Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 11, Page 1781-1793

http://www.jmaterenvironsci.com

Characterization of day clusters based on the clearness index in three sites in Côte d'Ivoire

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Received 12 June 2020,
Revised 25 Oct 2020,
Accepted 04 Nov 2020

Keywords
- *Solar radiation,*
- Classification,
- Clearness index,
- Characterization,
- Statistical criterion.

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Abstract

In a previous study, a classification of solar radiation clearness index in the district of Yamoussoukro (Côte d'Ivoire) was made using several software programs that generally deal with the classification process. It was highlighted a first aspect which focused on the classification of the clearness index. Three classes of days were identified, according to the state of the sky, with the corresponding percentages. The second aspect, subject of this study uses the statistical criterion of the test value and the critical probability to characterize the obtained class or cluster. For this study, data from three weather-climatic stations were used: Abidjan (site of University Felix Houphouet-Boigny), M'Brimbo (small village situated at 140 km north of Abidjan), Yamoussoukro (site of Polytechnic National Institute Felix Houphouet-Boigny). After processing this data followed by a comparative study, it appears that the clearness index of solar radiation remains a good indicator to perform this characterization, even if the days contained in the three class are scattered throughout the year.

1. Introduction

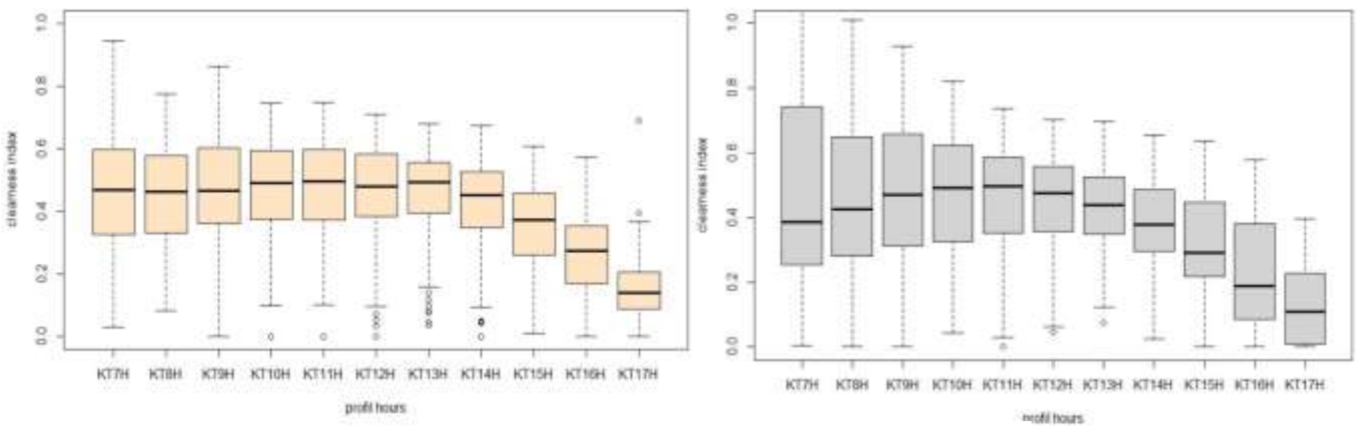
The word "classification" generally refers to a process for grouping data by clusters and provide a set of clusters that have meaning and practical interest [1]. In a previous study [2] dealing with the classification of hourly clearness index (Kt) in the District of Yamoussoukro, it was shown that this region is composed of three clusters of days depending on the sky condition. For this classification, a combination of several methods was used: the Principal Component Analysis (PCA), the hierarchical clustering [3] and K-Means method [4]. Three clusters of days were so obtained by the classification process implemented in the FactoMineR package [5] of the R software. In fact, for an efficient dimensioning and optimization of energy conversion systems it is important and necessary to characterize the local solar energy resource [6]. So, in order to have better quantification of solar radiation in each region of Côte d'Ivoire, we extended for the same period, the year 2017, this classification to two other stations of the weather-climatic observation network stations and solar monitoring in Côte d'Ivoire (ROSSCI) [2]. These stations are located in Abidjan (Site of University Felix Houphouet-Boigny) reference (3 ° 59 '23.78 "west; 5 ° 20' 52.08" North) and in M'brimbo (small village situated at 140 km north of Abidjan) reference (4 ° 54 '15.12 "west; 6 ° 2' 18.96" North). Here we present a comparative study of the results obtained for these three stations on the one hand and on the other hand the characterization procedure of the different clusters of days. Cluster characterization consists of determining the intrinsic characteristics of each cluster, by interpreting the partition of the days in each of the three stations during the year 2017. For this interpretation, we used the statistical criterion of the test value and the critical probability. This study was carried out in order to have an excellent forecasting tool at national level, both in the energy and climatological fields. This knowledge contributes to an important part of the design process of solar energy systems.

2. Data

The data format, the calculations and the classification method applied in this study are the same as those of the previous study [2].

The data from the weather station is recorded with a resolution of one minute 24h / 24h during the 365 days of the year 2017. Eight climatic weather parameters can be thus measured and others are calculated from them. Of all these parameters, only the values of the instantaneous global solar irradiance (Ei in W / m²) are considered for this study. We had respectively 522960 and 509760 records of instantaneous global solar irradiance respectively for Abidjan and M'Brimbo considering the missing and lost data. These data losses are due to connection problems, power cuts or software transmission errors. Then, from the database, the values of the instantaneous global solar irradiation from 7 am to 5.59 pm are extracted. Since the irradiation is recorded in steps of one minute, we obtain the hourly global solar irradiation (IGH Wh / m²) by integrating the instantaneous global solar irradiance values over one hour. The extraterrestrial solar irradiation (IGH_0 Wh / m²) is determined by taking into account the solar constant and the distance from earth to the sun (as a function of the time and position parameters). Knowledge of the hourly global solar irradiation and the hourly global extraterrestrial irradiation of the city of Abidjan and the village of M'Brimbo made it possible to determine the hourly clearness index (Kt) which is defined as the ratio between the IGH at the surface of the earth and the IGH_0. All of these formulas are consigned in the previous study [2]. It is used as a reference to characterize the sunshine conditions at a given site when only the overall irradiation is known. Therefore, it takes into account, without distinction, the absorption and diffusion phenomena of the atmosphere and clouds.

Figure 1 illustrates the distribution of hourly clearness index values for the village of M'Brimbo (figure 1a) and the city of Abidjan (figure 1b) after calculation. The hourly clearness index values for these two localities are between 0 and 1, so the distribution of these values throughout the year is asymmetrical. The values of the hourly clearness index profiles are those for the classification introduced in an algorithm combining principal component analyses, hierarchical clustering and K-Means method.



a b

Figure 1: boxplot of hourly clearness index (a: M’Brimbo; b: Yamoussoukro)

3.Methods

For the characterization of classes obtained after the classification procedure, the statistical criterion of test value and critical probability were used. They were ranked according to the critical probabilities [7] to classify the variables in order of importance. The most typical variable in the group is the one that corresponds to the smallest probability and generally, more a result is extraordinary, lower is the P value [8-11]. The test value (T.Value) was used essentially to characterize a group of individuals, defined by a characterizing variable or resulting from a calculation [12]. According to Morineau [13], the test value represents the difference between the mean of a variable in a group and its general mean. More the difference is "significant" better the variable characterizes the group. It then assigns a sign to the test-value:

- if the term is positive, the group is characterized by high values of the variable;
- if the term is negative, the group is characterized by low values of the variable.

We therefore consider that the difference
is significant when the absolute value of test value is greater than 2.

4. Results

4.1. Hourly clearness index classification results for Abidjan and M'Brimbo stations

The PCA (Principal component Analysis) made it possible to highlight the affinities between the hours profile's (variable) and to deduce the distributions of the hourly clearness index over the year. The analysis is limited to the first two factors whose eigenvalues, greater than unity, explain more than 75% of the initial variance. It outputs provide two types of graphs (Figure 2), the graph of variables or correlation circle (Figure 2a and 2c) and the graph of individuals or statistical unit (Figure 2b and 2d). The correlation circle reflects the relationship between the different hours profile's, i.e. between the variables and the plan of statistical unit shows the spatial distribution of individuals.

In the case of Abidjan, the graph illustrates that the variable axis 1 carries positively the clearness index from 7 am (Kt7h) to 1 pm (Kt13h) and negatively the profiles from 2 pm (Kt14h) to 5 pm (Kt17h). It highlights an opposition between these hourly clearness index profiles. The analysis of the averages of each profile shows that the hourly clearness index profiles from 7 am to 1 pm have relatively higher average than those from 2 pm to 5 pm. However, axis 2 carries positively all hourly clearness index profiles (Kt) except 7am profile. The graph of individuals indicates a tendency to favor three grouping.

For M'Brimbo, the first factorial dimension positively carries all hourly clearness index profiles. The second dimension positively carries the clearness index profiles from 2 pm to 5 pm and negatively those from 7 am to 1 pm which have higher averages. The statistical unit plan does not clearly distinguish different groupings.

Observing the hierarchical clustering analysis (HCA), the FactoMineR package provided two outputs. The first is a dendrogram accompanied by the inertia gain graph. This dendrogram presents a cut level illustrating three groups differentiated by colors (Figure 3a and 3c). It is then screened in three dimensions (3D) on the factorial axes of principal component analysis (Figure 3b and 3d), which makes it appear clearly three clusters of color, black, red and green.

At consolidation of cluster by K-Means method, a map of days based on their membership in each cluster indicates the outputs (Figure 4). It accurately distinguishes there three class or cluster of days.

4.2. Characterization of the obtained cluster's

For the characterization of cluster, we note that FactoMineR Package of software R provides different outputs for a statistical description of the variables (hourly clearness index), the factorial dimensions (PCA Axis) and by the individuals (days).

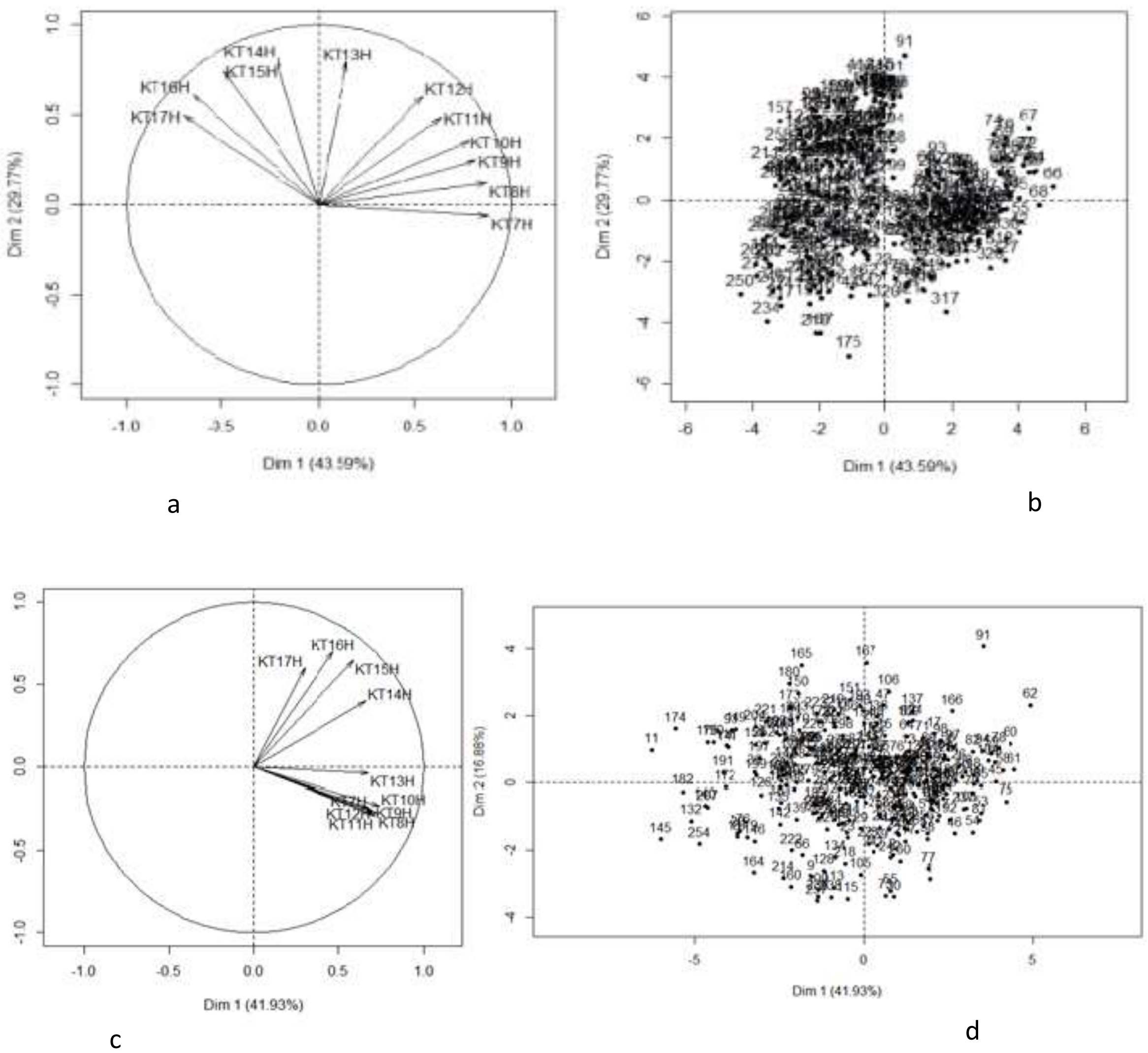


Figure 2: PCA Output: projection of the variables (hourly clearness index profile) on the factorial dimensions I and II (Abidjan station (a); M'Brimbo station (c)); projection of the individuals (days) on the same dimension (Abidjan station (b), M'Brimbo station (d))

4.2.1. Description of cluster by the variables

Figure 5 below shows the test value (T.Value) and critical probabilities (P.value) of variables that make up the cluster 1 of Yamoussoukro, Abidjan and M'Brimbo. By analyzing this figure, we see that all test values of the variables in this class are negative and highly significant except that of 4 and 5pm (KT16H and KT17H) hourly clearness index profile for Yamoussoukro and Abidjan. This means that the average of the variables (hourly clearness index profiles) in this class is very low compared to the overall average of each variable except that of 5 pm (KT17H) for Yamoussoukro and those of 4 pm (KT16H) and 5 pm (KT17H) for Abidjan. As for the M'brimbo site, all the test values characterizing the class are negative and very significant. Also, all the critical probabilities of the variables associated with this class regardless of the location are low and less than 0.005. The test value being negative and very significant for the majority of the variables, we could conclude that this cluster contains low values of clearness index. It should be noted that only the variables that characterize the class or cluster 1 are shown for each locality. This induces that the variables 4pm (KT16H), 3pm (KT15H) and 5pm (KT17H) do not characterize class 1 respectively for Yamoussoukro, Abidjan and M'Brimbo.

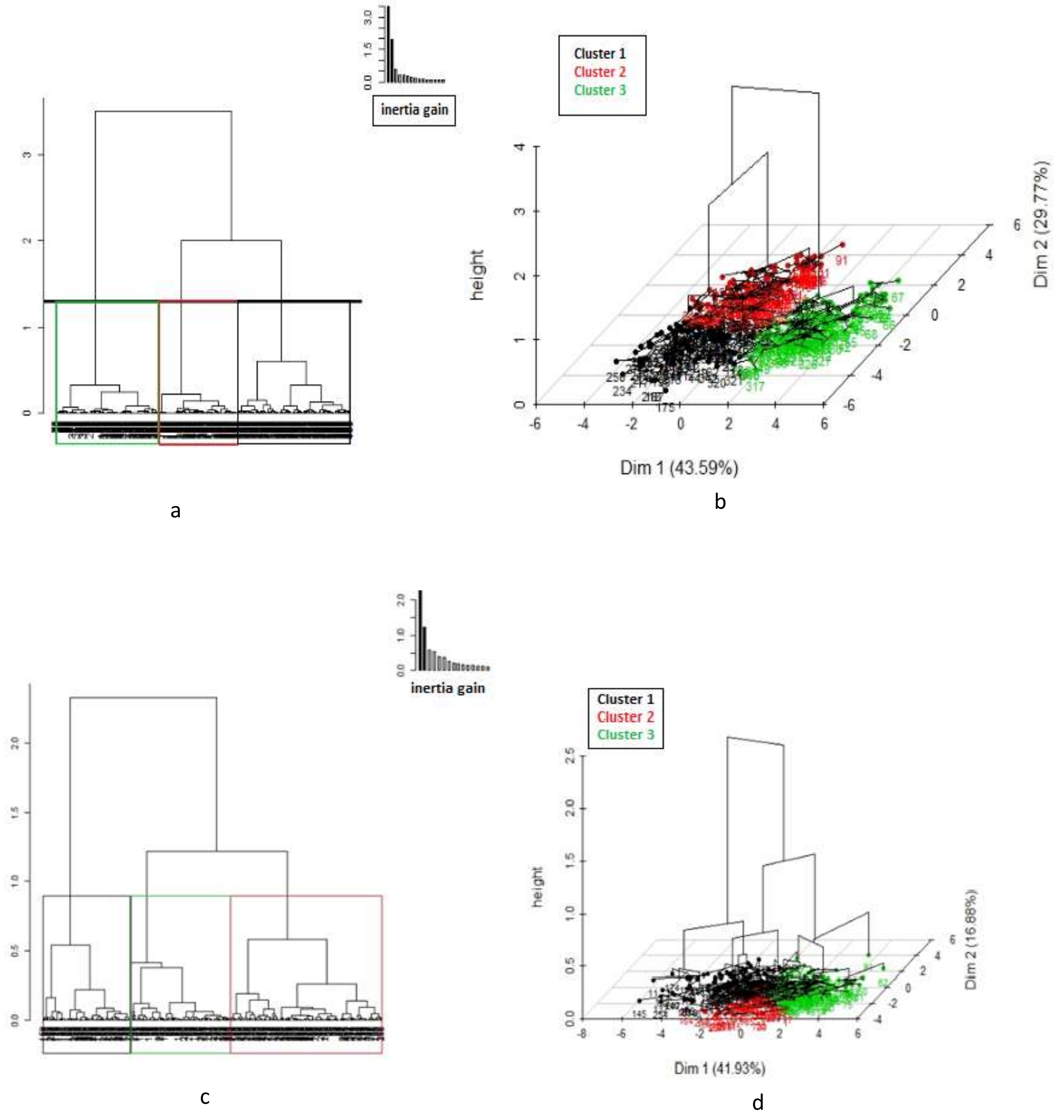
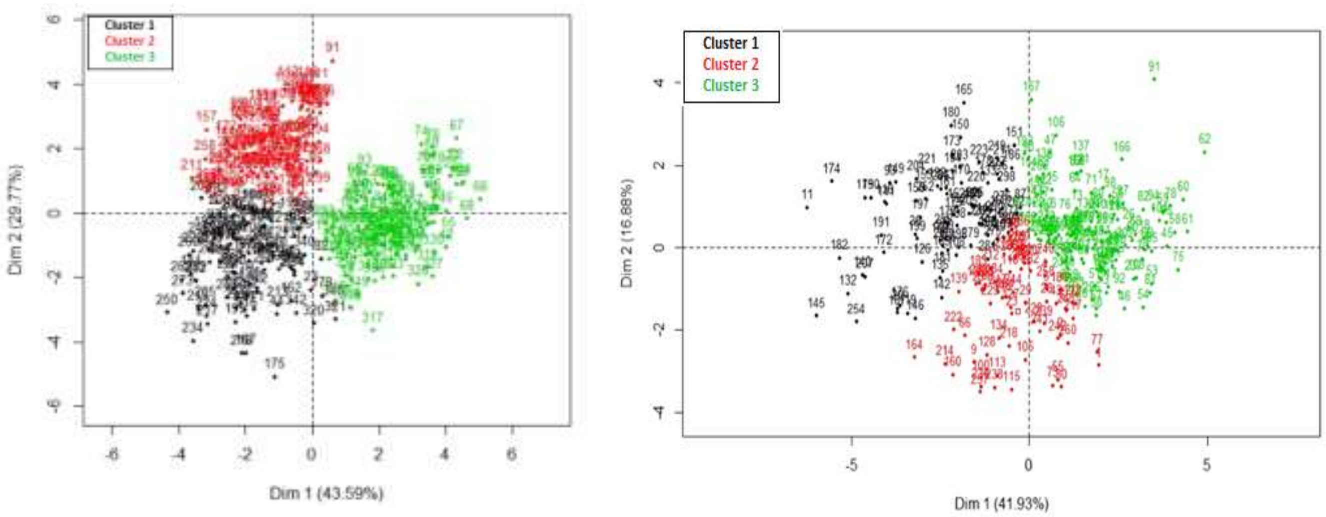


Figure 3: HCA Outputs: dendrogram accompanied by the graph of inertia gains (Abidjan (a), M'Brimbo (b)); dendrogram projection in 3D (Abidjan (b) M'Brimbo (c))

As for Class 2 (Figure 6), it consists of high and low values of clearness index because test values of the variables of this class are positive, highly significant from 11am (KT11H) to 5pm (KT17H) and negative from 7am (KT7H) to 8 am (KT8H) for the localities of Yamoussoukro and Abidjan. For M'Brimbo, the test value is positive for variable from 10 am (KT7H) to 12 pm (KT12H), negative and highly significant for the variables from 2pm (KT14H) to 5pm (KT17H). So, we see that the average of variable at positive test value in this class whatever the location is large compared to their overall average. The critical probabilities of the variables associated with this class for the three localities are extremely low. In addition, all variables best characterize this class except those of 9 am (KT9H) and 10 am (KT10H) for Yamoussoukro, 9 am for Abidjan, 7am (KT7H), 8 am (KT8H), 9 am (KT9H) to 1pm (KT13H) for M'Brimbo.



a b

Figure 4: Days clusters consolidation by K-Means (Abidjan (a), M'Brimbo (b)

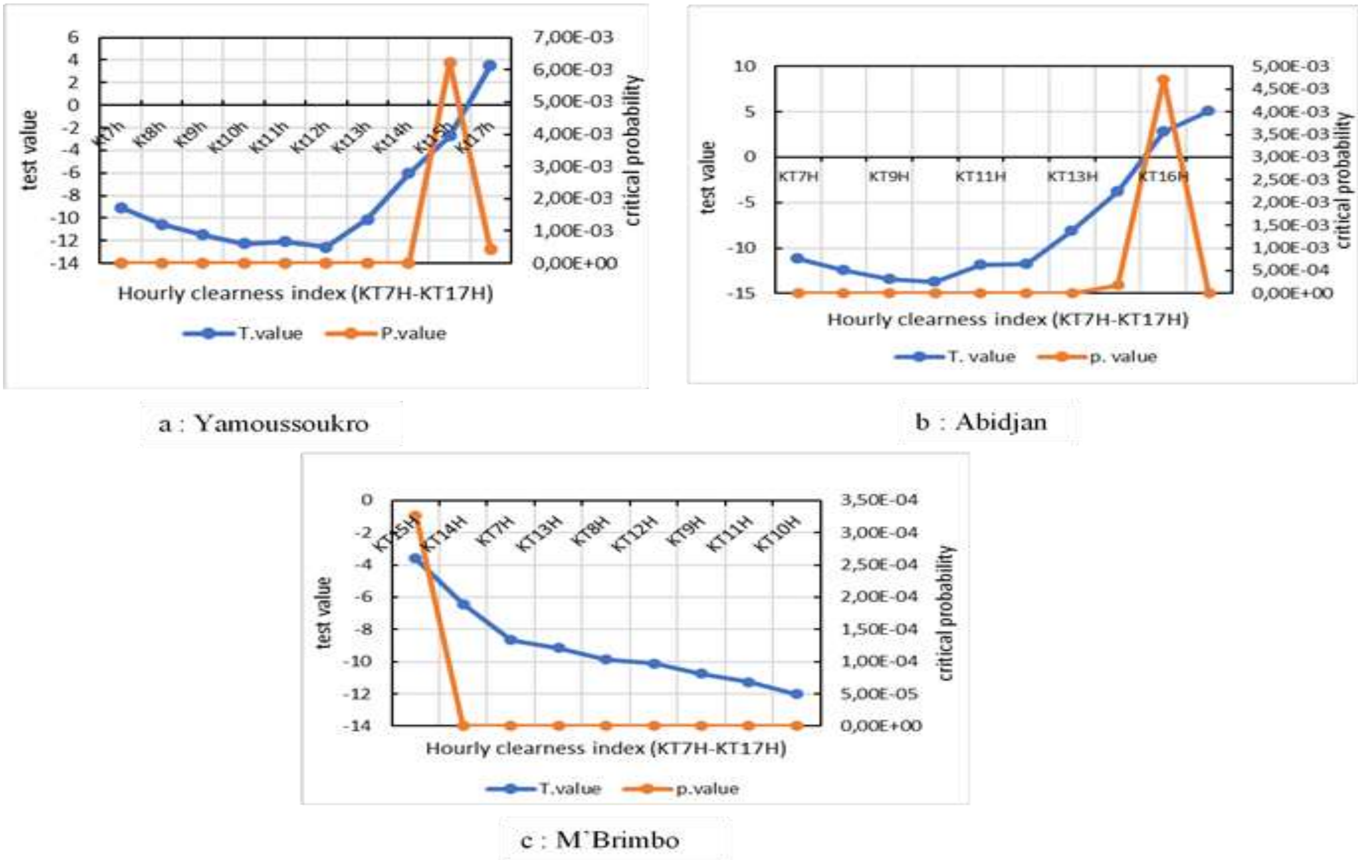


Figure 5: Description of cluster 1 for Yamoussoukro, Abidjan and M'Brimbo by the variables that compose it

For Class 3 (Figure 7), the deviation between the average of the variable in the class and their overall average is very significant because their test value is very high and positive from 7 am (KT7H) to 12 pm (KT12H) , negative from 2pm (KT14H) to 5pm (KT17H) profiles in the localities of Yamoussoukro and Abidjan. It appears that these deviations are significantly higher compared to the deviations of the means of variables in classes 1 and 2. We then note that the average in the class of variable with positive test value is very high compared to overall average and conversely for variables with negative test value. Otherwise, for M'Brimbo, the test value of all the variables characterizing Class 3 are positive and highly significant. This induces that the average of variables in this class are very high compared to their overall average. Also, the critical probabilities are very low for all localities. The variables of 1pm (KT13H) and 5pm (KT17H) do not characterize this class for any locality.

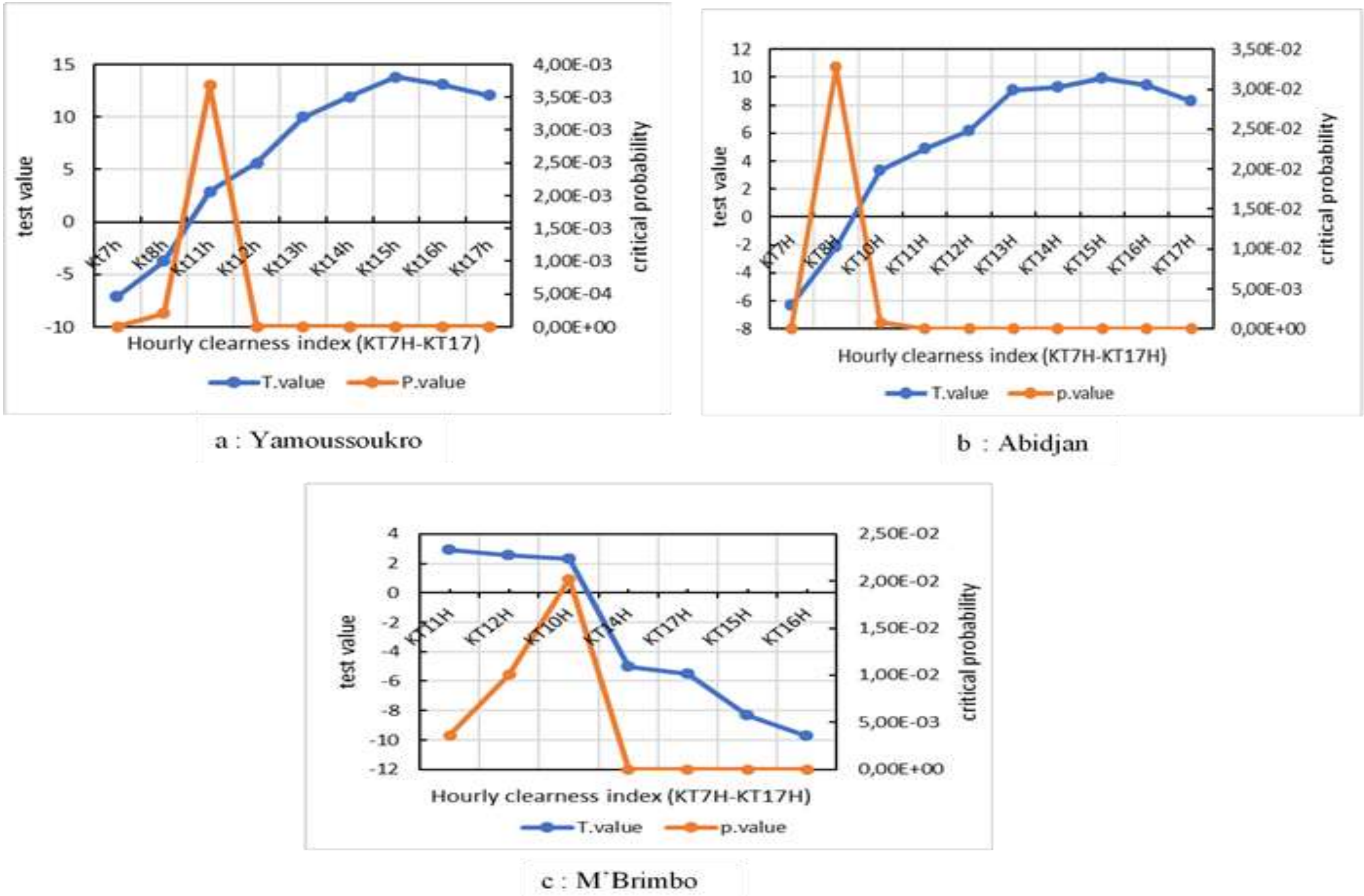
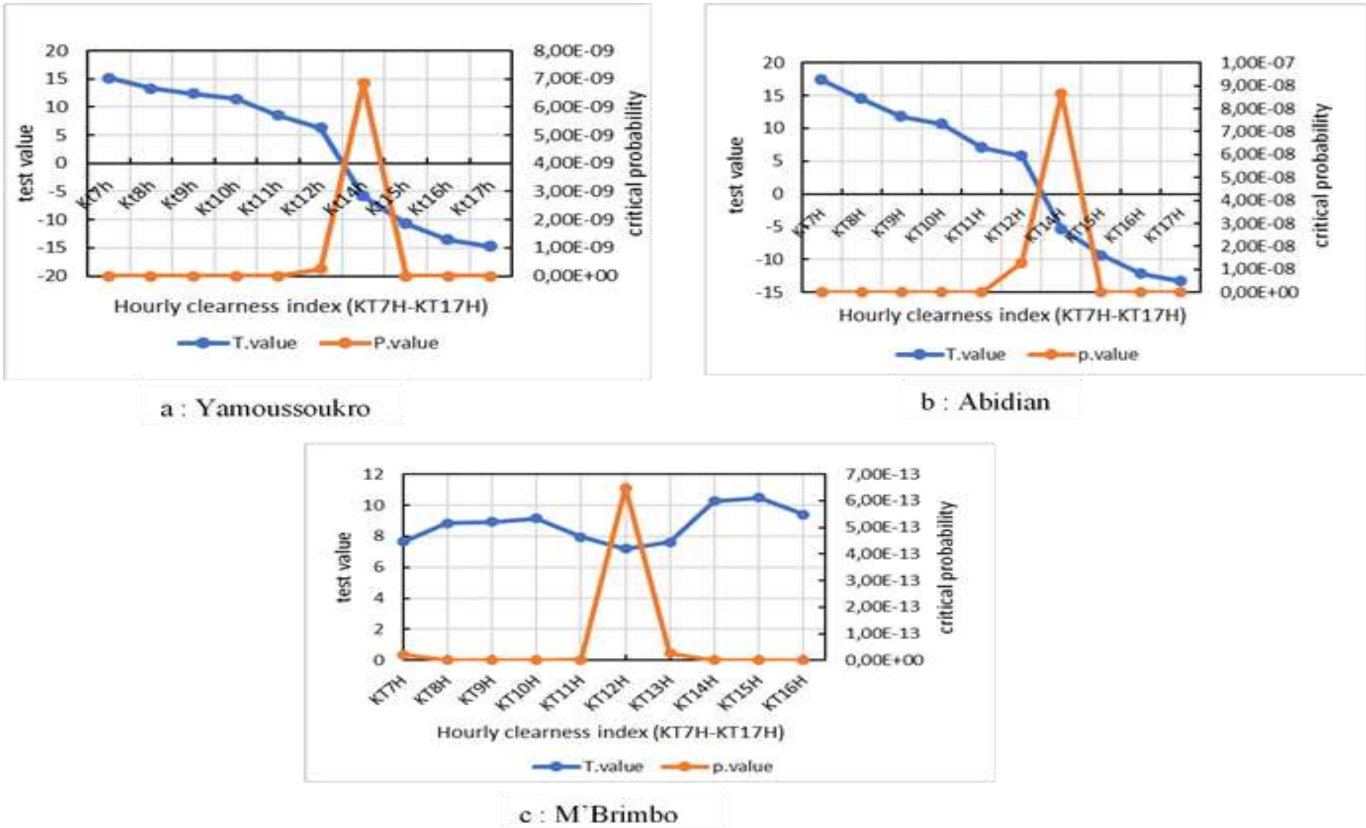


Figure 6: Description of cluster 2 for Yamoussoukro, Abidjan and M'Brimbo by the variables that compose it

4.2.2. Description of days clusters by the factorial dimensions

The description by factorial dimensions (Figure 8) shows that class 1 contains low clearness index values on both axes PCA for all localities because the variables test values (TV) are negative on these axes except M'brimbo where variables test value are positive on the second factorial axis. Also, the test value of the variables of class 2 is positive on axis 2 and negative on axis 1 for Yamoussoukro and Abidjan. This means that Class 2 contains low values of clearness index on the first factorial axis and high values on the second axis. For M'Brimbo, class 2 is not explanatory on the first factorial dimension but the test value appears negative on the second and third factorial dimension. As for Class 3, the variables of this class have very high values of clearness index on the first axis and low values on the second since their test value is very significant and positive on axis 1, negative on the axis 2 for the localities of Yamoussoukro and Abidjan. For M'Brimbo, the test value of the variables of class 3 are positive and significant on both factorial dimensions. In this description the overall averages of the main components are zero since these components are linear combinations of the initial variables. Critical probabilities of the class variables on each axis are very low for all localities.

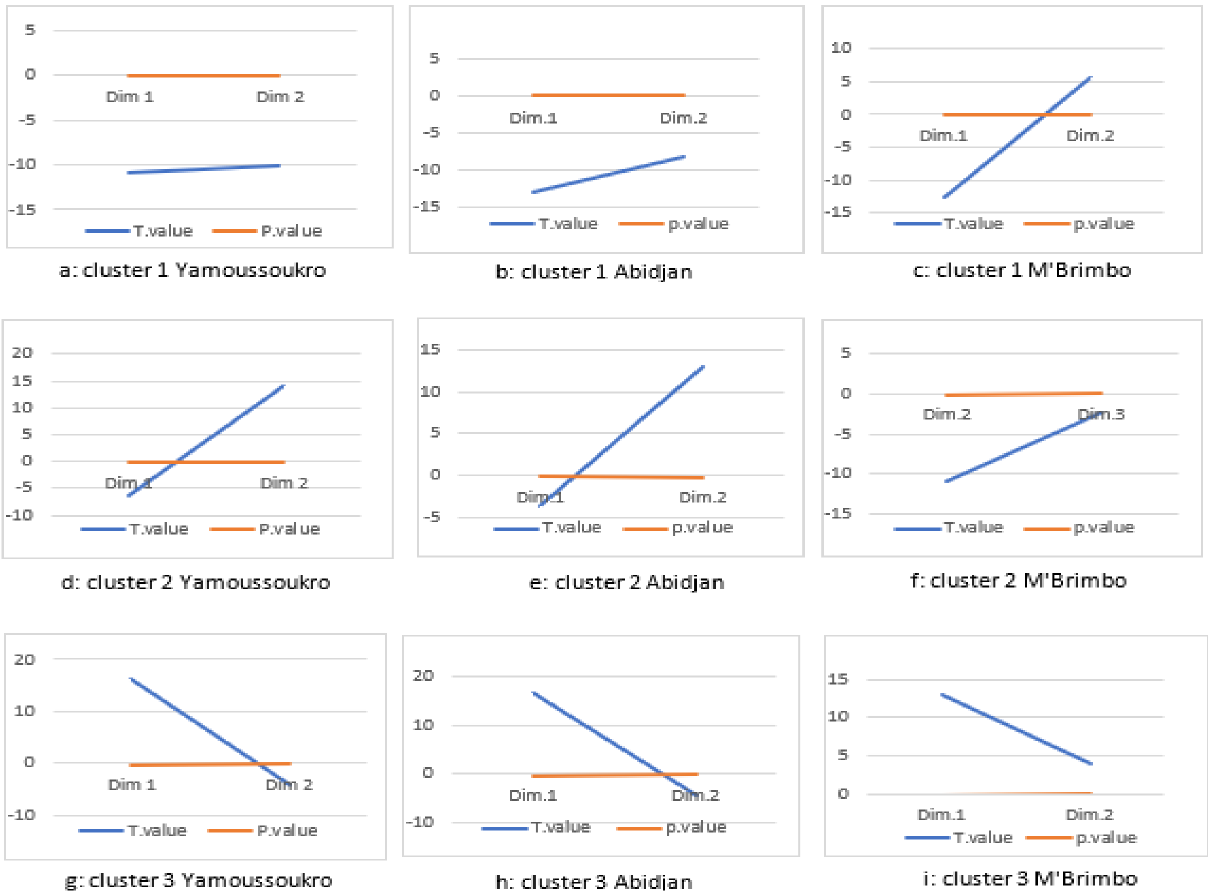


a : Yamoussoukro

b : Abidian

c : M`Brimbo

Figure 7: Description of Cluster 3 of Yamoussoukro, Abidjan and M'Brimbo by the variables that compose it



a: cluster 1 Yamoussoukro

b: cluster 1 Abidjan

c: cluster 1 M'Brimbo

d: cluster 2 Yamoussoukro

e: cluster 2 Abidjan

f: cluster 2 M'Brimbo

g: cluster 3 Yamoussoukro

h: cluster 3 Abidjan

i: cluster 3 M'Brimbo

Figure 8: Description of days cluster for the localities of Yamoussoukro, Abidjan and M'Brimbo by the factorial dimensions.

4.2.3. Clusters descriptions by the individuals

The package FactoMineR provides two informations for the description by the individuals (Figure 9): the first gives the paragon of each class, this paragon is the closest individual to the gravity center of the class, since the gravity center is a fictitious individual. It illustrates the subject on the average of the class and is arranged in descending order.

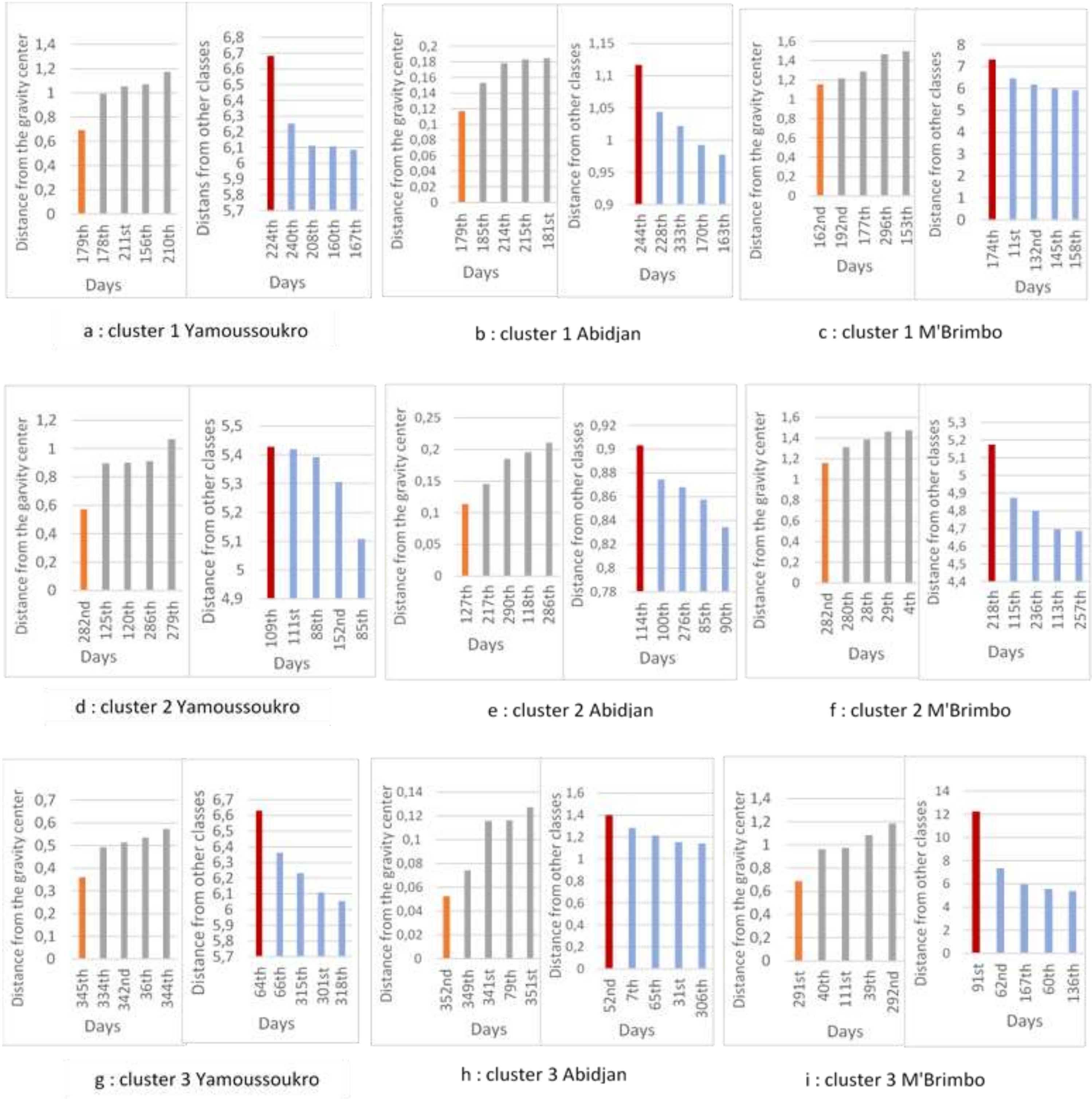


Figure 9: Clusters description for Yamoussoukro, Abidjan and M'Brimbo by the individuals

Thus, at the level of Class 1 in Yamoussoukro and Abidjan, the closest individual of gravity center for this class is the 179th day; for M'Brimbo it is the 162nd day. That of the class 2 is the 282nd day for Yamoussoukro and M'brimbo and the 352nd day for Abidjan. The paragon of class 3 is the 345th day for Yamoussoukro, 127th day for Abidjan and 291st day for M'Brimbo.
The second information provides distances between each class. It represents the most characteristic individuals of each class in the sense that they are the most distant individuals of other class.
So, the individual most characteristic of class 1 is the 224th day for Yamoussoukro and Abidjan, the 174th day for M'Brimbo. That of the Class 2 is the 109th day, the 52nd day and the 218th day respectively for Yamoussoukro, Abidjan and M'Brimbo. Classe 3 is best described by the 64th day for Yamoussoukro, the 114th day and 91st day for Abidjan and M'Brimbo.

4.3 Classification Review

Our classification criterion Kt, varies between 0 and 1 and describes different situations related to climatic conditions: A low cleaness index means a small portion of light intensity reaching the ground and is therefore synonymous with an cloudy sky; A high clearness index represents a clear sky with a small portion of diffuse radiation and a intermediate values represents partly cloudy sky days.
From the above, based on the description combined by the variables (hourly clearness index), the factorial dimensions and the individuals (days) we can summarize as:

- cluster or class 1 containing low clearness index values ($0 \leq KT \leq 0.25$) is that of cloudy sky days;
- cluster or class 2 with intermediate values of clearness index ($0.25 \leq KT \leq 0.45$) represents the group of partly cloudy sky days;
- cluster or class 3 composed of high clearness index values ($0.45 \leq KT \leq 1$) consists of clear sky days.

The different intervals of the values of hourly clearness index (KT) given here are deduced from our previous article [2] and by analyzing each cluster independently. Table 1 below presents the characteristics of the classified days and Figure 10 gives the distribution of days in each of the localities.

Table 1: Days characteristics

Number of days classified	Clear sky days	Partly cloudy sky days	Cloudy sky Days
346 in Yamoussoukro (-5 ° 14 '22.56 " ; 6 ° 52' 9.12")	135 (39%)	111 (32%)	100 (29%)
353 in Abidjan (-3 ° 59 '23.78 " ; 5 ° 20' 52.08")	121 (34%)	111 (32%)	121 (34%)
298 in M'Brimbo (-4 ° 54 '15.12 " ; 6 ° 2' 18.96")	135 (45%)	71 (24%)	91 (31%)

5. Discussion

Since the method and procedure for classifying Data from M'Brimbo and Abidjan are the same dimensions as those of Yamoussoukro [2], the discussion of these results does not remain far from it either.
At the end of the class characterization, we could distinguish the intrinsic characteristics of each class. The low values of clearness index correspond to cloudy sky days, the intermediate values to partly cloudy sky days and the high values to clear sky days. These results are in good agreement with those reported in the literature [14-16]. So, we established the percentages and types of days in Yamoussoukro, Abidjan and M'Brimbo (Table 1). The clear sky days have a higher percentage at M'Brimbo than Yamoussoukro and

Abidjan. Table 1 shows that the days types and percentages are a function of the site position. Indeed, in addition to the difference between their geographical coordinates, M'Brimbo is a small village with preserved natural environment, while Yamoussoukro, in savannah continental area is one of the capitals of the Côte d'Ivoire and Abidjan main capital in the coastal zone is the seat of intense industrial activities, sources of atmospheric pollution.

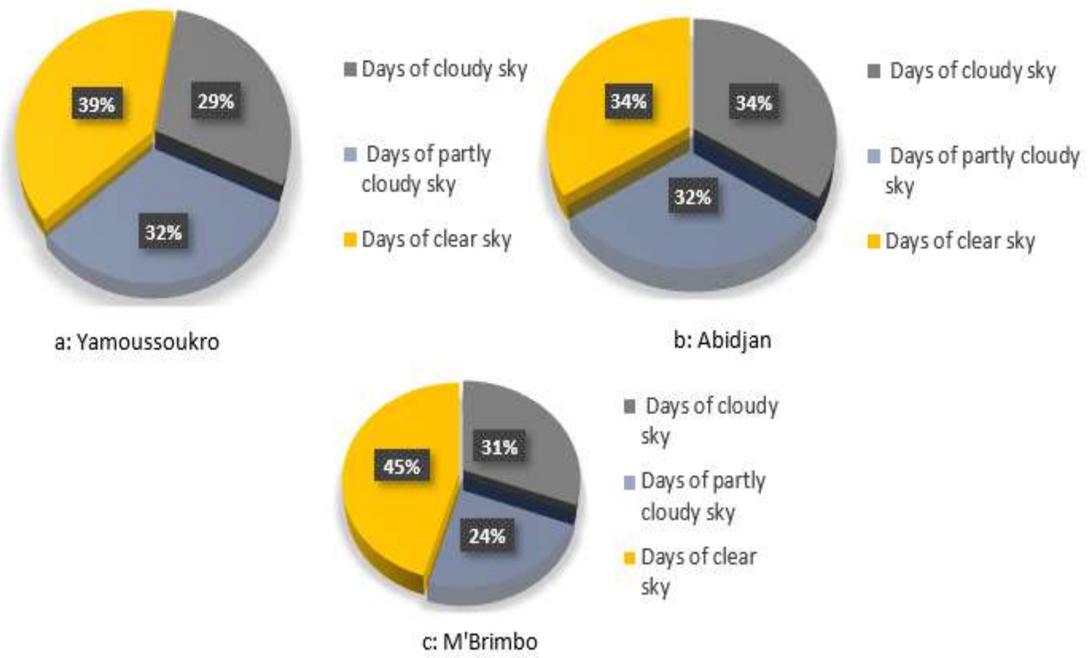


Figure 10: Distribution of days in the different localities

Similar studies carried out in the district of Abidjan in 2016 [17] gave also three class of days. The criteria for classification in these studies, different from ours, are daily global radiation, the energy efficiency and hourly fraction. Other methods of classifying days of the year have been used elsewhere [18] used the combination of the fractal dimension and the clearness index to obtain three class of days in the great south of Algeria. Tejera and al [4] have meanwhile used the method of aggregation of ward followed by a discriminant analysis and get also three class of days on the sites of the Mediterranean coasts. Thus, whatever the place and the method used to classify the days; we always get three class of days. Our classification method confirms the same number of days class (three class) as in other studies mentioned above. Some authors have managed to find subclasses [4,19], but this is not crucial importance for energy uses in solar installations.

In addition, to consolidate our partition, we used the description of classes made by the individuals. This description allowed us to confirm the partition already obtained. Indeed, according to [20], separation distances such as the smallest distance between a point in the class and a point belonging to another class can be calculated. This calculation criterion makes it possible to validate the partition from a statistical point of view. The classes obtained are thus intrinsically homogeneous and very different from each other.

Conclusion

After classification of hourly clearness index profiles in the districts of Yamoussoukro and Abidjan and in the village of M'Brimbo, we were able to identify the intrinsic characteristics of the different classes of days in these localities of Côte d'Ivoire. This characterization was made using the statistical criterion of the test value and critical probabilities directly calculated by the software R. Using these criteria, we have determined the internal properties in each class. Thus, it appears that the clearness index of the solar radiation is a suitable indicator to perform this characterization. It should be noted that the days contained in the three class are scattered throughout the year; they are not located in a specific period. Additional studies are underway to refine the distribution and partition of days, especially cloudy days and partially cloudy days, in connection with mists, rains or thunderstorms and winds, and even weather-climatic parameters.

Acknowledgements-We thank the State of Côte d'Ivoire to finance PresEd-CI and AMRUGE-CI projects via Contract Debt reduction and Development (C2D). Thanks also to the IRD for the management of funds received and France embassy in Côte d'Ivoire for their support. At the same time, we would like to thank the Polytechnic National Institute Felix Houphouet-Boigny (INP-HB) Yamoussoukro, Felix Houphouet-Boigny University of Cocody in Abidjan, Côte d'Ivoire, and Agricultural Society of Bandama at M'brimbo for the reception of measurement sites.

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(2020) ; http://www.jmaterenvironsci.com