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Nezha Mherzi, Fatima Lamchouri, Abdelouahab Zalaghi, Hamid Toufik

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Nezha Mherzi, Fatima Lamchouri*,
Abdelouahab Zalaghi and Hamid Toufik

Laboratory of Natural Substances, Pharmacology, Environment,
Modeling, Health and Quality of Life (SNAMOPEQ),
Polydisciplinary Faculty of Taza (FPT),
Sidi Mohamed Ben Abdellah University (USMBA) of Fez,
B.P. 1223 Taza-Gare, Taza, Morocco
Email: nezha.mherzi@usmba.ac.ma
Email: fatima.lamchouri@usmba.ac.ma
Email: fatima.lamchouri@gmail.com
Email: abdelouahab.zalaghi@gmail.com
Email: hamid.toufik@usmba.ac.ma
*Corresponding author

Abstract: In this study, a botanical inventory, five physico-chemical parameters, results of bacteriological and parasitological analyses of soil and water during three periods (dry-2017, wet-2018, and dry-2018) on nine stations of Oued Lârbaa, were analysed by principal component analysis and ascending hierarchical classification. The interpretation of results using these tools allowed us to understand that acidity and salinity are stress factors for the survival of bacteria because of negative correlations between them. The analysis also showed negative correlations between bacteria and parasites which means the presence of competition, vegetation is negatively affected by temperature and pollution. Ascending hierarchical classification showed that stations having received the same type of discharges meet in the same group; station S8 which receives the leachates of the uncontrolled landfill is alone in a group indicating the unique polluting character of leachate.

Keywords: principal component analysis; PCA; Oued Lârbaa; water; soil; physicochemical-bacteriological-parasitological parameters; hierarchical ascending classification; HAC; botanical inventory; Morocco.

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Biographical notes: Nezha Mherzi is a PhD student in Environmental Engineering and Technology – Environmental Monitoring, Surveillance and Assessment at the Laboratory of Natural Substances, Pharmacology, Environment, Modeling, Health and Quality of Life (SNAMOPEQ), Polydisciplinary Faculty of Taza (FPT), USMBA of Fez, Morocco. Her research focuses on the assessment and management of health and environmental risks related to environmental pollution, and development of bio treatment technology to reduce the impacts of pollution.

Fatima Lamchouri is a Professor at the Polydisciplinary Faculty of Taza (FPT), Sidi Mohamed Ben Abdellah University (USMBA) of Fez, Morocco, and also the Deputy Director of Natural Substances, Pharmacology, Environment, Modeling, Health and Quality of Life Laboratory (SNAMOPEQ). Her research interests: environment, sustainable development, molecular modelling, natural substances, phytochemistry, pharmacology, and toxicology. She is also a member of the editorial boards and reviewers of several scientific journals. She was a member of the Advisory Board on Education and Outreach (ABEO) of the Organisation for the Prohibition of Chemical Weapons (OPCW) (1st term 2016–2018) and 2nd term (2019–2021).

Abdelouahab Zalaghi obtained his PhD in Biology: Microbiology and Environmental Biotechnology at the Polydisciplinary Faculty of Taza (FPT), Sidi Mohamed Ben Abdellah University (USMBA) of Fez, Morocco.

Hamid Toufik is a Professor at the Polydisciplinary Faculty of Taza, USMBA of Fez, Morocco and the Head of Chemistry Department. Her research focuses on inorganic materials, environment, natural substances, therapeutic chemistry and modelling and reviewers of several scientific journals.

1 Introduction

Water systems are valuable and essential natural resources for multiple uses (domestic, industrial and agricultural), their quality is a factor influencing the state of health and mortality in both humans and animals (Kazi et al., 2009). Therefore, the pollution of these resources which is defined as a physical, chemical or biological degradation of its compartments (water, soil, vegetation, …) caused by human activity, disrupts the living conditions and aquatic balances compromising their multiple uses (Genin et al., 2003; Emmanuel et al., 2008; Amira and Mezmaze, 2021). This is why the monitoring of the quality of these resources remains essential to control the sources of pollution in order to seek solutions and take actions to protect them.

Nevertheless, monitoring the quality of water resources generates large amounts of data that are not simple to interpret (Felipe-Sotelo et al., 2007; Kowalkowski et al., 2006). In this context, the use of different multivariate statistical techniques [principal component analysis (PCA), classification methods] for data interpretation seems to be an interesting solution for a better understanding of water quality, soil and ecological states of the studied environments (Simeonov et al., 2003; Pejman et al., 2009; Sadat et al., 2011; Garizi et al., 2011; Phung et al., 2015; Nyieku et al., 2021). These techniques also have the advantage of identifying and linking the various factors (or sources) to the observed effects on aquatic systems. They are therefore better tools for water resources management, enabling rapid solutions to pollution problems (Felipe-Sotelo et al., 2007; Vega et al., 1998; Ouyang, 2005; Swaine et al., 2006; Shrestha and Kazama, 2007; Menció and Mas Pla, 2008; Muangthong and Shrestha, 2015).

Among the most widely known multidimensional descriptive methods, there is: PCA and hierarchical ascending classification (HAC), PCA is a factorial analysis, in the sense that it produces factors (or principal axes) which are linear combinations of the initial variables, hierarchical and independent of each other. These factors are sometimes called ‘latent dimensions’ because they are the expression of general processes directing the distribution of several phenomena that are thus correlated with each other (Béguin and Pumain, 2000).

HAC is one of the most important approaches for the exploration of multivariate data, it is an iterative classification method whose objective is to identify groups of similar objects (Campello et al., 2015). These successive groupings produce a binary classification tree (dendrogram), the root of which corresponds to the class grouping together all the individuals. This dendrogram represents a hierarchy of partitions (Nikhath and Subrahmanyam, 2019).

The use of PCA and CHA for the interpretation of data appears to be an interesting solution for a better understanding of the quality of river compartments (Bennasser, 1997; El Morhit et al., 2008; Brogueira and Cabeçadas, 2006; Kannel et al., 2008). This technique also has the advantage of transforming the initial quantitative variables, all more or less correlated with each other, into new, uncorrelated quantitative variables, called principal components (Davis, 1986; Güler et al., 2002; Duby and Robin, 2006; Cordella, 2010).

For this reason, the objective of the work is to use the methods of multivariate statistics to analyse the huge experimental results that we have obtained in the laboratory, thus revealing the links between the different parameters. This is in order to conclude the degree of pollution of Oued Lârbaa and to propose the appropriate prevention solutions. The studies focused on the monitoring of physicochemical parameters, the evaluation of parasitological and bacteriological qualities of the soil and water of Oued Lârbaa (Mherzi et al., 2021) and also on the realisation of a floristic inventory which allowed to define the ecological types and the groups of dominant plants in relation to the seasonal factors and the types of pollution (Mherzi et al., 2020a). These studies were conducted at nine stations during two dry periods (2017 and 2018) and one rainy period (2018). The results of the laboratory analysis and the field results generate a lot of data, a total of 66 plant species, a very important load was shown in parasites and bacteria indicators of faecal contamination of water and soil. In front of these results which are enormous, it is necessary to use a statistical tool which will help us to interpret the obtained results and to understand the relations between the different studied parameters.

Therefore, the objective of the present study is to apply PCA and HAC on the physicochemical, bacteriological, parasitological and floristic data that we obtained and collected during three periods of study (dry seasons of the years 2017 and 2018 and the rainy season of the year 2018) in order to:

1 control the quality of the soil and water of Oued Lârbaa considered as a main watercourse of the City of Taza, Morocco

2 visualise and analyse the existing correlations between the different variables through their structuring and their orientations

3 identify the main factors responsible and at the origin of the pollution and which impact the phytobiodiversity, the quality of the soil and the water of the said Oued.

2 Materials and methods

2.1 *Quantitative data on the quality of Oued Lârbaa*

Oued Lârbaa, one of the most important watercourses of the City of Taza, is affected by anthropogenic inputs that we have demonstrated and evaluated in previous work of our laboratory (Mherzi et al., 2021, 2020a; Lakhloufi et al., 2021). The said anthropic impacts have led to the mobilisation of microbiological agents (bacteria and parasites) (Mherzi et al., 2021) and an imbalance in the riparian vegetation (Mherzi et al., 2020a) and aquatic fauna of the said river (Lakhloufi et al., 2021). The experimental analyses at the laboratory level require statistical analysis of the results obtained from the said analyses to facilitate the understanding and visualisation of the environmental state of the watercourse.

The data used to establish the PCA and the HAC of this study were obtained from our previous work on monitoring the quality of Oued Lârbaa during three periods: 2 dry seasons and one wet season: (dry season-2017, wet season-2018 and dry season-2018) (Mherzi et al., 2021, 2020a). These data are composed by: *in situ* measurements of physicochemical parameters (The pH, conductivity, temperature, salinity and total dissolved substances (TDS), the results of bacteriological and parasitological analyses of the soil and water of Oued Lârbaa carried out at the Laboratory of Natural Substances, Pharmacology, Environment, Modeling, Health and Quality of Life (SNAMOPEQ) at the Polydisciplinary Faculty of Taza (PFT), University Sidi Mohamed Ben Abdellah (USMBA) of Fez, Morocco. These analyses focused on the research of faecal bacteria and intestinal helminths in the soil and water of Oued Lârbaa (Mherzi et al., 2021), and by the results of the floristic study of the vegetation of the said oued (Mherzi et al., 2020a).

2.2 *Statistical processing of data*

2.2.1 *Statistical processing by PCA*

PCA is a part of multivariate descriptive analysis (Mountadar et al., 2016). It is used to analyse quantitative numerical data to reduce its dimensionality by finding a new set of variables smaller than the set of variables, which nonetheless contains the information in its entirety (Mouissi and Alayat, 2016). The principal components are obtained by diagonalising the matrix of bi-variate correlations. This diagonalisation defines a set of eigenvalues whose observation of each component determines the number of graphs to examine (Menció and Mas Pla, 2008). The water and soil analyses for nine stations and three sampling periods generate a lot of data that are not easy to interpret without using an adequate statistical tool. Therefore, in this work, we used this explanatory method for a matrix of nine stations and 30 variables, in order to determine the relationship between these physico-chemicals, bacteriological, parasitological and floristic variables studied and the distribution of the stations. The statistical software XLSTAT was used to process the data. The final phase of the PCA consists of a graphical representation that provides an overview of the results that the numerical expressions do not provide.

2.2.2 Statistical processing by HAC

We used a HAC, to sort all the collected information, in order to group the sampling stations with similar pollution rates. The statistical tool used is always XLSTAT. It is important to emphasise that HAC is useful for a reliable classification of surface waters in the study area and also for a faster assessment of water quality, as it is possible to select only the representative points of each group and to design a better strategy for future monitoring with fewer sampling sites and reduced costs (Timm, 2002; Rencher, 2005; Silla and Freitas, 2011; Murtagh and Contreras, 2012; McGarigal et al., 2013; Gan et al., 2020).

3 Results and discussion

3.1 Principal component analysis

In order to better evaluate the effects of anthropic activities on the quality of water and soil of Oued Lârbaa, we applied a statistical treatment of the PCA to all the data obtained following the monitoring of different physicochemical, bacteriological, parasitological and floristic parameters. Similarly, the PCA was also applied to relate the different parameters. The choice of this method is explained by its wide use in the interpretation of environmental data (Bennasser, 1997; El Morhit et al., 2008). The results of the different analyses are presented and discussed below.

3.1.1 Component extraction

In a PCA, the number of components to be extracted is determined by the variance accumulation test, commonly known as the screen test. Vega et al. (1998) suggested that the extraction of components should be stopped at the point where the change in slope in the eigenvalue graph occurs. This decision about the number of components to extract must also take into account the interpretability of the extracted dimensions. Figure 1 shows the eigenvalue graph obtained during our present study.

PCA of the data in this study showed that approximately 100% of the variation in the data is explained by eight principal components (F1 to F2), with F1 and F2 alone accounting for 50.89%, 51.87%, and 49.59% of variance for the low water-2017, wet water-2018, and low water-2018 periods respectively (Table 1).

The principal components are obtained by linear combination of the initial variables which are more or less correlated to them. These components thus define a space of reduced dimension in which the initial variables are projected to account for the maximum of information. Tables 2, 3 and 4 show the values of the correlation coefficients linking the variables to the eight components. The most significant correlations are shown in italic, in the other words, those which best explain each of the components.

Table 1 Total explained variance of the studied variables for all stations (S1 to S9) of Oued Lârbaa, Taza, Morocco during the dry-2017, wet-2018 and dry-2018 periods

Sampling period	*Total variance*	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*
Dry period-2017	Eigenvalue	8.2347	7.0349	4.5450	3.4190	2.4831	1.8850	1.4889	0.9094
	Variability (%)	*27.4489*	*23.4498*	15.1500	11.3965	8.2771	6.2832	4.9630	3.0313
	Cumulative (%)	27.4489	50.8988	66.0488	77.4453	85.7224	92.0056	96.9687	100.0000
Wet period-2018	Eigenvalue	10.1060	5.4555	3.4975	3.1186	2.7429	2.1547	1.6809	1.2438
	Variability (%)	*33.6867*	*18.1851*	11.6583	10.3955	9.1431	7.1823	5.6030	4.1460
	Cumulative (%)	33.6867	51.8718	63.5301	73.9255	83.0686	90.2510	95.8540	100.0000
Dry period-2018	Eigenvalue	8.3023	6.5753	4.6474	3.9459	2.6262	2.1999	1.0944	0.6086
	Variability (%)	*27.6744*	*21.9176*	15.4914	13.1529	8.7540	7.3330	3.6480	2.0288
	Cumulative (%)	27.6744	49.5919	65.0834	78.2362	86.9903	94.3233	97.9712	100.0000

Table 2 Correlation matrix between the variables and the first eight components of the analyses performed during the dry period of 2017

Variable/ component	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*
W-STAPH	*0.7763*	0.3794	–0.3531	–0.1745	0.2198	–0.1904	0.0512	–0.1048
W-FC	–0.0895	*0.8820*	0.1873	0.3628	0.0203	–0.0104	–0.2164	0.0088
W-TC	–0.3048	*0.6535*	0.1610	*0.6368*	0.0055	–0.1362	–0.1522	–0.0833
W-TMAF	*0.6358*	0.0025	0.3296	–0.1160	–0.5705	0.0798	–0.3537	–0.1290
W-FS	–0.0554	*0.7859*	–0.0774	0.0506	0.2042	*0.5625*	0.1048	–0.0405
S-STAPH	*0.7575*	*0.5428*	–0.2246	–0.1919	–0.1818	–0.0478	0.0886	0.0333
S-FC	*0.5806*	0.3320	0.4967	0.0064	0.1269	*0.5281*	0.0396	0.0968
S-TC	*0.8290*	–0.0859	0.2696	0.3018	–0.0479	0.3535	0.0417	–0.1122
S-TMAF	0.0264	*0.8641*	0.1616	–0.3992	–0.2449	–0.0835	–0.0063	–0.0147
S-FS	*0.8787*	0.3431	0.0696	0.2729	–0.0877	–0.1485	–0.0328	0.0010
W-EV	*0.6860*	–0.3483	0.4279	0.3762	0.2499	0.0862	0.1161	–0.0156
W-AL	0.4919	*0.7320*	0.2046	–0.2772	–0.1703	–0.1218	–0.2442	0.0072
W-Tr	0.2673	0.1473	–0.4316	*0.6904*	0.1731	0.4312	0.0772	0.1486
W-Capp	0.4021	–0.0410	*0.7218*	0.1819	0.0298	–0.4722	0.2411	–0.0233
W-Toxo	–0.4815	*0.5164*	0.4854	0.0102	0.4944	–0.1269	0.0717	0.0117
W-Hn	0.4292	–0.6627	0.4928	–0.1964	0.2062	0.1886	–0.1000	–0.0845
W-Tae	0.5538	*0.5081*	0.3436	0.2091	–0.1619	–0.2154	0.3761	0.2434
S-EV	0.1833	–0.4652	–0.1138	*0.6945*	–0.4130	–0.2759	–0.0585	–0.0675
S-AL	–0.4269	0.3016	*0.5744*	–0.1014	–0.3161	–0.1132	–0.2706	0.4479
S-Tr	–0.1929	0.4760	0.0530	0.1682	–0.5397	0.0002	0.5358	–0.3560
S-Capp	0.0963	–0.2528	*0.8928*	0.2565	0.0485	0.0950	–0.2219	0.0580
S-Toxo	–0.4604	0.3991	*0.6082*	0.1252	0.3533	0.0539	0.3286	–0.0868
S-Hn	–0.6318	*0.5690*	0.3038	–0.3667	0.1762	–0.1158	–0.0640	–0.0415
S-Tae	*0.5526*	*0.5099*	–0.4581	–0.0736	0.2942	–0.2601	–0.2004	0.1578
T°	0.4856	0.3310	–0.3361	–0.3687	–0.3303	0.3450	0.2652	0.3275
CD	0.0044	–0.6572	0.2281	–0.3175	0.0860	–0.1475	0.4942	0.3766
SLT	*0.5901*	0.0613	0.0549	–0.4924	*0.5892*	0.0330	–0.1495	–0.1787
TDS	*0.8447*	–0.4495	0.1858	–0.0135	0.0505	–0.0939	–0.1613	0.1106
pH	–0.1040	0.2217	–0.4928	*0.6612*	0.3790	–0.1716	–0.1016	0.2767
TN	–0.7727	–0.0990	0.2344	0.0650	–0.3103	0.4253	–0.1889	0.1455

Notes: W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

Table 3 Correlation matrix between variables and the first eight components of the analyses performed during the wet period of 2018

Variable/ component	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*
W-STAPH	*0.9153*	–0.1151	–0.0657	0.1461	–0.2249	–0.2371	0.0407	0.1218
W-FC	–0.0347	*0.7594*	–0.1606	–0.0040	0.1201	0.1413	0.6013	–0.0206
W-TC	*0.8776*	0.2394	–0.2912	0.2290	–0.0440	0.1389	0.1148	0.0281
W-TMAF	0.3149	*0.7748*	0.4030	0.2092	–0.1062	–0.0106	–0.0105	0.2879
W-FS	*0.9043*	0.3111	0.1101	0.1327	–0.0204	–0.0709	–0.1430	0.1728
S-STAPH	*0.7532*	0.1578	0.0937	–0.4459	0.1088	0.2180	0.3485	–0.1390
S-FC	*0.8595*	–0.0762	–0.4183	0.0015	0.0213	0.2539	0.1146	0.0485
S-TC	*0.6659*	0.2467	–0.3805	–0.4788	0.1914	–0.0572	–0.2845	0.0280
S-TMAF	–0.1221	0.3503	*0.7805*	–0.1235	–0.1915	0.1744	–0.3296	0.2495
S-FS	*0.9414*	0.1910	–0.0566	0.1780	0.0672	–0.1561	–0.0670	0.0946
W-EV	0.3114	–0.5811	–0.0640	0.0930	0.6279	0.1659	0.0499	0.3582
W-AL	*0.9039*	0.3193	0.2142	0.0070	0.0492	0.1144	–0.0411	–0.1335
W-Tr	0.2218	–0.1737	–0.5493	–0.0068	–0.3022	0.6739	0.0617	0.2639
W-Capp	–0.3279	–0.0033	–0.2597	–0.3068	*0.7726*	–0.1887	0.0957	0.2988
W-Toxo	–0.0048	–0.6536	0.1392	0.0101	–0.5456	–0.3855	0.3170	0.0812
W-Hn	*0.6927*	–0.4717	0.1891	–0.0592	0.3627	–0.3519	0.0372	0.0408
W-Tae	0.3880	0.2185	*0.6088*	0.3361	0.4084	0.3516	–0.0041	–0.1662
S-EV	–0.2218	*0.6761*	–0.3771	0.3461	0.0093	–0.2031	0.4095	0.1508
S-AL	*0.9534*	0.1245	0.0074	0.0721	0.0220	–0.0886	–0.1867	–0.1645
S-Tr	–0.5087	*0.7838*	–0.0239	0.2384	–0.1096	–0.1462	0.0983	0.1628
S-Capp	*0.9127*	0.2690	0.1193	0.1479	0.0255	–0.1173	–0.1434	0.1534
S-Toxo	0.1643	–0.2242	–0.4698	–0.2782	–0.5274	*0.5193*	–0.0803	0.2652
S-Hn	0.0881	–0.0960	–0.0870	*0.9270*	0.1449	0.1881	0.2249	–0.0955
S-Tae	–0.3775	*0.5091*	–0.5523	0.0700	0.0025	–0.5122	–0.0498	0.1533
T°	0.2956	0.0855	*0.5893*	–0.4062	–0.2222	0.0216	*0.5839*	–0.0469
CD	–0.2365	–0.6445	0.1024	0.4320	0.5041	0.1265	0.0630	0.2398
SLT	0.4695	–0.6684	0.1759	–0.2712	–0.0168	–0.1789	0.4395	0.0539
TDS	*0.5977*	–0.3880	0.0197	0.1731	–0.4055	–0.4620	–0.0386	0.2871
pH	–0.2026	–0.4086	–0.1885	*0.7939*	–0.3358	0.1159	0.0021	0.0097
TN	–0.4883	0.1689	*0.5541*	–0.2416	0.0035	0.1752	0.0673	*0.5765*

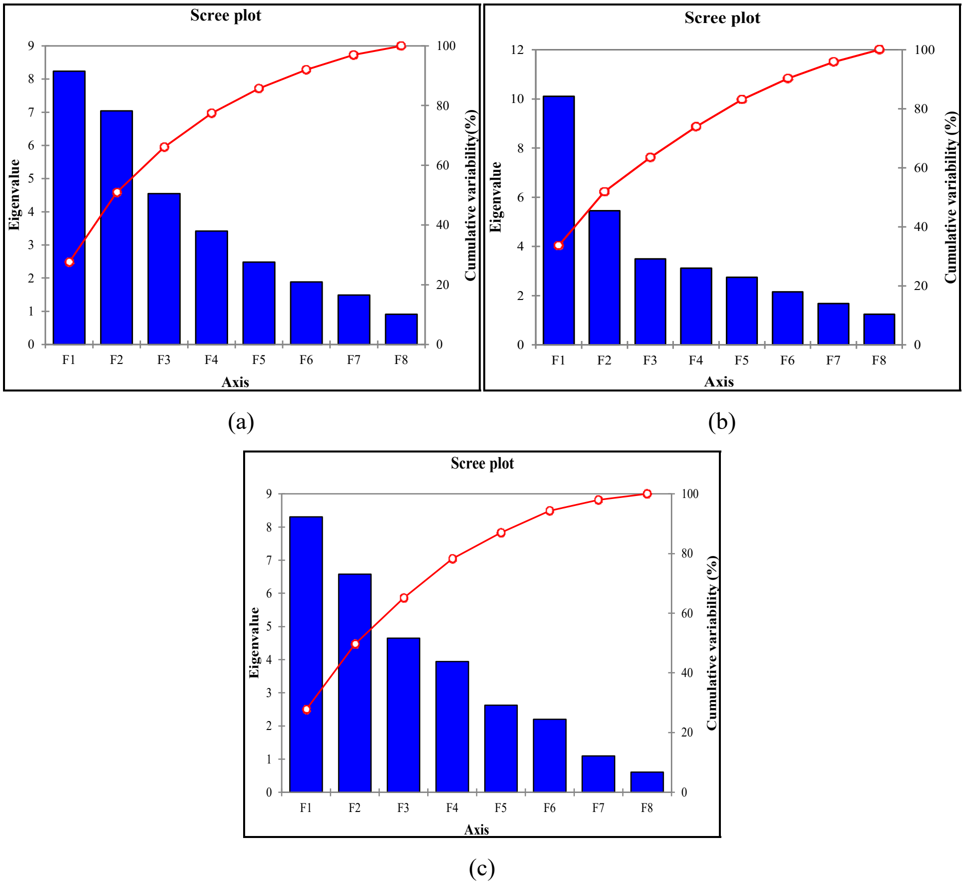
Notes: W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

Table 4 Correlation matrix between the variables and the first 8 components of the analyses performed during the dry period of 2018

Variable/ component	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*
W-STAPH	0.4128	*0.6953*	–0.3217	–0.3515	–0.3043	–0.0319	0.0797	–0.1383
W-FC	*0.7903*	–0.2757	–0.0301	0.1722	–0.1825	0.4325	–0.1380	0.1716
W-TC	*0.6102*	–0.4577	–0.1491	*0.5528*	–0.1327	0.2342	–0.1088	0.0775
W-TMAF	*0.6233*	0.1322	0.2188	0.1219	0.6406	0.2442	–0.0096	–0.2474
W-FS	*0.8365*	–0.2192	–0.2688	–0.0359	–0.1943	–0.1040	–0.2561	–0.2540
S-STAPH	0.0533	–0.1664	–0.1182	–0.6048	0.7195	–0.0523	–0.2584	0.0506
S-FC	0.6109	0.5116	0.2574	0.2894	–0.0929	–0.2871	–0.3460	–0.0656
S-TC	0.2874	*0.7603*	0.2455	0.3933	0.2241	0.1518	–0.1812	–0.1353
S-TMAF	*0.7829*	–0.2785	–0.1096	–0.3807	0.3209	–0.1904	0.0824	–0.0806
S-FS	*0.5840*	*0.7412*	–0.0914	0.2011	0.1412	0.1097	0.1552	0.0691
W-EV	–0.0320	*0.8702*	0.0367	0.1533	–0.4013	–0.2257	–0.0523	0.0464
W-AL	0.7507	–0.0887	0.0797	–0.5413	–0.1177	0.2683	0.2018	0.0515
W-Tr	0.2448	0.2648	–0.5771	0.3331	–0.5372	0.1876	–0.2733	0.1658
W-Capp	*0.6094*	0.2917	0.2751	0.3029	0.1416	–0.3357	0.4924	–0.0286
W-Toxo	*0.5547*	–0.6560	0.3368	0.0751	–0.3765	–0.0106	–0.0212	0.0238
W-Hn	–0.1376	0.2574	*0.8546*	–0.1738	–0.0459	0.3727	–0.0082	–0.1145
W-Tae	*0.9213*	–0.1399	0.0830	0.1872	–0.0555	–0.2367	0.0412	0.1699
S-EV	–0.4335	0.3074	–0.2832	*0.6668*	0.2800	0.1448	0.2920	0.0903
S-AL	0.4514	–0.6779	0.2310	0.0994	0.3928	–0.1095	–0.0701	0.3198
S-Tr	–0.0114	–0.1554	–0.5903	*0.7036*	0.3146	0.0544	0.1740	–0.0057
S-Capp	0.1263	–0.0427	*0.7853*	0.4236	0.2658	0.2407	–0.2189	0.0981
S-Toxo	0.2017	–0.3043	*0.6662*	0.4360	–0.2275	–0.3836	0.0516	–0.1768
S-Hn	0.4801	–0.7541	0.2690	–0.2850	–0.1501	–0.0285	0.1535	0.0200
S-Tae	*0.5211*	0.4390	–0.3686	–0.5672	–0.1213	0.0807	0.1771	0.1599
T°	0.3371	*0.5128*	–0.4384	–0.3452	0.3787	–0.2736	–0.2926	0.0903
CD	–0.4944	0.2468	*0.6016*	–0.1935	–0.0849	–0.4527	0.0534	0.2833
SLT	0.4577	*0.5420*	*0.6156*	–0.3140	–0.1132	–0.0749	0.0266	0.0109
TDS	–0.2537	*0.7101*	*0.5106*	–0.0675	0.1230	0.3166	–0.0947	0.2042
pH	–0.7147	–0.3809	–0.0177	0.0704	–0.0054	–0.5325	–0.2329	–0.0315
TN	–0.6082	–0.3301	0.1664	–0.3232	–0.1867	*0.5886*	–0.0082	–0.0875

Notes: W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

Figure 1 Eigenvalue plot for PCA, (a) dry period of the year 2017 (b) 2018 wet period (c) dry period of the year 2018 (see online version for colours)



According to the extracted component matrix (Tables 2, 3 and 4), component 1 (F1) with variances of 27.44%, 33.68%, and 27.67% for the dry-2017, wet-2018, and dry-2018 periods, respectively, consists mainly during the dry-2017 period of *Staphylococci*, TMAF, *Enterobius vermicularis*, water TDS, *Staphylococci*, total and faecal *Coliforms*, *Streptococci*, and soil *Taenia* (Table 2). During the wet period of the year 2018, it is composed by *Staphylococci*, total *Coliforms*, *Streptococci*, *Ascaris lumbricoides*, of the waters and soil in addition to *Capillaria sp* of the soil and *Hymenolepis nana* of the waters. During the dry period of the year 2018, this component consists of the concentrations of TMAF, *Streptococci*, *Taenia* in the soil and in the waters, moreover the concentrations of faecal and total *Coliforms*, *Capillaria sp* and *Toxocara* in the waters. These variables show coefficients greater than 0.5 and are mostly dependent on anthropogenic activity and is related to a point source, particularly human through the discharge of wastewater and leachate from the uncontrolled landfill of the City of Taza, Morocco.

Component 2 is made up in its positive part by faecal *Coliforms*, *Streptococci*, *Ascaris lumbricoides*, *Toxocara* and *Taenia* from waters in addition to *Staphylococci*, TMAF, *Hymenolepis nana* and *Taenia* from soil during the dry period of the year 2017.

This component is constituted during the rainy period of 2018 by faecal *Coliforms* and TMAF of waters, *Enterobius vermicularis*, *Trichuris* and *Taenia* of soil, while during the dry period of 2018, component 2 is formed by total *Coliforms*, *Streptococci*, *Enterobius vermicularis* of soil and *Staphylococci*, temperature, salinity and TDS of waters. Salinity and TDS characterise both the presence of organic and inorganic matter, since it is composed by inorganic salts and some organic matter. The common inorganic salts found in TDS include calcium, magnesium, potassium and sodium which are all cations and carbonates, nitrates, bicarbonates, chlorides and sulphates which are all anions. This could indicate a certain diversity of origin of organic and inorganic matter in these waters. Component 2, which is characteristic of anthropic organic and mineral inputs, can therefore be linked here to the notion of trophic potential of waters.

Component 3 is represented by the following variables: *Capillaria sp* of water and soil, *Ascaris lumbricoides* and *Toxocara* in the soil during the dry period of 2017. This component is composed during the rainy period of 2018 by the TMAF of the soil, *Taenia* and the temperature of the waters in addition to the number of taxa found in the banks of Oued Lârbaa, during the dry period of 2018 this component is consisted by *Capillaria sp* and *Toxocara* of the soil besides *Hymenolepis nana*, conductivity, salinity and TDS of the waters. This component gathers the parameters of microbial activity (bacterial and parasitic), organic and mineral matter and also the abundance of vegetation. It also reflects the processes induced by macrophytes that make the environment more reductive and acidic (negatively affects the pH).

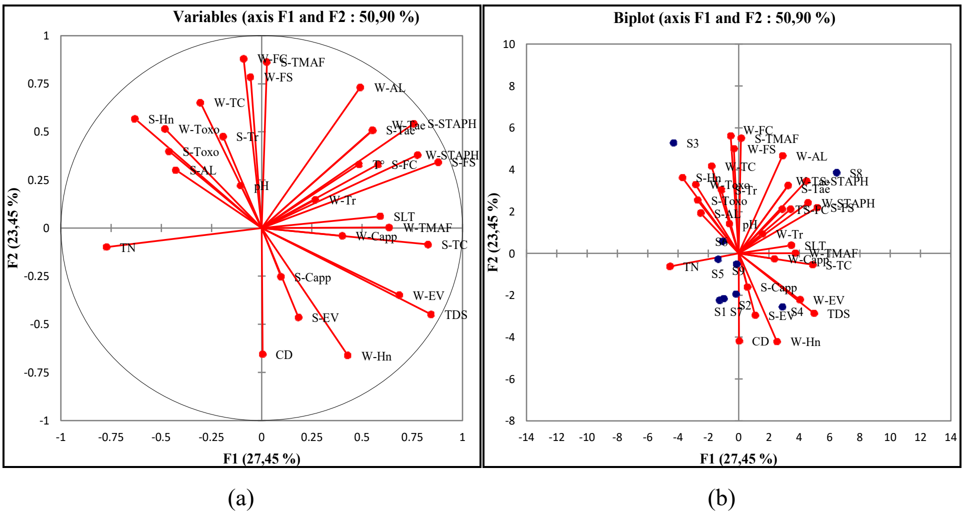
Component 4 is characterised by the variables total *Coliforms*, *Trichuris* and pH of water and *Enterobius vermicularis* of soil during the dry period of 2017. It is constituted during the rainy period of 2018 by *Hymenolepis nana* of the soil and the pH of the waters and during the dry period of 2018 this component is constituted by the total *Coliforms* of the waters and *Enterobius vermicularis* and *Trichuris* of the soil. Component 5 consists of water salinity during the dry period-2017 and *Capillaria sp* of water during the wet period-2018 and neither variable during the dry period-2018. Component 6 is made up of *Streptococci* of water and faecal *Coliforms* from soil during the dry period-2017 and *Toxocara* from soil during the wet period-2018 and the number of taxa during the dry period-2018. Components 7 and 8 are characterised during the rainy period by the variables faecal *Coliforms*, water temperature and the number of taxa, these two components are not presented by any variable during the dry periods of the years 2017 and 2018. These last components (4, 5, 6, 7 and 8) all reflect anthropogenic pollution that is manifested in Oued Lârbaa by wastewater discharges, solid waste and leachate from the uncontrolled landfill of the City of Taza, Morocco.

3.1.2 PCA analysis and variables correlations

The correlation coefficients analysis between the variables and the first 8 components showed that the two factorial axes (F1; F2) represent the maximum of information and extract for the three sampling periods respectively (27.45%; 23.45%), (27.67%; 21.92%) and (33.69%; 18.19%) of the total variance, representing a cumulated percentage of 50, 90%, 49.59% and 51.87%.

Figures 2, 3 and 4 shows the graphical representation of the PCA results obtained according to the sampling period.

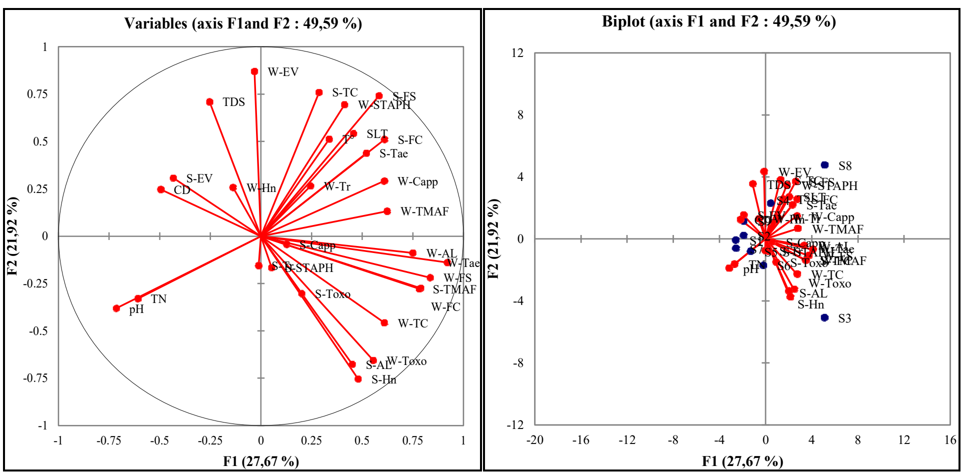
Figure 2 PCA of the distribution of biological pollution (bacteriological and parasitological), physicochemical parameters and the number of plant species according to the prospected stations in Oued Lârbaa-Taza-Morocco during the dry period of 2017, (a) correlation between the variables (b) correspondence between the variables and the studied stations (see online version for colours)



Notes: S: station; W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

The study of bivariate linear correlations between the studied parameters provides information about the strength of associations between them. From Figure 2, we can say that during the dry period of the year 2017, there is a positive correlation between the parasites of soil *Ascaris lumbricoides*, *Toxocara*, *Hymenolepis nana*, *Taenia* of water and soil which means that the presence and concentrations of these parasites present the same information, being an origin of faecal contamination. The pH is positively correlated with total *Coliforms* in water and *Trichuris* in soil, indicating a resistance of these two species to the neutral pH recorded during this period, which is not the case for other bacteria and parasites. There is also a correlation between *Coliforms* and faecal *Streptococci* in water, indicating similar information presented by these two bacteria that have a faecal origin of contamination. The temperature is positively correlated with the concentration of *Staphylococci* in water and soil, *Coliforms* and faecal *Streptococci* in soil and *Trichuris* in water, this indicates that the temperature recorded in the waters of Oued Lârbaa during the dry period of 2017 is conducive to the survival and multiplication of these species [Figure 2(a)]. The increase in temperature and sunshine duration during low water periods has led to increases in bacterial and parasitic load, these seasonal variations can be partly influenced by changes in hydrometeorological conditions (Aboulkacem et al., 2007; Hunter and McDonald, 1991), and they can induce an increase in bacterial and parasitic contamination of the watercourses, especially in summer period and therefore constitute a real sanitary risk. Salinity and TDS positively affect the concentrations of total aerobic *Mesophilic* flora (TAMF), *Capillaria sp* and *Enterobius vermicularis* in water and total *Coliforms* in soil, this indicates that organic and inorganic salts are essential for the survival of these species.

Figure 3 PCA of the distribution of biological pollution (bacteriological and parasitological), physicochemical parameters and the number of plant species according to the prospected stations in Oued Lârbaa-Taza-Morocco during the dry period of 2018, (a) correlation between variables (b) correspondence between variables and the studied stations (see online version for colours)



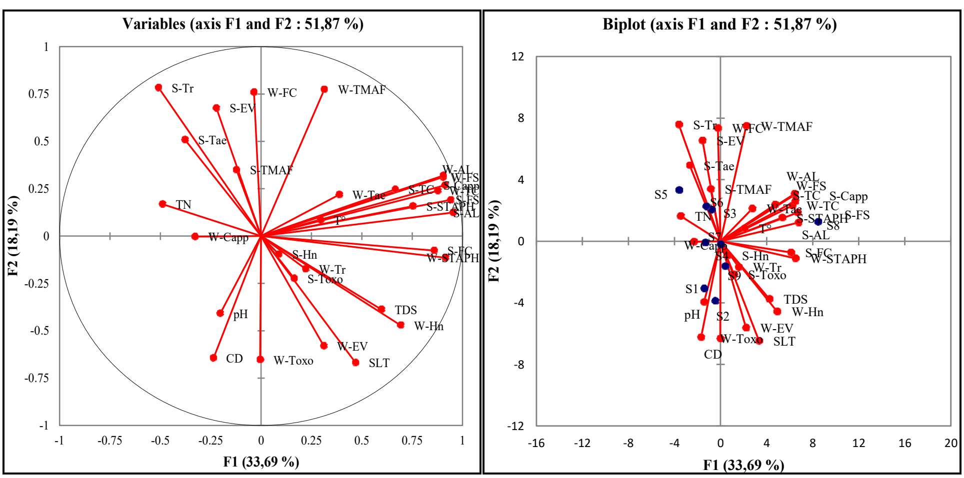
(a) (b)

Notes: S: station; W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

The negative correlations observed during this period concern *Hymenolepis nana*, total *Coliforms* of water and *Trichuris* of soil, *Hymenolepis nana* of soil are negatively correlated with total *Coliforms* of soil, *Enterobius vermicularis* of soil are negatively correlated with faecal *Streptococci* and *Toxocara* of water, TMAF of soil is negatively correlated with *Enterobius vermicularis* of water and soil, *Ascaris lumbricoides* is negatively correlated with *Staphylococci*, *Toxocara* of water and soil are correlated with

Hymenolepis nana of soil which are also negatively correlated with the TDS of water. Another negative correlation was observed for *Hymenolepis nana* in water and soil, conductivity is negatively correlated with faecal bacteria of water (total and faecal *Coliforms* and *Streptococci*), salinity negatively affects the presence of *Enterobius vermicularis* in soil, pH negatively influences the presence of *Hymenolepis nana* and TMAF in Oued Lârbaa water [Figure 2(a)]. The number of plant species encountered in each station is negatively affected by temperature and the presence in the soil of faecal *Streptococci*, faecal *Coliforms* and *Staphylococci* indicative of faecal pollution, these results confirm those obtained in our previous study which was devoted to monitoring the influence of anthropogenic pollution and seasonal changes on the distribution of flora along the Oued Lârbaa-Taza-Morocco. This study allowed us to observe and deduce that the increase in temperature in the dry season and pollution negatively influences the abundance of the taxa in the banks in Oued Lârbaa, being that 44 species were identified during the wet period (2018) and only 27 species during the dry periods (2017 and 2018) (Mherzi et al., 2020a).

Figure 4 PCA of the distribution of biological pollution (bacteriological and parasitological), physicochemical parameters and the number of plant species according to prospected stations in Oued Lârbaa-Taza-Morocco during the wet period of 2018, (a) correlation between variables (b) correspondence between variables and studied stations (see online version for colours)



(a) (b)

Notes: S: station; W-STAPH: *Staphylococci* in water; W-FC: faecal *Coliforms* in water; W-TC: total *Coliforms* in water; W-TMAF: total *Mesophilic* aerobic flora in water; W-FS: faecal *Streptococci* in water; S-STAPH: *Staphylococci* in soil; S-FC: faecal *Coliforms* in soil; S-TC: total *Coliforms* in soil; S-TMAF: total *Mesophilic* aerobic flora in soil; S-FS: faecal *Streptococci* in soil; W-Ev: *Enterobius vermicularis* in water; W-Al: *Ascaris lumbricoides* in water; W-Tr: *Trichuris* in water; W-Capp: *Capillaria sp* in water; W-Toxo: *Toxocara* in water; W-Hn: *Hymenolepis nana* in water; W-Tae: *Taenia* in water; S-Ev: *Enterobius vermicularis* in soil; S-Al: *Ascaris lumbricoides* in soil; S-Tr: *Trichuris* in soil; S-Capp: *Capillaria sp* in soil; S-Toxo: *Toxocara* in soil; S-Hn: *Hymenolepis nana* in soil; S-Tae: *Taenia* in soil; T°: temperature; CD: conductivity; SLT: salinity; TDS: total dissolved substances; pH: water potential; TN: taxa number.

During the dry period of the year 2018, the PCA showed that there is a strong correlation between the microorganisms of faecal origin of water (faecal *Coliforms*, total *Coliforms*, *Streptococci*, *Taenia*, *Ascaris lumbricoides*, *Capillaria sp*, and *Toxocara*) [Figure 3(a)], which means that these species present the same information of the faecal origin of the contamination. The salinity and temperature of water as during the dry season 2017 are correlated with the station S8 close to the landfill and also with the station S4, this allowed us to conclude that the stations S8 and S4 are the most impacted by the pollution of biological nature [Figure 3(b)]. On the other hand, there are also significant correlations between biological parameters of the soil such as between conductivity and *Enterobius vermicularis*, between *Ascaris lumbricoides* and *Hymenolepis nana*, between *Capillaria sp*, *Trichuris*, *Toxocara* and *Staphylococci* represented by stations S3 and S6 [Figure 3(b)]. The number of taxa (TN) is positively correlated with pH, these are represented by vegetation rich stations S1, S2 and S7 as shown in our previous study (Mherzi et al., 2020a). The pH affects the presence of faecal and total *Coliforms*, *Staphylococci*, TMAF and *Streptococci* in water and these latter negatively affect the abundance of vegetation in the stations. A negative correlation was also observed between *Enterobius vermicularis* and *Hymenolepis nana* in the soil, indicating competition between these two parasitic genera.

During the wet period, the observation of the Cartesian diagram confirms the correlation between *Ascaris lumbricoides* in water and soil, faecal *Streptococci* in water and soil, total *Coliforms* in water and soil and *Capillaria sp* and *Staphylococci* in soil, which are all correlated with temperature [Figure 4(a)], indicating a positive influence of the temperature on the survival of these species in water and soil. These correlations are represented by station S8 characterised by a high temperature of 32.2°C and high concentrations of microorganisms with values of 18.57 eggs/l, 56.15 eggs/l, 1.35 10^4 CFU/ml, 8.92 10^6 and 9.3 10^8 CFU/ml for *Enterobius vermicularis*, *Ascaris lumbricoides*, faecal *Coliforms*, *Staphylococci* and TAMF, during the wet period of 2018 (Mherzi et al., 2021). On the other side, we observed that these indicator parameters of faecal pollution are negatively correlated with pH and electrical conductivity [Figure 4(a)], indicating a negative effect of neutral pH on bacterial survival. A negative correlation between *Taenia* of water and soil that are negatively correlated also with salinity, this means that organic and inorganic salts present in water during the wet period have negative influences on the survival of these species. As in the dry season, the number of taxa is negatively affected by the presence in the soil of microorganisms indicative of faecal pollution, which confirms what we obtained in our previous study that an excess of pollution has a negative effect on the abundance and spread of vegetation (Mherzi et al., 2021).

During the three study seasons, station S8, which is the most polluted, is always located far from the other stations. Stations S1, S2, and S9, the least polluted, are opposite to station S8 on both axes and also opposite to stations S3 and S4 on axis 1. The separation of station S8 reveals high concentrations of faecal contamination indicator bacteria and intestinal parasites. This pollution could be explained by the discharge of leachate which is conveyed directly to the Oued Lârbaa at this station (S8) without any prior treatment. Indeed, the previous work of our laboratory on the characterisation of leachate from this landfill, have shown particularly that they are highly polluted, characterised by a very high biological oxygen demand (BOD) (4,220 mg/l) and a high chemical oxygen demand (COD) (5,687, 18 mg/l), suspended matter is in the order of

3,991 mg/l, ammonium nitrogen is 48.43 mg/l, nitrate is 33.04 mg/l, nitrite is in the order of 255.85 mg/l, and the pH is acidic 7.35 (Zalaghi et al., 2014). These leachates also revealed high microbiological pollution with a mean concentration of total *Coliforms* (TC) of 1.12 107 CFU/ml while the mean concentrations of faecal *Coliforms* (FC) and faecal *Streptococci* (FS) are 6.7 10^6 and 5.26 10^4, respectively, and helminth concentrations in the order of 33.51 eggs/l for the non-viable form and 48.77 eggs/l for the viable form (Mherzi et al., 2020b). Therefore, to reduce the risk of pollution of Oued Lârbaa it is recommended to change the location of the uncontrolled landfill of the City of Taza which is located at the ends of this Oued, or its rehabilitation in order to be able to collect and treat the leachate before it is discharged.

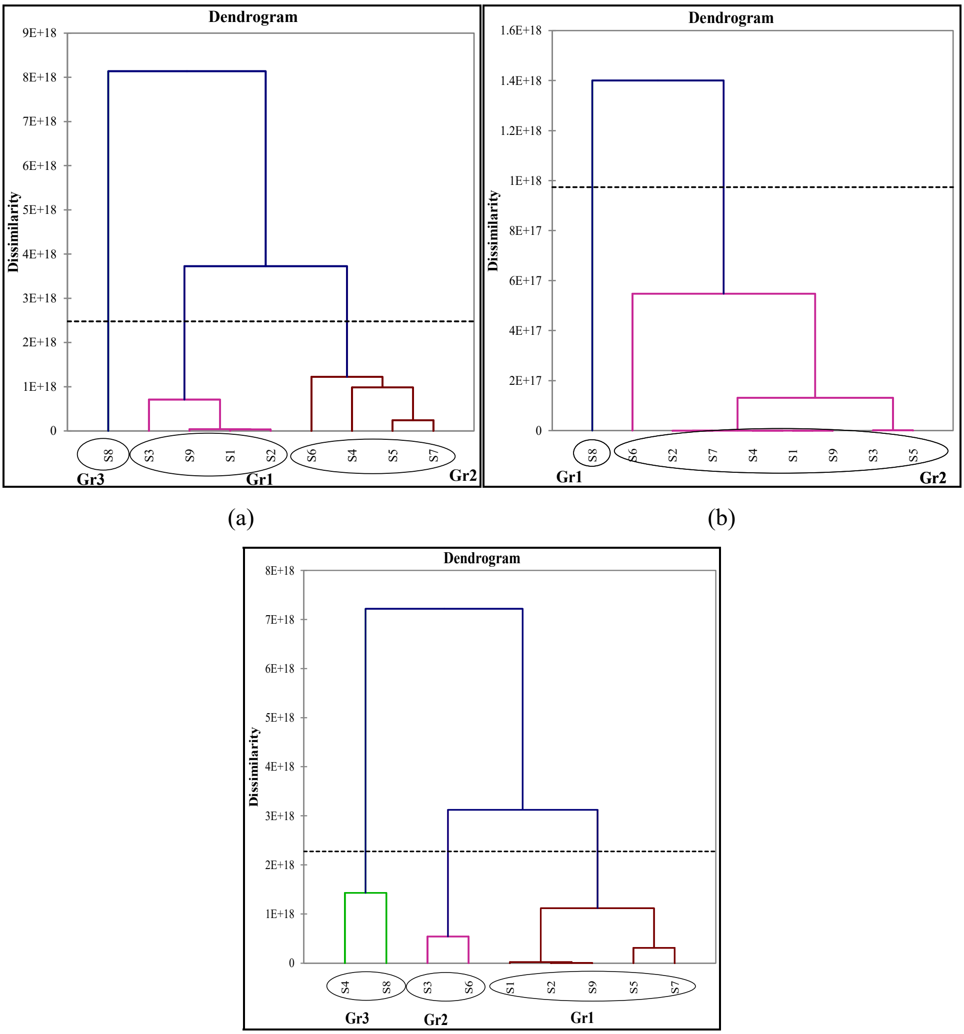
The obtained results are in agreement with those reported by N'diaye et al. (2011), Fouad et al. (2013) and Givord and Dorioz (2010), who also inferred that when pH moves away from neutrality, bacterial survival seems to be negatively affected. Bennani et al. (2012) and Chedad and Assobhei (2007) also showed that salinity is a very important stress factor experienced by faecal pollution bacteria in the salty environment. The negative correlations obtained between biological parameters (bacteria and parasites) are witnesses of a competition between these microorganisms in water and in soil. The station S8 is the most polluted in bacteria and parasites because there is a discharge of leachate from the uncontrolled landfill of the City of Taza, these latter find favourable conditions for their survival. These results show that the studied stations of Oued Lârbaa reveal a very important contamination translated by a great microbial load (bacteriological and parasitological), which are largely higher than the directives of the WHO and the standards fixed by the Brazilian National Council of the Environment (CONAMA Resolutions No. 357/2005 and No. 274/2000). A fall in the number of taxa was also observed, this drop is explained by the negative effect of pollutants from wastewater and leachate from the uncontrolled landfill of the City of Taza-Morocco on the floristic richness. Indeed, we noticed a total disappearance of the vegetation at the level of station 8 located near the uncontrolled landfill of the Taza City (Mherzi et al., 2020a). This pollution also has a detrimental effect on the survival of aquatic fauna, as shown by a study conducted in our Laboratory of Natural Substances, Pharmacology, Environment, Modeling, Health and Quality of Life (SNAMOPEQ) at the Polydisciplinary Faculty of Taza (PFT), University Sidi Mohamed Ben Abdellah (USMBA) of Fez, Morocco (Lakhloufi et al., 2021). Indeed, this study indicated that the stations that record high rates of pollution (wastewater discharges or leachate) have a low faunal biodiversity represented mainly by macroinvertebrates that colonise waters of critical quality (Diptera).

3.2 Stations typology by HAC

The typology of surveyed stations in our study is based on the expression of the ascending distribution (HAC) to physico-chemical, bacteriological, parasitological, floristic parameters and to all surveyed stations of Oued Lârbaa. Analysing the different groups of parameters, this method allows classifying the nine sampling stations into groups with a similar water and soil pollution profile.

Figure 5 shows the dendrograms resulting from the application of the hierarchical classification.

Figure 5 Dendrograms of the hierarchical clustering showing the grouping of the surveyed stations according to the sampling season, (a) during the dry period of 2017 (b) during the wet period of 2018 (c) during the dry period of 2018 (see online version for colours)



(a) (b)

(c)

Notes: S: station; Gr: group.

The HAC revealed the existence of three groups of stations during the dry period of the year 2017 [Figure 5(a)], a group (Gr1) that gathers the least polluted stations S1, S2, S3, and S9, a second group (Gr2) contains the stations that record high pollutions S4, S5, S6 and S7, this stretch presents many wastewater discharges, mainly domestic as mentioned previously in our previous study (Mherzi et al., 2021) as the most critical stretch. Finally the station close to the landfill where large amounts of leachate runoff isolates in a single group (Gr3), we can infer at this station, a greater influence of contamination from point sources, mainly associated with leachate discharges from the uncontrolled landfill of the City of Taza. These results are similar to those obtained by Alves et al. (2018) revealing the isolation of the station most polluted by effluent discharges into the Pardo-Brazil River. These clusters indicate that stations of the same group gather common characters such as the nature of pollution and the abundance of the same type of biological pollutants.

During the dry period of the year 2018, the HAC shows that the arrangement of the stations of Oued Lârbaa also revealed the existence of three groups of stations [Figure 5(c)], a group 1 that contains the stations S1, S2, S5, S7 and S9 (Gr1), the second group brings together stations S3 and S6 (Gr2) which are heavily polluted by wastewater and finally a group 3 (Gr3) which brings together the stations most threatened according to the PCA [Figure 5(c)] stations S4 and S8. This discrimination of the groups of stations is related more to the irregular regime, the nature of pollution and the composition of wastewater discharged in these stations.

During the wet period of 2018, the HAC [Figure 5(b)] shows the existence of two groups, one group (Gr1) containing station S8 by itself and the others are in another single group (Gr2). These results show the different character of the impact of the landfill leachate discharged in station S8 compared to the wastewater discharged in the other stations. The cluster of this study showed the obvious seasonal influence on the disappearance of the polluting effect of wastewater during the winter season, since the stations recording high pollution during the dry season (S4, S5, S6 and S7) and are kept in a single group with the stations recording less pollution during the dry season (S1, S2, S3, and S9). This effect would be related to the rains that took place during this season.

4 Conclusions

Environmental control and monitoring studies produce large amounts of data that are often not easy to interpret. In this context, the use of different multivariate statistical techniques (PCA, classification methods) for the interpretation of data seems to be an interesting solution for a better understanding of the quality of water, soil and ecological states of the studied environments. They are therefore better tools for water resource management and can provide quick solutions to pollution problems. In this study, to evaluate the quality of water and soil and thereby the floristic state of Oued Lârbaa-Taza, Morocco, an application of multivariate statistical techniques (PCA and HAC) on nine individuals (Oued Lârbaa stations) and 30 variables (botanical and floristic inventory, physicochemical parameters, bacterial and parasitic concentrations in water and Oued Lârbaa soil) showed:

1. The existence of competition between the studied bacteria and parasites, given the negative correlations observed between them.
2. Acidity and salinity negatively affect the load of bacteria indicative of faecal pollution.
3. Temperature and the presence of faecal pollution indicator bacteria in the soil are stress factors for the vegetation of Oued Lârbaa.

According to HAC, the stations of the same type of discharge gather in the same group, the station close to the landfill S8 during the two dry periods (2017–2018) is alone in the group1 denoting the specific pollutant character of the leachates of the uncontrolled landfill of the City of Taza, Morocco.

Experimental and statistical studies by multidimensional analysis have shown the current anthropic pressure on the Oued Lârbaa, a main watercourse of the Taza City, Morocco, particularly by wastewater discharges, solid waste and leachates from the uncontrolled landfill of the city. For this reason and in the face of this situation, it is essential that water resources are used wisely and that the conditions for their protection are optimal. It is also important to identify the risks of pollution in order to avoid or reduce their harmful effects. Therefore, it is mandatory to develop an action plan for the reduction and elimination of adverse impacts of water and soil pollution in order to maintain the quality of aquatic ecosystems that remain an important source for irrigation and livestock watering in the region of Taza. To achieve this, it is advisable to change the location of the uncontrolled landfill and create sewerage systems and wastewater treatment plants in the city.

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Supplementary material (see online version for colours)