Original Research Article

Contribution of principal component analysis to assessing Culicidae fluctuation in the Souk elArbaa region, Morocco.

ABSTRACT

The degradation of the natural environment with urbanization and ruralization leads to the creation of new areas favorable to the proliferation of mosquitoes, which explains their generally considerable dispersion. The objective of our statistical study is to highlight how the quality of wastewater influences the density and proliferation of mosquitoes in the region of Souk elArbaa (North-West Morocco).

For two years, we carried out a statistical analysis (Principal Component Analysis (PCA), elementary and descriptive) on the variations in the density of species in the three sites studied.

After having identified 5 species of the genus Culex (Culex pipiens Linné 1758, Culex theileri Theobald 1903, Culex perexiguus Theobald 1901, Culex impudicusFicalbi 1890, Culex quinquefasciatus 1823). In the prospected breeding sites, the systematic inventory of Culicidae revealed that a breeding site must be rich in chloride, organic matter and ammoniacal nitrogen to allow the mosquito to develop rapidly and reach high densities.

Keywords: mosquitoes, proliferation, Culicidae, statistics, ACP, breeding grounds, Morocco

1. INTRODUCTION

One of the main threats to the environment is pollution, which causes a rapid deterioration of natural ecosystems. In particular, contaminated waters have a major impact on the disruption of the ecological balance and the degradation of habitats. Water quality is not only affected by this pollution, but it also encourages the proliferation of certain harmful species such as mosquitoes. Aquatic environments polluted by organic and chemical waste create favorable conditions for the growth of mosquito larvae, which thus become vectors of diseases. The link between pollution and the demographic growth of the culicid population highlights the direct effect of environmental deterioration on public health, highlighting the importance of finding solutions to preserve ecosystems and reduce health risks. Indeed, surface water pollution has a considerable impact on the environment and causes major health problems on a global scale. In addition, urbanization, often poorly managed, has significant consequences on hygiene and public health, which can cause various diseases such as cholera. In addition, it promotes the development of culinary fauna, which causes nuisances (painful and annoying bites) as well as the spread of parasitic diseases such as malaria and bilharzia [1].

This fauna is of major importance and health interest due to these characteristics [2]. Over the last twenty years, the Culicidian fauna of Morocco has been the subject of a large number of studies that focus more particularly on systematics, biochemistry and chemical and biological control in different regions; [3], [4] and [5].

The objective of our work is to study the spatial variations of certain physicochemical parameters during a period extending from February 2012 to September 2014, at the level of the deposits of the city region. Using a data analysis tool that helps explain the structure of correlations between variables and larval density.

2. MATERIAL AND METHODS

2.1. STUDY AREA DESCRIPTION

Souk elArbaa is located on the national road RN No.1 between Kenitra and Larache, 120 km from Rabat, at the northern edge of the Gharb plain. The larval breeding sites were selected based on their ease of access, the abundance of stagnant water conducive to the development of culicid mosquitoes, and their proximity to populated areas.

2.2. WATER ANALYSIS TECHNIQUE

The water from the breeding sites was analyzed monthly throughout the study period. Samples underwent physicochemical analysis and were preserved according to the general guidelines for sample conservation and handling, in compliance with ISO 5667/3 (1994)[6]. Using a multiparameter analyzer Model CONSORT 535, pH, temperature, electrical conductivity, and dissolved oxygen were measured directly. All other parameters, including BOD5, COD, chlorides, nitrates, nitrites, and ammonium, were measured in the laboratory at the Faculty of Sciences, Ibn Tofail University in Kenitra, and the Environmental Laboratory in Rabat (DIN, 1992a)[7],[8],[9] and [10].

2.3. LARVAL SAMPLING TECHNIQUE

Sampling was conducted using the dipper method with a capacity of 500 milliliters. This technique involves immersing the dipper into the water and moving it uniformly while avoiding any disturbances or turbulence.

2.4. DATA ANALYSIS METHODS

The main elements are obtained by diagonalizing the bivariate correlation matrix. According to Menció and Mas-Pla (2008)[11], this diagonalization establishes a set of eigenvalues, with the observation of each component determining the number of graphs to be analyzed. The structure of the correlations or covariances can be explained by Principal Component Analysis (PCA), a data analysis tool that uses linear combinations of the initial data. The use of PCA makes it possible to reduce and analyze the data in a restricted space (Maliki, 2000)[12]. According to Lagarde(1995)[13]. PCA aims to graphically illustrate as much information as possible from a data table, using the principle of double projection onto factorial axes. Concerning the variables, it aims to illustrate the relationships between them using synthetic variables and highlight a typology of variables. Generally, PCA attempts to establish links between these two categories.

3. RESULTS AND DISCUSSION

3.1.ELEMENTARY STATISTICS

The physico-chemical analysis data were processed using the SPAD software (System for Data Analysis) produced by DECISA. The choice of this software is justified by its simplified usage mode, its interface enriched by Excel software for data entry and result editing, and its comprehensive guide for interpreting the various data processing modules such as PCA and hierarchical classification. For the data processing through principal component analysis, we used 10 variables: temperature, pH, electrical conductivity, suspended solids, dissolved O2, BOD5, chlorides, ammonium, nitrates, and nitrites. The study's individuals were the 4 stations (the two swamps, River Mda, and the main collector) throughout the study period. The elementary statistics on the variables (Table 1), and the standard deviation values, show that conductivity, chlorides, BOD5, and suspended solids are more dispersed around the mean.

Table 1. Descriptive Statistics during the Current Study

Variable	Observations	Observation with missing data	Observation without missing data	Minimum	Maximum	Average	Standard deviation
Temperature °C	4	0	4	11,540	30,030	21,788	8,165
pH	4	0	4	7,610	8,150	7,938	0,263
CE (s/cm)	4	0	4	1538,000	2800,000	2174,400	626,638
Dissolved Oxygen (mg/l)	4	0	4	0,660	4,930	2,518	1,881
TSS (mg/l)	4	0	4	34,940	125,100	75,360	39,204
BOD5 (mg/l)	4	0	4	15,250	78,330	37,193	29,455
Chlorides (mg/l)	4	0	4	187,800	342,040	233,480	72,815
$N(NH^+_4)$ (mg/l)	4	0	4	4,760	21,880	11,130	7,532
$N(NO^-_2)$(mg/l)	4	0	4	1,680	3,880	2,788	1,013
$N(NO^-_3)$ (mg/l)	4	0	4	0,370	3,320	1,275	1,373

3.2. Correlation between variable

the intermediate correlation matrices are presented in Table 2

Table 2. Intermediate correlation matrix

Variables	T °c	pH	C.E	Dissolved Oxygen	TSS	BOD5	Cl^-	$N(NH^+_4)$	$N(NO^-_2)$	$N(NO^-_3)$
T °c	1									
pH	0,463	1								
C.E (s/cm)	0,860	0,079	1							
Dissolved Oxygen(mg/l)	-0,934	-0,660	-0,801	1						
TSS (mg/l)	-0,605	0,015	-0,902	0,659	1					
BOD5 (mg/l)	0,660	0,491	0,754	-0,849	-0,852	1				
Cl^- (mg/l)	0,432	0,487	0,560	-0,695	-0,762	0,960	1			
$N(NH^+_4)$ (mg/l)	0,638	0,616	0,664	-0,857	-0,757	0,987	0,965	1		
$N(NO^-_2)$ (mg/l)	-0,654	-0,309	-0,286	0,426	-0,154	0,113	0,352	0,095	1	
$N(NO^-_3)$ (mg/l)	-0,850	-0,850	-0,507	0,900	0,265	-0,591	-0,444	-0,656	0,641	1

The physicochemical parameters that are positively correlated vary in the same direction; that is, the increase in one influences the increase in the other, while those that are negatively correlated vary in opposite directions; that is, the increase in one leads to the decrease in the other (Table 2).

3.2. Positive Correlation

Based on the positive correlations (parameters varying in the same direction) and the strong degrees of correlation between variables, we can highlight the following:

- Temperature has a positive and highly significant correlation with electrical conductivity (0.860), a moderately significant correlation with BOD5 (0.660), and with ammonium ions (0.638).
- BOD5 shows a strong positive correlation with chlorides (0.960) and ammonium ions (0.960).
- Dissolved O2 is correlated with suspended solids (0.659) and has a highly significant correlation with nitrates (0.900).
- Ammonium is strongly correlated with chlorides (0.965) and significantly correlated with pH (0.616).
- Nitrates have a highly significant correlation with nitrites (0.641).

The temperature in the river's water between winter and summer, along with high evaporation rates, causes other variables to follow similar variations as temperature.

3.3.Negative Correlation

Temperature has an inversely proportional correlation with:

- Dissolvedoxygen (-0.934),
- Suspendedsolids (-0.605),
- Nitrites (-0.654),
- Nitrates (-0.850).

BOD5 is inversely correlated with nitrates (-0.591) and with dissolved O2 (-0.849). Dissolved oxygen is inversely proportional to ammonium (-0.857). The pH is correlated with nitrates (-0.850) and with dissolved O2 (-0.660).
Oxygen is the key variable controlling these three negatively correlated groups. The variation in dissolved oxygen in wastewater and the river between winter (when the waters are agitated) and summer (with high evaporation and increased activity of aerobic microorganisms) causes the other variables to vary in an opposite direction to that of oxygen.

3.4. Correlation Circle

Each variable is associated with a point, where its coordinate on a factorial axis is a measure of the correlation between this variable and the factor (Axis 1 or Axis 2). For example, the coordinate on Axis 1 of the variable temperature is (-0.307) and on Axis 2 it is (-0.426). However, we know that the variables belong to a sphere with a radius of 1.
Therefore, when projected onto a factorial plane, the variables are represented within a circle of radius 1 (Correlation Circle). The closer a variable is to the edge of the circle; the better it is represented by the factorial plane, meaning that the variable is well correlated with the two factors that make up this plane.
The correlations between the variables and the axes of the projection of the variables in the space of axes F1 and F2 are presented in Figure 1.

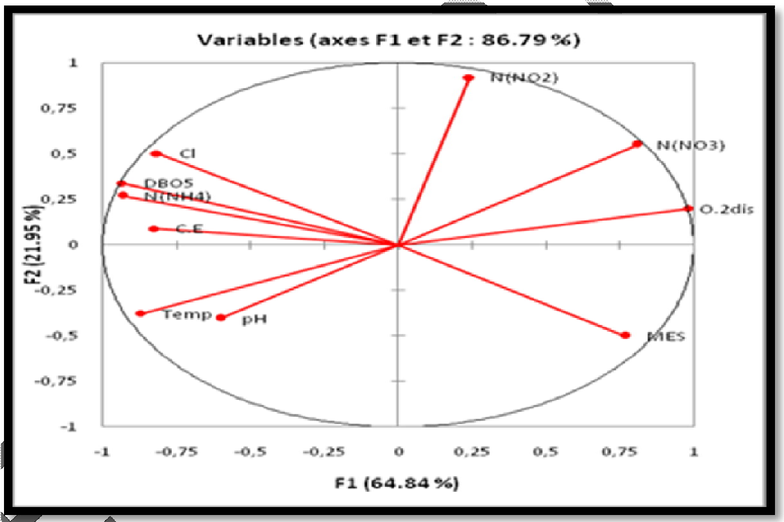

Fig.1.Projection of the physicochemical parameters on the plane of the two factorial axes(F1 and F2).

The angle between two variables xj and xk, measured by its cosine, is equal to the linear correlation coefficient between the two variables (cos θjk). The interpretation of the principal components is done by looking at the correlations with the initial variables. Thus we have:

- All variables are fairly distant from 0, and the angles they form are somewhat distorted in the projection. More precisely, the percentages of inertia are 64.84% (Axis 1, horizontal) and 21.95% (Axis 2, vertical) for Plane 1.
- The variables occupy fairly dispersed areas in the correlation circle. The angle between some variables is less than 90°, suggesting that these variables are positively correlated. Conversely, the angle between other variables is greater than 90°, indicating that these variables are negatively correlated.
- The values of the four physicochemical parameters (Cl$^-$, BOD5, ammonium, and electrical conductivity) are more closely linked to each other than to other parameters such as nitrates, nitrites, and dissolved oxygen. pH and temperature are also linked to each other. This suggests the absence of shared qualities of the medium that would lead to the variation of physicochemical parameters in the same direction. In other words, the differences between these parameters suggest different qualities.

The analysis of the factorial plane F1 and F2 reveals that over 86.79% of the variance is expressed. The PCA performed shows a zoning by group of individuals corresponding to water qualities: Axis F1, with a variance of 64.84%, is considered the mineral pollution axis, and is positively defined by the four variables: nitrates, nitrites, dissolved oxygen, and suspended solids.

Axis 2 has a variance of 21.95% and is considered the organic pollution axis. It is positively defined by BOD5, ammonium, chlorides,andelectrical,conductivity.

Suspended solids are considered vectors of pollution since many pollutants, particularly heavy metals, are absorbed by these particles. The high rate of suspended solids results in a significant amount of sludge at the river level.

In conclusion, the correlation circle allows us to observe, among the initial variables, the groups of variables that are highly correlated with each other. Therefore, its analysis is simpler and more informative than the direct examination of the correlation matrix.

3.5. Diagonalization of the Correlation Matrix.

Table 3 and Figure 2 present the diagonalization of the correlation matrix. The second row indicates the eigenvalues of the correlation matrix, while the third row provides information on the percentage explained by each eigenvalue.

Table 3. Diagonalization of the correlation matrix of the studied values

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigenvalue	4,698	2,058	1,327	0,707	0,606	0,326	0,141	0,089	0,044	0,003
Variability (%)	46,981	20,583	13,274	7,068	6,063	3,261	1,410	0,890	0,438	0,032
% cumulative	46,981	67,564	80,838	87,906	93,969	97,230	98,640	99,531	99,968	100,000

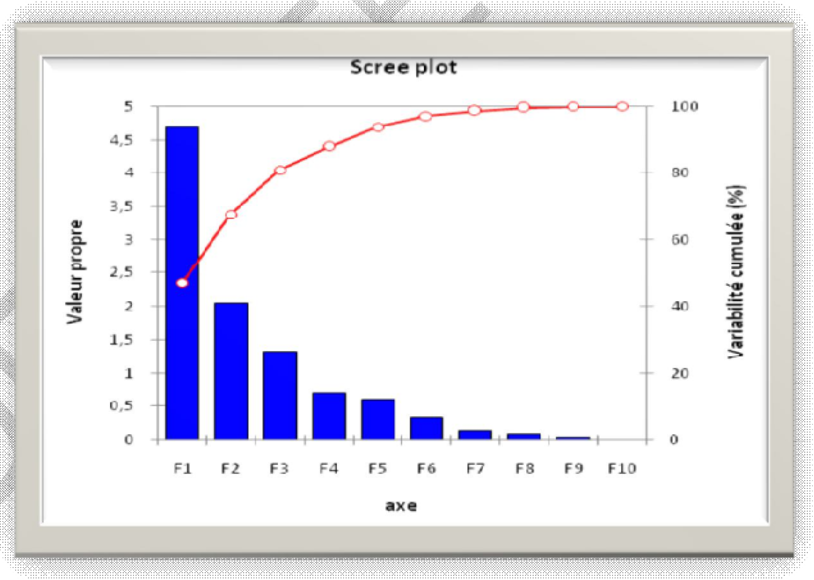

Figure 2.Graphical representation of eigenvalue and cumulative variability

The coordinates of the variables with respect to the axial planes (F1, F2, F3, F4, F5, F6, F7, F8, F9, F10) represented in Table 3 show the representation of the variables in the plane (factor 1, factor 2) explaining 86.79% of the initial inertia.

3.6.STATISTICAL EXPLOITATION OF RESULTS

3.6.1.PRINCIPAL COMPONENT ANALYSIS.

For data processing by principal component analysis, we used 11 variables: density, temperature, pH, electrical conductivity, suspended matter, dissolved O2, BOD5, chlorides, ammonium, nitrates and nitrites, and as individuals the samples taken monthly during the study period.

Table 4. Descriptive statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Average	Standard deviation
Density	12	0	12	0,000	328,750	164,375	232,461354
T°C	12	0	12	7,850	30,030	19,542	6,990
pH	12	0	12	7,390	8,450	7 ,92	0,338
C.E (m/s)	12	0	12	1119,300	3320,000	2219,65	1556,1298
TSS (mg/l)	12	0	12	34,940	204,250	119, 595	119,720
Dissolved Oxygen(mg/l)	12	0	12	0,660	4,930	2,795	3,0193
BOD5(mg/l)	12	0	12	9,000	143,750	76,375	95,2826
CL$^-$ (mg/l)	12	0	12	87,710	620,470	354,09	376,718
NH$^+$4(mg/l)	12	0	12	3,170	35,870	19,52	23,12239
NO$^-$2 (mg/l)	12	0	12	0,630	6,370	3,5	4,058792
NO$^-$3 (mg/l)	12	0	12	0,370	6,370	3,37	4,24264

The elementary statistics on the variables, based on the standard deviation values, show that density, electrical conductivity, BOD5, and chlorides are more dispersed around the mean. Regarding larval density, it is related to water temperature, ammonium, BOD5, and chlorides; high values of larval density are recorded in autumn and summer, while low values are recorded in winter, which explains this dispersion around the mean.

3.7.CORRELATION BETWEEN VARIABLES

The intermediate correlation matrices are given in Table 5

Table 5. Intermediate correlation matrix

Variables	Density	T°C	pH	C.E	TSS	Dissolved Oxygen	BOD5	CL$^-$	NH$^+$4	NO$^-$2	NO$^-$3
Density	1										
T°C	0,666	1									
pH	-0,083	0,339	1								
C.E (m/s)	0,444	0,811	-0,117	1							
TSS (mg/l)	0,228	-0,096	-0,057	-0,264	1						
Dissolved Oxygen(mg/l)	-0,510	-0,694	-0,288	-0,531	0,027	1					
BOD5 (mg/l)	0,477	0,264	0,084	0,081	0,551	-0,674	1				
CL$^{-(mg/l)}$	0,352	0,399	-0,145	0,481	0,431	-0,665	0,812	1			
NH$^+$4 (mg/l)	0,369	0,470	0,293	0,373	0,066	-0,741	0,557	0,469	1		
NO$^-$2 (mg/l)	-0,457	-0,262	-0,139	-0,030	-0,458	0,521	-0,683	-0,584	-0,316	1	
NO$^-$3 (mg/l)	-0,508	-0,410	-0,263	-0,113	-0,246	0,606	-0,618	-0,463	-0,484	0,875	1

Larval density shows a strong positive correlation with temperature (0.666), supporting the results previously obtained by Ghazi (1995)[14]. It also has a positive correlation with electrical conductivity (0.444). The results indicate that this parameter has high levels in summer and autumn (in both swamps). During these seasons, there is strong evaporation, resulting in an increase in dissolved salts. Additionally, larval density is positively correlated with BOD5 (0.477), suggesting that female mosquitoes are attracted to products derived from the fermentation of organic matter (Suleman and Shirin, 1981.[15].

Larval density also has a moderately positive correlation with chlorides and suspended solids. The variations in concentrations of dissolved elements and suspended solids are influenced by water flow rates and, therefore, by seasons Brunet R.C. et al., 1995[16]. According to Nisbet and Verneaux (1970)[17], ammoniacal nitrogen is only found in waters rich in decomposing matter when the oxygen level is insufficient to enable its transformation. Based on the above tables, it appears that the concentration of ammonia has a positive effect on mosquito larval density.

On the other hand, larval density has a negative correlation with dissolved oxygen (-0.510). High BOD5 levels and high larval density in summer and autumn demonstrate low oxygen content. It seems that *Culex pipiens* is not influenced by this parameter. Additionally, larval density has a negative correlation with nitrates (-0.508) and nitrites (-0.457).

The correlations between the variables and the projection axes of the variables in the space of axes F1 and F2 are presented in Figure 3.

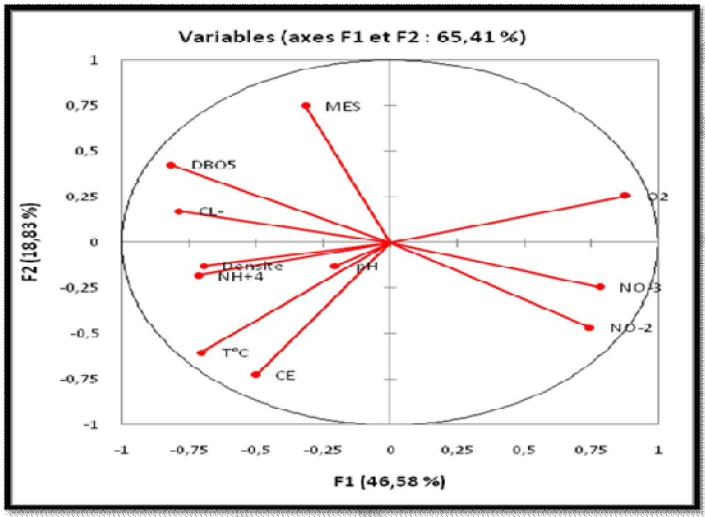

Figure 3.Projection of variables into the space of factorial axes (F1 and F2).

These axes show a good distribution of the variables studied.

The F1 and F2 factorial plan explains more than 65.41% of the variance (46.58% for the F1 axis and 18.83% for the F2 axis). The F1 axis is expressed towards its positive pole by dissolved oxygen, nitrates and nitrites, while density, ammonium ions, pH, temperature and electrical conductivity are in the negative direction.

The F2 axis is expressed towards its positive pole by suspended matter, BOD5 and chlorides. Density, ammonium ions, temperature, electrical conductivity and pH are in the negative direction. Thus, we can distinguish an opposition between the four groups of variables:

Group 4 consisting of: density, ammonium, temperature, electrical conductivity and pH

Group 3 consisting of: BOD5, MES, and chlorides.

Group 2 consisting only of dissolved oxygen.

Group 1 consisting of: nitrates and nitrites.

3.8. REPRESENTATION OF STATIONS

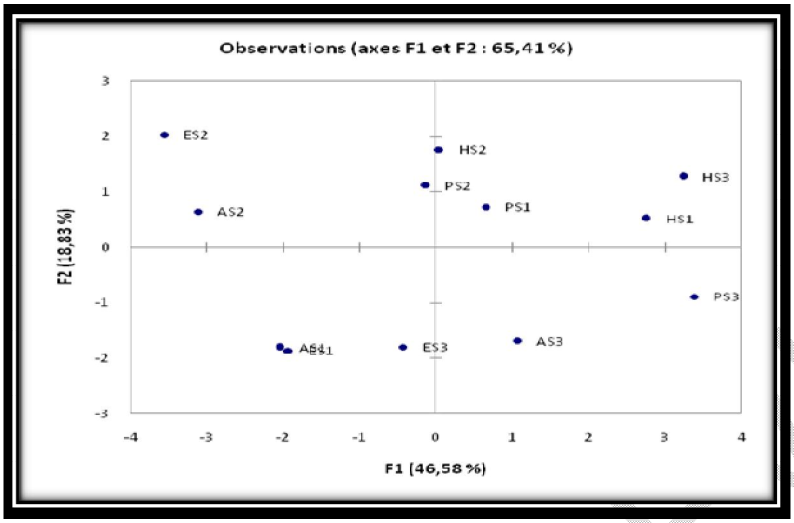

Figure 4. Factorial axis map (F1-F2) of the different stations according to the seasons

(HS1: Winter, Station 1), (PS1: Spring. Station 1), (ES1: Summer, Station 1). (AS1: Autumn, Station1). Station1: Dâadaâ. Station2; Hay Salam; Station 3: River Mda.

The aim is to provide approximate flat images of the cloud of stations located in space. The set of projections of all points from the cloud of the three stations on its first factorial axis F1, known as the first factor, based on the parameters, constitutes a new variable. This variable, to a certain norm, coincides with the first principal component obtained from the projection of the cloud of variables.

Therefore, the interpretation of the axes of this graph is, by definition, that of the principal components.

The two graphs (Figures 4 and 5) show the graphical representation of the studied stations and their distribution based on physicochemical properties, larval density, and season. The arrangement of the stations defined by the graphs indicates seasonal variations throughout our study period.

Thus, the x-axis represents the overall level of the stations, while the y-axis represents their profile. Indeed, the stations belonging to group 2 generally exhibit better values for dissolved oxygen concentrations; this is the case, for example, for stations HS2, PS1, HS1, and HS3.

In contrast, a station belonging to group 4 possesses high values in parameters that induce environmental toxicity (BOD5, chlorides, and suspended solids), such as stations ES2, PS2, and AS2. A station belonging to group 3 shows high values in parameters that promote mosquito proliferation (ammonium, temperature, and electrical conductivity), as observed in stations ES3, AS1, and ES3.

Therefore, the first axis (horizontal axis) contrasts stations with generally good values against those with generally poor values. Meanwhile, the second axis contrasts stations with very high values for parameters inducing environmental toxicity against those with low values for these parameters (Figure 5).

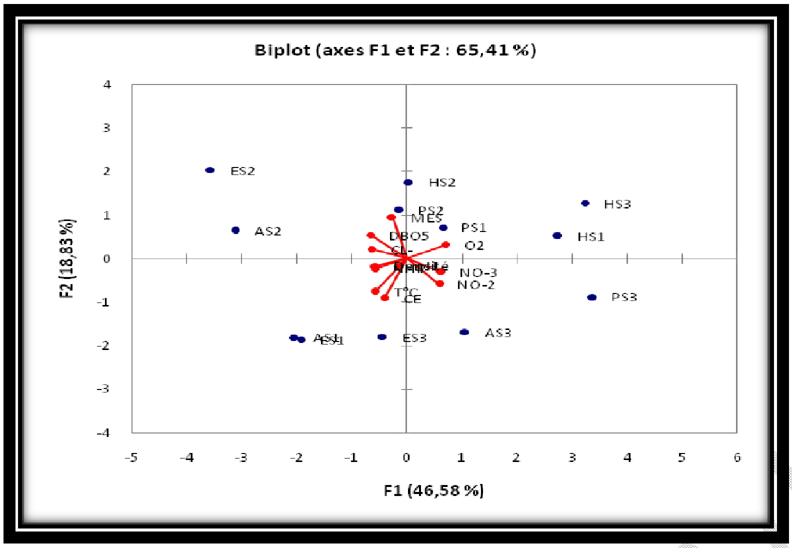

Figure 5. Factorial axis map (F1-F2) of the distribution of stations according to physicochemistry and larval density.

It seems that nitrite and nitrate concentrations have toxic effects on larval density, which can be explained by:

• The transformation of ammonia into nitrite and then into nitrate, hence the decrease in ammonia concentration.

• Either by plant proliferation which is pushed to excess (Eutrophication phenomenon).

The results show a positive correlation between electrical conductivity and the preimaginal density of culicidian species. The results show an increase in this parameter during the summer and autumn in both swamps Dâadaâ and Hay Salam. This is explained by the high evaporation during the summer season, which leads to an increase in the content of dissolved salts in the water. Temperature is positively linked to larval density, which confirms the results previously obtained by Ghazi (1995)[14].

During the summer and autumn, a low concentration of oxygen and a high concentration of organic matter (BOD5) were observed. The fact that the breeding sites show high larval densities in response to low oxygen levels suggests that culicid species do not seem to be affected by this parameter.

According to Subra (1973)[19], gravid females are more attracted to polluted water for laying eggs than to less polluted water.

4. CONCLUSION

Principal Component Analysis (PCA) is an exploratory method that uses concepts from linear algebra and geometry to help address this issue. PCA has the advantage, on the one hand, of summarizing the set of initial correlated variables into a reduced number of uncorrelated factors (F1 and F2 with 65.41%). On the other hand, it has allowed us to highlight similarities or oppositions between stations and parameters. Thus, it has shown us the presence of two pollution axes:

- Axis F1 consists of mineral pollution, rich in nitrates, nitrites, dissolved oxygen, and suspended solids.
- Axis F2 consists of organic pollution, characterized by BOD5, ammonium, and chlorides.

The results obtained from the physicochemical analysis of the waters in the breeding sites of the city have allowed us to highlight various types of contamination, primarily expressed by two types of pollution: organic pollution and chemical pollution ranging from low to significant in all the breeding sites studied, originating from agriculture and domestic waste.

In parallel with the physicochemical study, a contribution to the inventory of the culicid fauna was made during the study period. Three breeding sites were surveyed, and it was concluded that most culicid species and their companion fauna appear when climatic conditions are favorable. However, the climatic factor, represented by temperature and precipitation, is the key element determining the distribution of the culicid fauna (Dajoz, 1971)[20]. According to the statistical study (PCA), it appears that the concentration of nitrates and nitrites has a negative impact on larval density, while ammonium is positively linked to the density of mosquito larvae. The seasonal frequency of the species captured in the study area is characterized by two peaks, one in summer and the second in autumn. Culicidae are low in specificity and vary from station to station, depending on the physicochemical and abiotic parameters of the larval habitats. It is noted that larval density varies significantly according to the seasons, resulting in zonation of the area.

Due to the simultaneous impact of abiotic parameters on larval populations of culicid fauna, the development rate increases, leading to a significant proliferation of mosquitoes. Two essential elements are highlighted in this study: the physicochemical factor, which includes organic matter, electrical conductivity, and ammonium ions, as well as the seasonal factor. As the rainy season progresses, open-air breeding sites will retain water longer, increasing their positivity.

Inventory of species captured in the region

Family: Culicidae
Subfamily: Culicinae
Tribe: Culicini
Genus : Culex Linné 1758
Species :
- Culex (Culex) pipiens Linné 1758
- Culex (Culex) theileri Theobald 1903
- Culex (Culex) perexiguus Theobald 1901
- Culex (Culex) quinquefasciatus 1823
- Culex (Culex) impudicusFicalbi, 1890

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