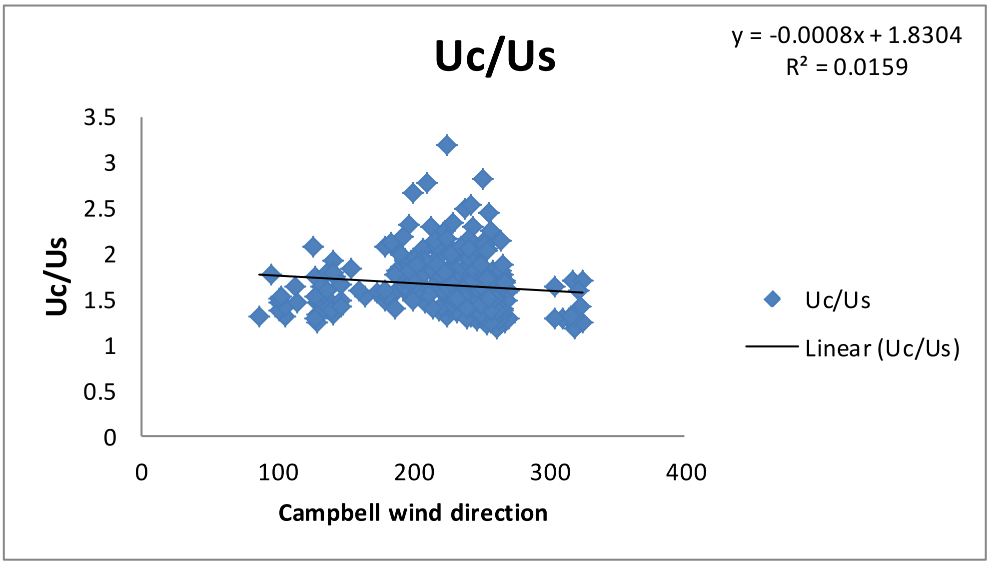

Fig.4.5a Campbell Variation of the ratios of wind direction to speed measured by sonic and cup anemometer.

Fig.4.5b Tahmo Variation of the ratios of wind direction to speed measured by sonic and cup anemometer.

The variation of the ratios of wind speed with direction as measured by sonic and cup anemometer is presented in figures 4.5 a and b. The figures shows that the location where the two AWS was sited is a low wind speed area. The wind speed ration for Campbell is almost constant between the wind directions of 18^0 to 270^0 while that of Tahmo is also constant between the wind directions of 100^0 to 325^0 but tends to decrease steadily.

3.4 Correlation between Wind speed (m/s^2) of Campbell and Tahmo

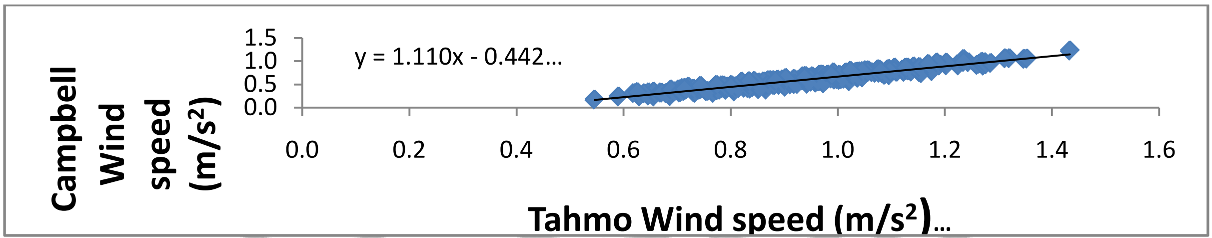

Figure 4.5 Correlation between Campbell wind speed (m/s^2) and Tahmo wind speed (m/s^2)

Figure 4.5 shows the correlation between the wind speed recorded by both Campbell and Tahmo weather station. The plot indicate a very high correlation value of about 0.9276. The wind speed for both stations reveals similar variation, both has the same approximate maximunm value and same minimum value. Both sensor tends to vary same way across the period of research as both tends to have their highest wind speed value between the month of February and March and their lowest value between November and December.

Table 4.1: Statistical analysis of Campbell versus Tahmo wind speed for the period of the study.

Wind speed	Campbell	Tahmo
Correlation	0.9276 (strong)	0.9276 (strong)
Standard deviation	0.50347 (m/s)	0.60075 (m/s)
Root mean square error	0.0048 (m/s)	0.0528 (m/s)
Maximum	6.50000 (m/s)	6.50000 (m/s)
Minimum	0.0000 (m/s)	0.0000 (m/s)

The relative indices (R^2=0.9276 and R=0.9276) indicated that the wind speed of the two Automatic weather stations values were in close agreement to the results. The RSME of Campbell is 0.0048 (m/s) while that of Tahmo is 0.0528 (m/s). The standard deviation of the respective stations (Campbell 0.50347 (m/s) and Tahmo 0.60075 (m/s)) also indicate greater agreement as shown in Table.

Table 4.2: Statistical analysis of Campbell versus Tahmo wind direction for the period of the study

Wind Direction	Campbell	Tahmo
Correlation	0.910	0.910

Standard deviation	84.36782 (deg)	149.25258 (deg)
Root mean square error	0.6261 (deg)	0.8331 (deg)
Maximum	360.00 (deg)	359.00 (deg)
Minimum	0.0000 (deg)	0.0000 (deg)

The relative indices (Campbell with the highest frequency of about 43% blowing from South to west indicated that it is higher than Tahmo with 22% blowing from the North to West direction. the wind direction of the two Automatic weather stations values were in close agreement. The RSME of Campbell is 0.6261 (deg) while that of Tahmo is 0.8331 (deg). The standard deviation of the respective stations (Campbell 84.36782 (deg) and Tahmo 149.25258 (deg)) also indicate a close-range agreement as shown in Table.

3.5: Comparison between Air Temperature (^{o} C) for both Campbell and Tahmo Stations

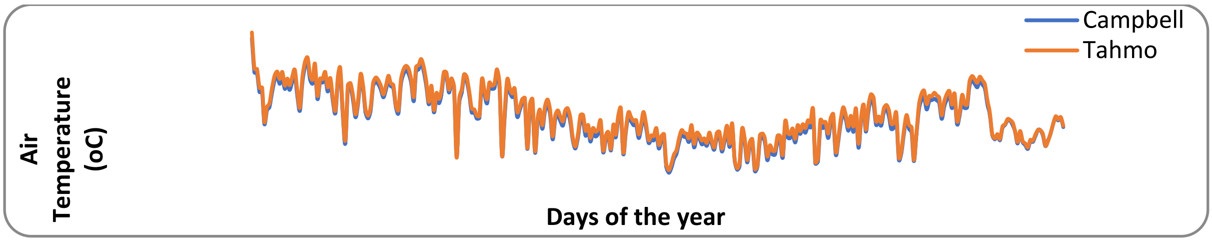

Figure 4.6: Comparison between Campbell and Tahmo station air temperature (^{o}C)

Figure 4.6 shows the comparison for air temperature (^{o} C) for both stations for the period of study. The air temperature showed similar variation, though the Tahmo has higher air temperature of (35.8^{0}C) than that of Campbell (35.2^{0}C). Tahmo station has maximum recorded data of about 35.8^{o}C and the lowest value of about 14.8^{o}C while Campbell station has maximum recorded value of about 35.2^{o}C and the lowest value of about 15.0^{o}C. Both sensors tend to vary same way, as both have peaks and decline between the month of May and December. But the two sensors recorded their highest values in month of February.

3.6: Correlation between Air Temperature for Tahmo and Campbell

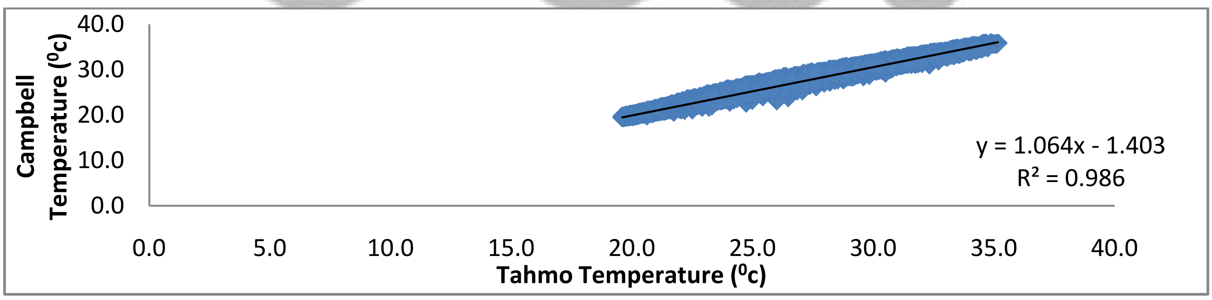

Figure 4.7: Scatter plot of air Temperature for Tahmo and Campbell.

Figure 4.7 shows the comparison for air temperature (^{o} C) for both station for the period of study. The air temperature for both stations reveals similar variation all through the period. Both stations responds highly during the research, as high correlation value of approximately 0.993. Both has the same maximunm value and same minimum value. Both has maximum recorded value of about 35^{o}C and the lowest value of about 15^{o}C Both sensor tends to vary same way across the period of research as both tends to have their respective lower values between the month of May and December.

Table 4.3: Statistical analysis of Campbell versus Tahmo Air Temperature for the period of the study

Air Temperature	Campbell	Tahmo
Correlation	0.993 (very strong)	0.993 (very strong)
Standard deviation	3.35191 (^{0}c)	3.62381 (^{0}c)
Root mean square error	0.1249 (^{0}c)	0.1296 (^{0}c)

Maximum	35.200 (^{0}c)	15.000 (^{0}c)
Minimum	35.800 (^{0}c)	14.800 (^{0}c)

The relative indices (R^2=0.9864 and R=0.993) indicated that the Air Temperature of the two Automatic weather stations values were in strong agreement. The RSME of Campbell is 0.1249 (^{0}c) while that of Tahmo is 0.1296 (^{0}c). The standard deviation of the respective stations; Campbell 3.35191 (^{0}c) and Tahmo 3.62381 (^{0}c) also indicate greater agreement as shown in Table.

Table 4.3: Statistical analysis of Campbell versus Tahmo Air Temperature for the period of the study

Air Temperature	Campbell	Tahmo
Correlation	0.993 (very strong)	0.993 (very strong)
Standard deviation	3.35191 (^{0}c)	3.62381 (^{0}c)
Root mean square error	0.1249 (^{0}c)	0.1296 (^{0}c)
Maximum	35.200 (^{0}c)	15.000 (^{0}c)
Minimum	35.800 (^{0}c)	14.800 (^{0}c)

The relative indices (R^2=0.9864 and R=0.993) indicated that the Air Temperature of the two Automatic weather stations values were in strong agreement. The RSME of Campbell is 0.1249 (^{0}c) while that of Tahmo is 0.1296 (^{0}c). The standard deviation of the respective stations; Campbell 3.35191 (^{0}c) and Tahmo 3.62381 (^{0}c) also indicate greater agreement as shown in Table.

3.7: Comparison between Percentage Relative Humidity (%) of both Campbell and Tahmo station

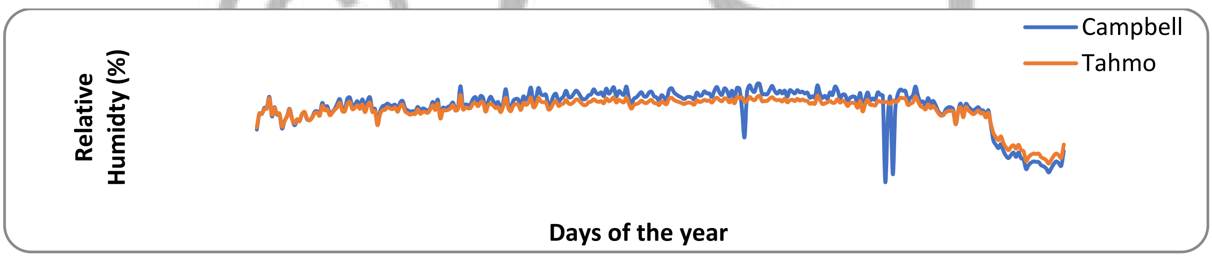

Figure 4.8: Comparison between Campbell and Tahmo station Relative Humidity (%).

Figure 4.8 shows the comparison for relative humidity (%) for the period of study. The variation of relative humidity for the two stations shows similar distribution. Campbell station tends to record highest percentage of about 98% relative humidity in between the months of April and May and a higher percentage of relativity humidity all through the period of research. Though there is a significant drop in percentage (%) of relative humidity to about 60% and 30% respectively in the month of September and October. In the month of December through January, there is a consistent drop in percentage (%) of relative humidity of about 20- 40%. While Tahmo station tends to record highest percentage of 90% relative humidity in the month of February and the lowest of about 35% in the month of January, which drops and rises until October when it continues to drop. Generally the difference between the relative humidity of the two stations is 8% (i.e Campbell station has 8% relative humidity more than Tahmo station). Campbell station recorded its least relative humidity in the months of September and October while Tahmo station recorded its least relative humidity in the month of December. This could be due to their difference in resolution (i.e Tahmo has a resolution of 0.1%RH while Campbell has resolution of <1%), but both stations have the same accuracy value of ±3%.

3.8: Correlation between Relative Humidity for Tahmo and Campbel

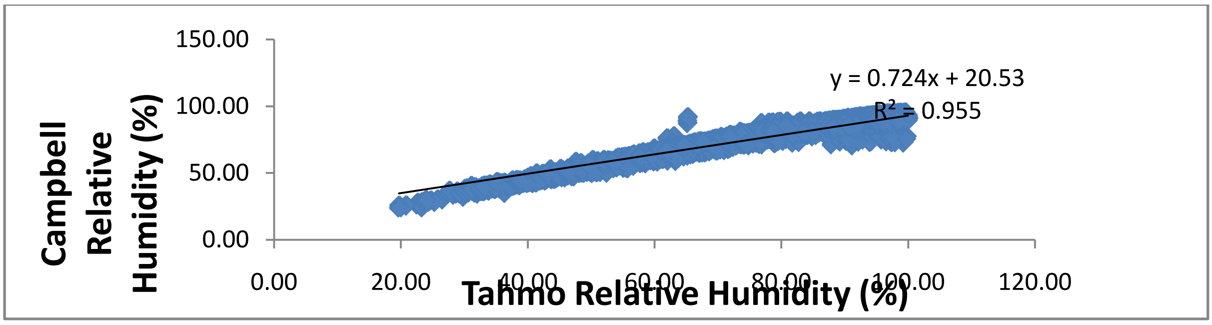

Figure 4.9: Scatter plot of Relative humidity for Tahmo and Campbell.

The relative humidity of both Tahmo and Campbell weather station are correlated to explore the relationship between both stations and to ascertain the reliability of both station. There is a high correlation between both stations as can be seen in Figure 4.9. Both stations responds highly during the research, as it shown by the high correlation value of approximately 0.98 but Tahmo responds highly for all the parameters under investigation during the course of this research.

Table 4.4: Statistical analysis of Campbell versus Tahmo Relative Humidity for the period of the study

Relative Humidity	Campbell	Tahmo
Correlation	0.9843 (very strong)	0.9843 (very strong)
Standard deviation	20.80467 (%)	15.13737 (%)
Root mean square error	0.9833 (%)	0.8384 (%)
Maximum	100.000 (%)	95.380 (%)
Minimum	13.34 (%)	17.990 (%)

The relative indices (R^2=0.969 and R=0.9843) indicated that the Relative Humidity of the two Automatic weather stations were in strong agreement. The RSME of Campbell is 20.80467 (%) while that of Tahmo is 0.8384 (%). The standard deviation of the respective stations; Campbell 3.35191 (^{0}c) and Tahmo 15.13737 (%) also indicate greater agreement as shown in Table.

3.9: Comparison between Radiation (W/m^2) of both Campbell and Tahmo station

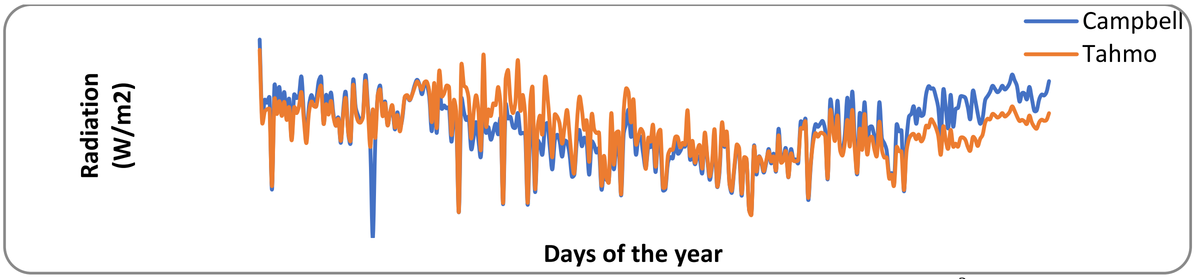

Figure 4.10: Comparison between Campbell and Tahmo station Radiation (W/m^2)

Figure 4.10 shows the comparison between Radiation (W/m^2) of both Campbell and Tahmo station for the period of the study. The variation of radiation for the two stations shows similar distribution, as both tends to peak at almost the same time. Campbell station tends to record the highest radiation value of about 270 W/m^2 in February and lowest value of 0 W/m^2 in the month of April. Though there is a recurrent trend in the radiation value in the months. Tahmo also tends to record its highest radiation value of about 250 W/m^2 in February and its lowest value of about 0 W/m^2 in the month of September. Likewise, there is a recurrent trend in the radiation value in the months of the study. Generally Campbell station is 20% higher than Tahmo station. It should be noted from Fig.4.10 below that there is an inconsistency in the measurements between the two automatic weather stations due to environmental factors one of which may be due to the fact that the two stations were overshadowed by a nearby tree and at another time the cable connecting the main sensors panel with the data logger was tempered with by the gardeners when trying to clear the grasses and these can be justified by the diurnal solar radiation plots for the period of one week starting from 14th February,2015 to 21st February,2015 as shown in the figures (4.10a,4.10b,4.10c,4.10d,4.10e,4.10f,4.10g and 4.10h) below. It should be noted that the effect of the shadow on the solar radiation shown exactly at 2:20pm on 14th and 16th February, 2015 as shown in Fig.4.10a and Fig.4.10c, 3:20pm on 15th February, 2015 in Fig.4.10b, 1:50pm on

17th February, 2015, 2:30pm on 19th February,2015, 2:40pm on 20th February, 2015 and 3:15pm on 21st February, 2015. 18th appears to be cloudy as shown in Fig.4.10e.

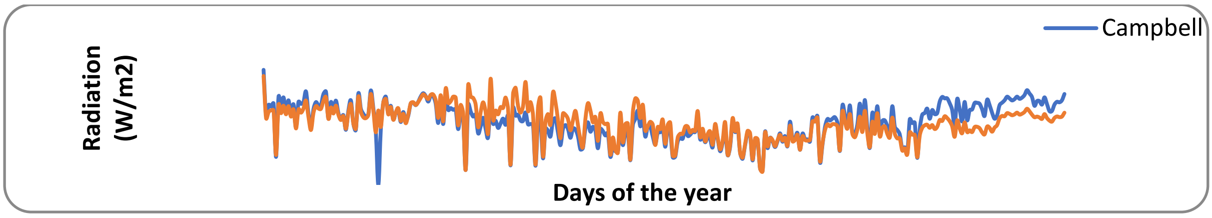

Figure 4.10: Comparison between Campbell and Tahmo station Radiation (W/m^2)

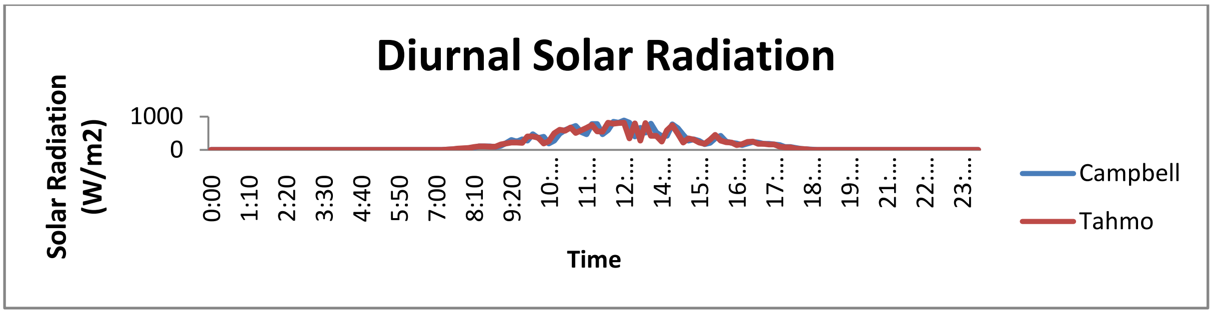

Figure 4.10a: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 14th February, 2015.

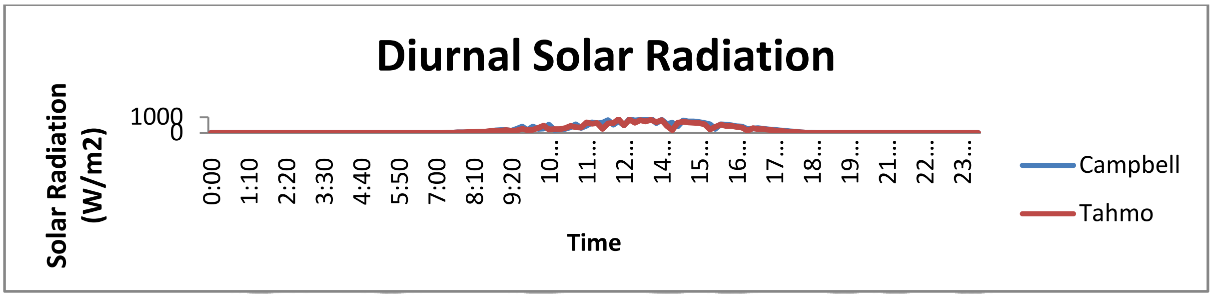

Figure 4.10b: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 15th February, 2015.

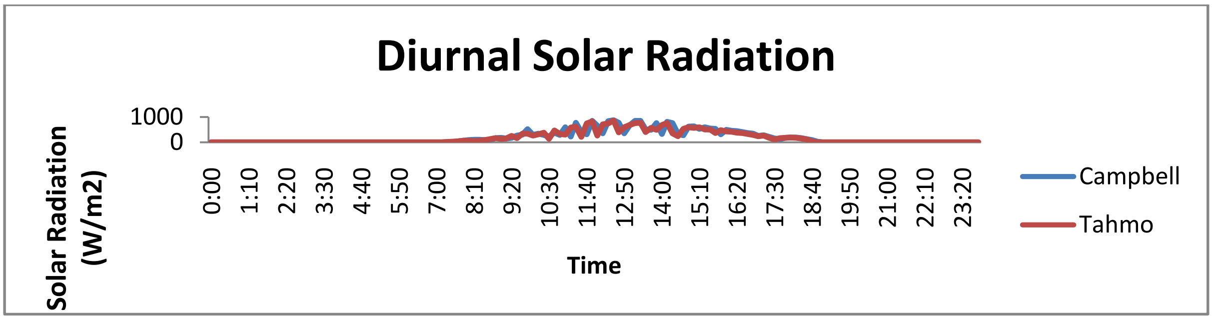

Figure 4.10c: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 16th February, 2015.

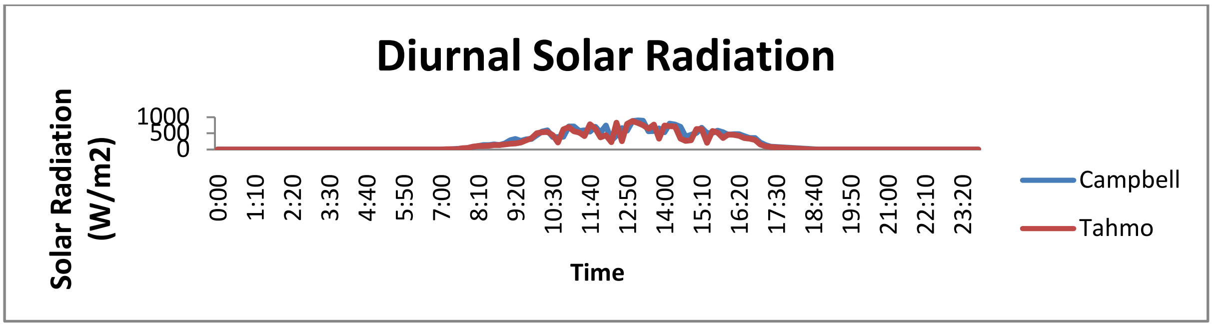

Figure 4.10d: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 17th February, 2015.

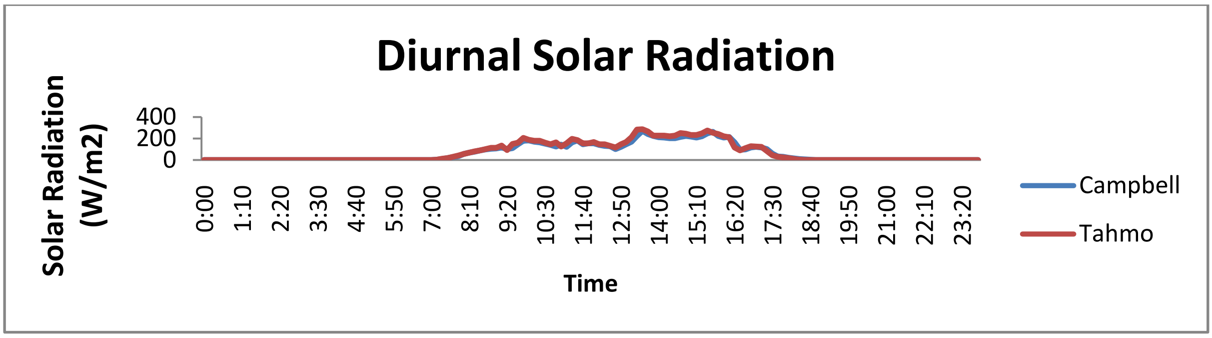

Figure 4.10e: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 18th February, 2015.

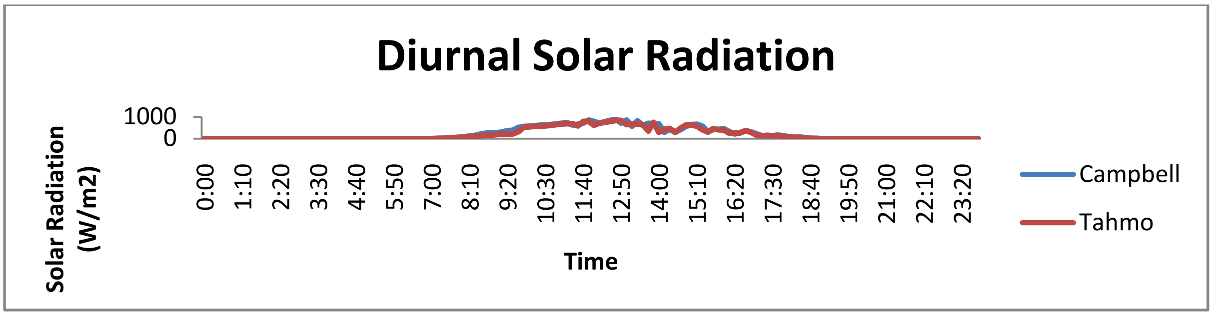

Figure 4.10f: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 19th February, 2015.

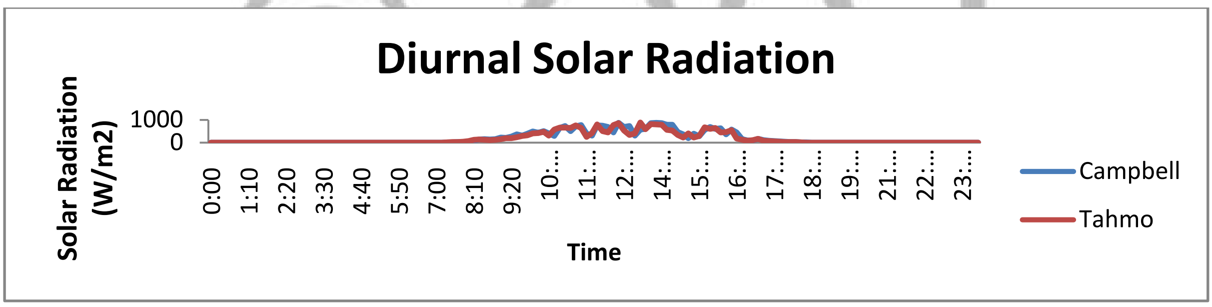

Figure 4.10g: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 20th February, 2015.

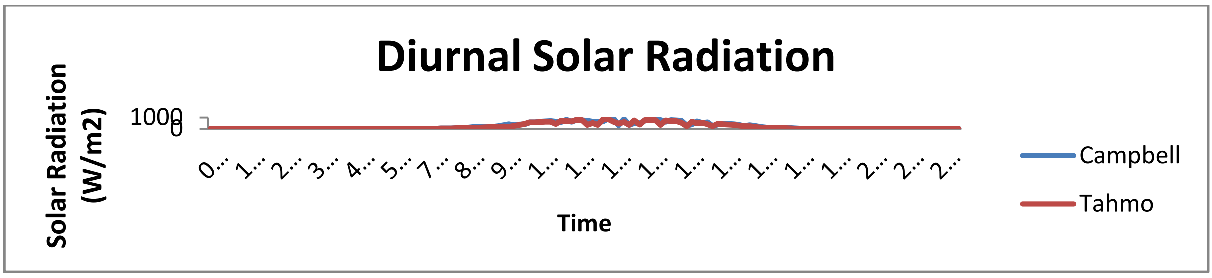

Figure 4.10h: Diurnal solar radiation between Campbell and Tahmo station Radiation (W/m2) for the period of 21th February, 2015.

3.10 : Correlation between Radiation for Tahmo and Campbell

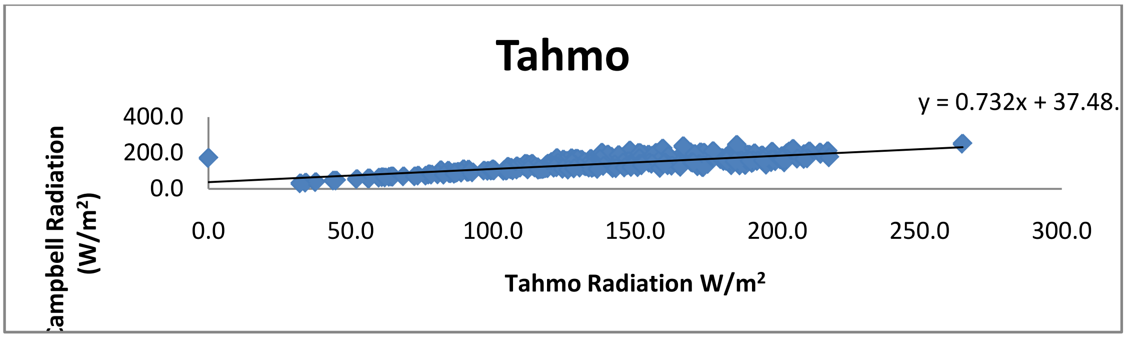

Figure 4.11: Scatter plot of Radiation for Campbell and Tahmo.

Figure 4.11 below shows the correlation between Campbell and Tahmo station Radiation (W/m^2) for the period of study. Both stations responds highly during the research, as it shown by the high correlation value of approximately 0.7999. Fig.4.11 below proves that The highest values were observed during the noon time when the sun is very intensed. Likewise, there is a significant decrease in solar radiation values in the latter periods of the day.

Table 4.5: Statistical analysis of Campbell versus Tahmo Solar Radiation for the period of the study.

Solar Radiation	Campbell	Tahmo
Correlation	0.7999 (strong)	0.7999 (strong)
Standard deviation	219.00127 (W/m^2)	217.43047 (W/m^2)
Root mean square error	1.1358 (W/m^2)	1.0049 (W/m^2)
Maximum	1003.4 (W/m^2)	1085.8 (W/m^2)
Minimum	0.0000 (W/m^2)	0.0000 (W/m^2)

The relative indices (R^2=0.6399 and R=0.7999) indicated that the Solar Radiation of the two Automatic weather stations were in strong agreement. The RSME of Campbell is 1.1358 (W/m^2) while that of Tahmo is 1.0049 (W/m^2). The standard deviation of the respective stations; Campbell 219.00127 (W/m^2) and Tahmo 217.43047 (W/m^2) also indicate greater agreement as shown in Table 4.5 below.

4.0 Conclusion

Based on the results of the analysis of the actual sensor data comparisons in Akure for hundreds of hourly observations it can be concluded that there is little statistical difference in the measured variables between the Campbell Sci Inc (control) versus the Tahmo station (measured) as they were found to be significantly correlated in all the studied meteorological parameters.

5.0 References

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