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Comparative Study Evaluating METEONORM Estimates of Sunshine Duration and air Temperature in Major Cities of Mali

Moussa Ibrahim MAIGA, Cheick Oumar SANOGO, Souleymane SANOGO
moussaibra6@gmail.com, jilincos@yahoo.fr, soulysanogo@gmail.com
Faculté des Sciences et Techniques
University of Sciences Techniques and Technology of Bamako
(USTT-B), Bamako, Mali

***Abstract* – The successful implementation of renewable energy project relies on the climatic data available in the site. Due to the scarcity of climatic station data, various estimation databases are proposed as an alternative. In this work, we performed an evaluation of METEONORM estimations of sunshine duration and air temperature by comparing them with stations records for some selected cities in the semi-arid zone of Mali, which are Bamako, Nara, Sikasso, Segou and Mopti. The results from the comparative study reveal that the METEONORM estimate of temperature has a very good correlation coefficient with the station record for all the cities. The bias and the root mean square error are very weak and do not exceed 1.5% of the reference values. The results of the sunshine duration show some difference between the two datasets with a maximum bias of 24.73 hours per month and a correlation coefficient that oscillates between 0.76 and 0.98. The semi-arid zone of West Africa being a region with less meteorological data records, it is advisable that METEONORM dataset could be used as an alternative for study energy systems.**

***Keywords* – METEONORM, sunshine duration, temperature, Mali**

I.INTRODUCTION

In the world, 1.2 billion of people lack access to electricity with 600 million living in sub-Saharan Africa [1]. Africa remains the least electrified continent and this is likely to be more marked in the coming years due to the significant demographic growth that the continent is facing [2]. Daily activities requiring energy, such as lighting, are then supplied by alternative means such as candles or kerosene lamps, whose risks (toxic fumes, fire) are well known. Many studies highlight the benefits of access to electricity and the link between energy and development. Although it is not proven to be a sufficient factor for development, it is still necessary and allows improvement in a large number of areas, such as socioeconomic activity, education or health [3].

In order to carry out an electrification project and ensure the success of it, climate conditions must be taken into account. Indeed, the decision-making process of electrification especially for population in least developed countries as Mali is a multifactorial problem, for which choosing economic technology requires consideration of socio-economic and environmental aspects [4]. Optimal sizing and management of energy systems required local meteorological conditions to which these systems are subject. The optimization of a photovoltaic system depends partly on instantaneous values of the meteorological variables. Extensive studies are being conducted in many parts of the world to evaluate and model solar potential. They allowed the development of models of solar radiation. More recent studies have focused on modeling the randomness of solar radiation using neural networks [5].

In Mali, the estimation of local solar irradiation is important for many applications. But, field measurements of solar radiation are available for small areas such as at synoptic weather stations in some cities. The potential for renewable energy is also considerable, especially the solar energy available throughout the year. It appears therefore that solar energy can bring real energy solutions without any side effect on climate in general. The intensity of solar radiation received at a photovoltaic module is therefore a function of many factors such as the weather conditions, the height of the sun in the sky and sunshine hours in the day.

However, the Earth's atmosphere receives solar radiation at an average illumination of 1.37kW/m2 and this value varies slightly depending on whether the earth is moving away from or approaching to the sun in its rotation around itself [9]. According to previous finding [17], among the meteorological parameters which affect the amount of solar radiation reaching a horizontal location, the greatest influence is exerted by the sunshine hours. This parameter is closely linked to the solar radiation [18, 19]. High temperature consists of the key condition for heat technology implementation; but for photovoltaic panels, increase in temperature causes a decrease in voltage with a slight increase in current and subsequently a relative decrease in maximum power [16].

The estimation of climate variables in West Africa is still a topical subject, due to the geographical and economic situation of these countries in the sub-Saharan Africa. Several databases provide estimates of climate variables that could be used for energy study. Some datasets are based on satellite products or station measurements, or a combination of both. However, the major wondering is about the real performance of those databases in the Sahelian zone like Mali where very few measurement stations are available.

METEONORM estimates have been used in various studies but not in context of Mali. The climatological annual mean of temperature and sunshine estimated by METEONORM was evaluated for the Odeillo site [10]; the estimated values were slightly lower than the weather station records. The estimations of METEONORM were used to simulate the evolution of the energy required for the air conditioning of building in Burkina Faso. The energy consumptions obtained from using station data and METEONORM estimates are of the same order of magnitude [12]. A comparative study of two models calculating solar radiation by clean sky has been performed in Algeria using METEONORM estimates [13]. As part of this study, it is proposed to evaluate the performance of the METEONORM estimations of sunshine duration and temperature in Mali. These two parameters are closely linked to solar energy, that is used for both heat and photovoltaic applications.

II. METHOD AND DATA

1. The study area and data used:

The study is done for the five selected cities in Mali. The topographical map of the country is presented in the Figure 1 highlighting the sites under study.

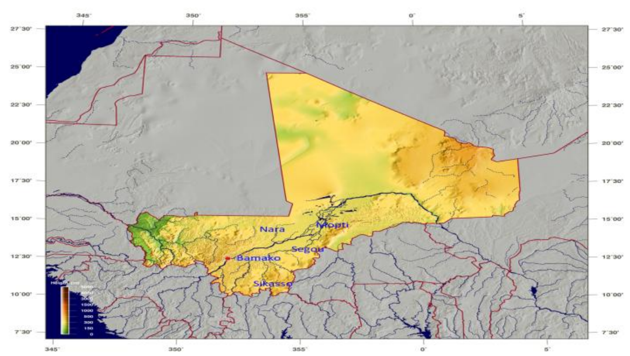

Fig1 Topographical map of Mali indicating the study site.

METEONORM estimates are used in this study. The dataset is a very comprehensive collection of meteorological data. It also contains algorithms for creating measured weather files from anywhere on the globe. The climatic data of five weather stations in Mali (Bamako, Sikasso, Segou, Nara and Mopti) are also used (Figure 1). The monthly climatological mean for the period 1980-2018 of temperature and sunshine hours are used to perform the evaluation of METEONORM dataset in Mali.

2. Methods:

The statistics used to evaluate the METEONORM dataset are the coefficient of correlation, the Bias and the Root Mean Square Error. The performance of the METEONORM dataset is characterized by comparison with good quality ground measurements from weather stations.

The bias measures the difference between actual measured and expected physical quantities. If P_i is the forecast on date i and O_i is the observation on date i, the bias between the forecast and the observation on date i is given by the following relation:

$$b_i = P_i - O_i \qquad (1)$$

The average bias over a long period of time (MB) is given by:

$$MB = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i) \qquad (2)$$

Where N is the expected date number of the period.

The indicator called Root Mean Square Error (RMSE) is the square root of the mean squared error. It measures the average magnitude of the errors made by the forecast by synthesizing them into a single value. He is particularly sensitive to large differences.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2} \qquad (3)$$

O_i is the value of the observation of the day i.

P_i is the value of the forecast of day i.

N is the number of months in the forecast.

The calculated error gives a synthetic measure of the overall error in a single value. The correlation coefficient r is used to measure the intensity of the linear connection between two variables [15]. It is obtained by the ratio:

$$r = \frac{cov\,(PR,OB)}{\sigma PR \times \sigma OB} \qquad (4)$$

Where $\sigma PR, \sigma OB$ are the standard deviations of PR and OB respectively, and $cov(PR, OB)$ are their covariances. Its value is between -1 and 1 or expressed as a percentage.

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III. RESULTS AND INTERPRETATIONS

1. Seasonality analysis

To obtain an evaluation of the METEONORM data in Mali, we will compare the METEONORM data with the synoptic stations of some big cities: Bamako, Nara, Sikasso, Ségou and Mopti. In the following figures, comparative graphs of sunshine duration and ground temperature, software and synoptic stations of the five sites selected as a function of time will be presented.

1.1. Bamako Site

The data of the synoptic station of Bamako comprised of the sunshine duration and the temperature which are compared with the data resulting from the METEONORM dataset.

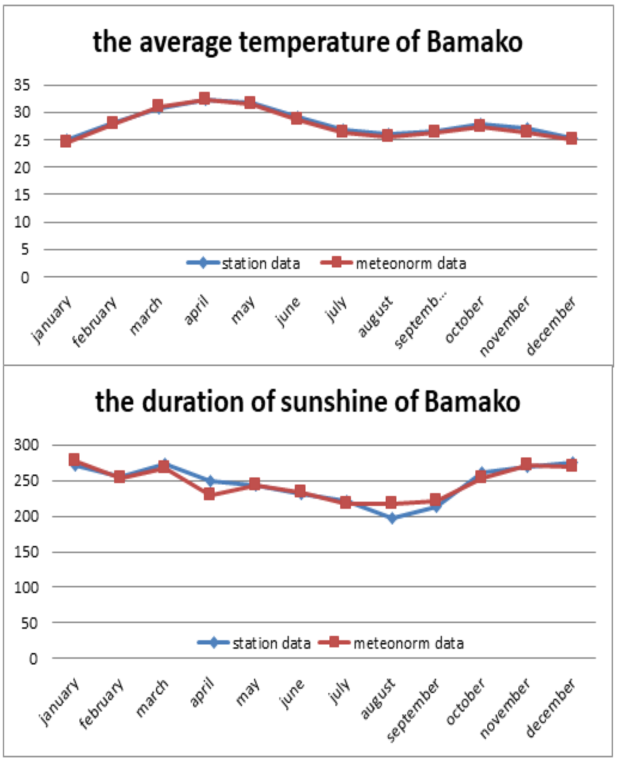

Fig 2: Comparison of the results of the sunshine duration (top) and ground temperature (bottom) from METEONORM dataset and synoptic stations in the city Bamako.

The seasonality of the temperature is well reproduced by Meteonorm (figure 2). However, disparity exist between the sunshine duration of Meteonorm and the station value for the hottest and driest month (April) and the coolest and wettest month (August).

1.2. Nara Site:

Figure 3 shows the results obtained from the comparison of METEONORM data and synoptic stations in the city of Nara.

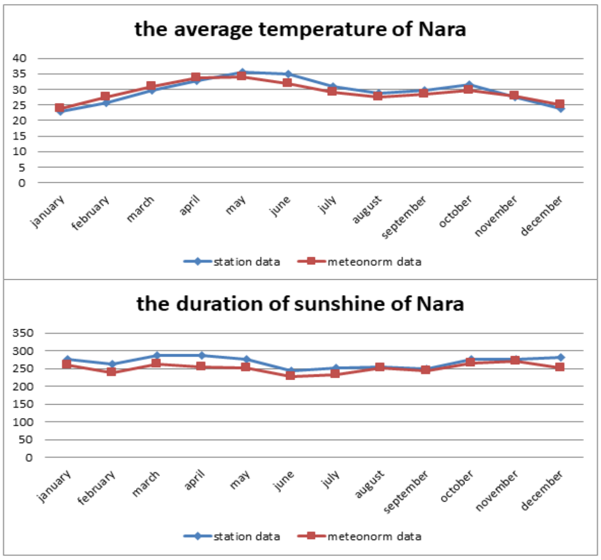

Fig .3 Comparisons of the results of sunshine duration and ground temperature of METEONORM data and synoptic stations in Nara city.

The temperature values from both data source follow similar seasonal pattern with a disparate through the year. Similar result is found for the sunshine duration with a difference more or less big in the dry season.

1.3. Sikasso Site:

The data of the synoptic station of the city of Sikasso make up the duration of sunshine and the ground temperature are compared with data from the METEONORM software in Figure 4. The seasonality of the temperature and sunshine duration is well reproduced by both datasets. The disparity between the sunshine duration for the two datasets remain consistent for the whole year.

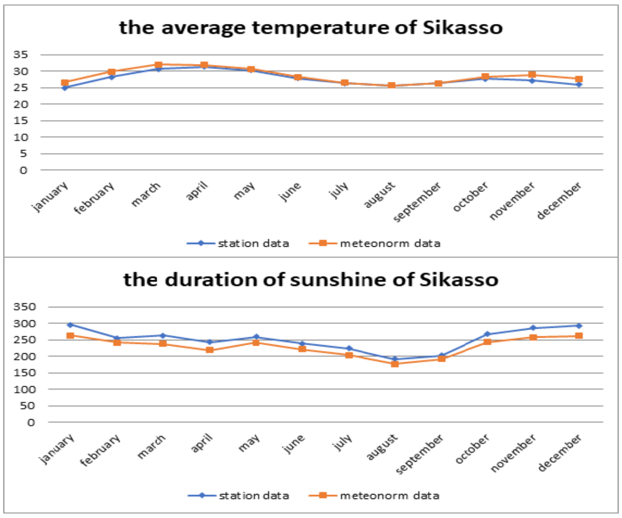

Fig 4: Comparison of the results of sunshine duration and ground temperature of METEONORM data and synoptic stations in Sikasso city.

1.4. Ségou Site:
The results of the comparison of METEONORM data and synoptic stations in the city of Ségou are as follows.

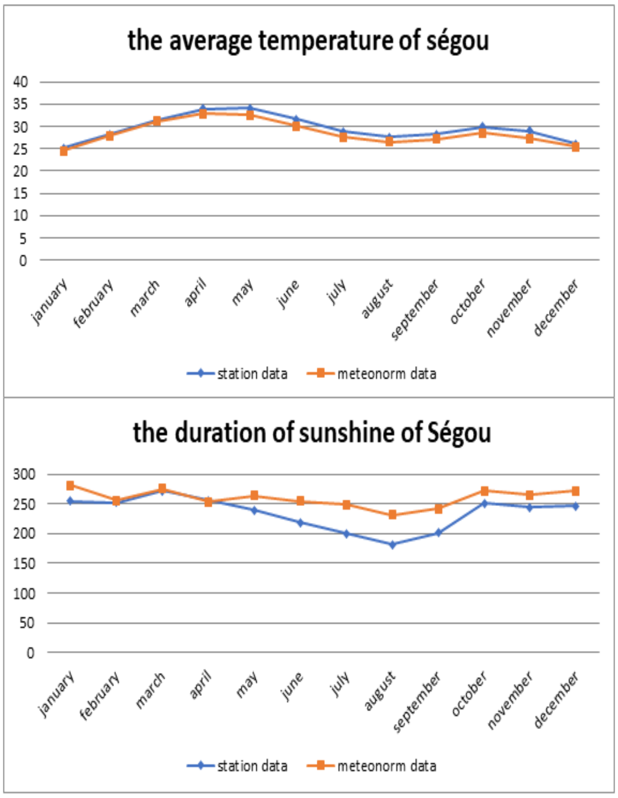

Fig 5: Comparison of the results of the duration of sunshine and ground temperature data METEONORM and synoptic stations in the city Segou.

Similar seasonal pattern is observed for the temperature of both datasets (Figure 5). However, meteonorm fails to reproduce the seasonality of the sunshine duration observed in the Segou station. Significant difference exists between the meteonorm data and the observation of the station for all the months of the year except February, March and April.

1.5. Mopti Site:
Figure 6 shows the results obtained from the comparison of METEONORM data and synoptic stations in the city of Nara. Parfait similarity is found between meteonorm dataset and station observation of temperature. The ability of meteonorm data to reproduce the seasonality of the sunshine duration is week for the site of Mopti with high different values in May and August. In this region of Mali, Meteonorm data can be used for study involving temperature but the sunshine duration of Meteonorm dataset can be used with high confidence for investigation in Mopti region.

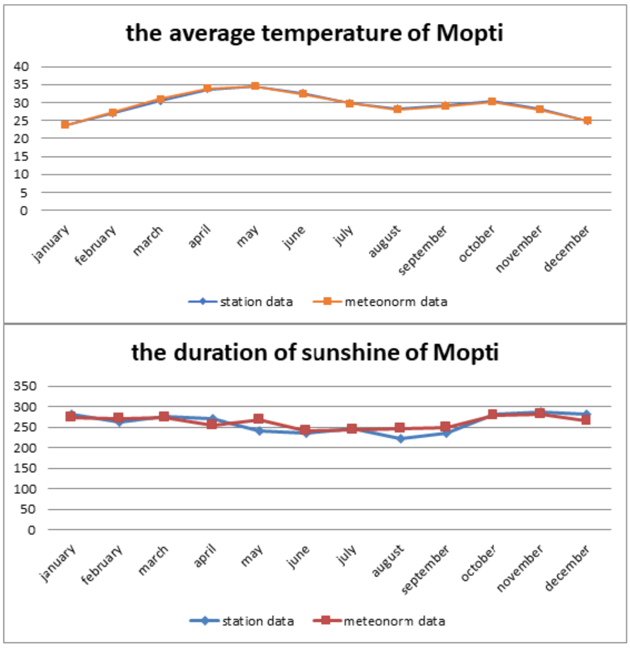

Fig 6: Comparison of sunshine duration and ground temperature results from METEONORM data and synoptic stations in Mopti city.

3.2 Comparative study and analysis:

3.2.1. Surface Air Temperature:
The statistical measures for METEONORM's performance in estimating average monthly temperature in Mali are indicated in the following table 1. Those statistical values are estimated by comparing meteonorm estimates with the stations observational data.

There is little validation demonstrating database accuracy provided by Meteonorm. Indeed, Meteonorm provides uncertainty estimates along with data values for a particular site as Nara and Sikasso with a correlation coefficient of about 0.92 and 0.94, respectively. The monthly average temperature results are shown in Table 1. Biases range from -1.04 to 0.001°C. The square root mean squared error values are small, reach its maximum at Nara with 1.58%, and correlation coefficients that tend to suggest that METEONORM monthly mean temperature estimates are reliable at the time.

Table 1: Meteonorm performance for estimating average monthly temperature in Mali.

Sites	Correlation coefficient	MB	RMSE
Bamako	0,99600781	-0,31283591	0,41020059
Nara	0,92784744	-0,40285441	1,58615578
Sikasso	0,94257732	0,87614943	1,11636419
Ségou	0,98369425	-1,04626337	1,15672339
Mopti	0,99587561	0,00139519	0,28613562

This is in agreement with the results [12] which evaluated the thermal and energy performances of the detailed simulations of TRNSYS with that of METEONORM.

3.2.2 Sunshine duration:

Table 2. Shows statistical measures for METEONORM's performance in estimating the average monthly sunshine duration at the five selected sites in Mali.

Table 2: METEONORM performance for estimating the average monthly sunshine duration in Mali.

Sites	Correlation coefficient	MB	RMSE
Bamako	0,92720762	0,22277778	9,48179942
Nara	0,76952965	17,9464286	20,2623503
Sikasso	0,98851238	21,7024074	22,7180709
Ségou	0,84335271	-24,7315476	29,6740034
Mopti	0,79371464	-2,35574074	14,3768789

We can observe in Table 2, the difference between the two datasets with biases are higher on all selected sites in Mali except Bamako and Mopti. In Nara it underestimates the duration with a maximum average bias of 17.94 hours, in Sikasso it underestimates the duration with a maximum average bias of 21.70 hours, in Segou it overestimates the duration with a maximum average bias of 24.73 hours. In terms of mean squared errors, the METEONORM estimates give lower performances than those of the synoptic stations of the five sites chosen in Mali, the correlation coefficients obtained are slightly higher compared to those of the average monthly temperature.

IV. CONCLUSION

The objective of this study was to evaluate the performance of METEONORM data in Mali. We compared the values of the sunshine duration and the ground temperature of METEONORM data to the data of five synoptic stations of Mali. The results showed that the measured monthly mean temperature data almost coincide with those of METEONORM with a correlation coefficient that tends to one, the bias varies only 1.04 ° C and the values of the square root of the error mean quadratic are weak, reaches its maximum in Nara with 1.58% which allows us to say the data of the temperature of METEONORM in Mali are reliable. In Nara and Sikasso the Meteonorm data underestimates the sunshine duration with a maximum average bias of 17, 94 hours and 21.70 hours, respectively. In Segou the sunshine duration is it overestimated with a maximum average bias of 24.73 hours. The data of the duration of sunshine requires a correction at the level of Mali, this difference is probably due to the interpolation method of the METEONORM. In perspective, we can consider conducting a more detailed study with daily data over a much longer period by adding the solar radiation that was removed from this study for lack of data on the selected sites.

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