Principal Component Analysis of Physicochemical and Microbiological Pollutants in Hospital Wastewater: A Diurnal and Seasonal Dynamics Case Study

Ayoub Ait Bella1*, El Habib El Azzouzi[1], Hayat Lafrikh[2]

[1] Geo-biodiversity and Natural Heritage Laboratory, Department of Zoology and Animal Ecology, University Mohammed V in Rabat, Scientific Institute, Av. Ibn Battota, BP.703, Rabat-Agdal, Morocco
[2] Mohammed VI University Hospital in Marrakech, Hospital Hygiene Office, BP2360 Principal, Av. Ibn Sina, Marrakesh, Morocco
* Corresponding author's email: ayoub_aitbella3@um5.ac.ma

Abstract

Hospital wastewater (HWW) is of particular public and environmental health concern because it represents a complex and toxic effluent. The objective of this study was to perform an exhaustive physicochemical and microbiological study of raw effluent of Mohammed VI University Hospital, Marrakech, Morocco, in order to determine the major pollution gradients and for the design of an optimum treatment process. Grab samples were taken four times a day from October 2022 to January 2023 and analyzed for a number of parameters such as BOD_5, COD, TSS, nutrients, and the important bacterial indicators. Principal Component Analysis (PCA) was used to study the complicated dataset. The research revealed that organic (mean BOD_5: 523 mg/L), mineral (mean TSS: 1120 mg/L; EC: 2094 µS/cm), and microbiological contaminants far surpassed national discharge constraint. PCA captured 95.83% of variance extremely well with a major axis (F1) dominated by seasonal temperature and a secondary axis (F2) of extremely strong global pollution gradient. This survey revealed a distinct diurnal trend, with the load of pollution reaching a maximum at 11:00 and 16:00. On the basis of peak Total Suspended Solids (TSS) and microbial loads, this paper concludes by suggesting that the most appropriate on-site treatment technology is a Membrane Bioreactor (MBR) system. High-resolution temporal data form a critical basis for the design and optimization of such a system, and form an unambiguous route to environmental and public health risk reduction.

Keywords: hospital wastewater, physicochemical characterization, microbiological contamination, principal component analysis, temporal dynamics, membrane bioreactor.

INTRODUCTION

Hospital wastewater (HWW) is worldwide known to be a complicated and severe environmental issue because of its complex and risky composition. In contrast to municipal wastewater, HWW possesses a complex spectrum of contaminants with high percentages of organic matter, chemical disinfectants, detergents, and most importantly, a large spectrum of pharmaceuticals and their metabolites (Verlicchi et al., 2012). These contaminants, referred to as emerging contaminants of concern (CECs), are a concern for aquatic life and human health upon discharge in an untreated manner (Kümmerer, 2009).

Of more concern, though, is the microbiological constitution of HWW. Hospitals are breeding grounds for pathogenic microbes and are known to be focal hotspots for the evolution and spread of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) (Rizzo et al., 2013). Their overuse exerts a severe selective pressure that selects for the survival of resistant bacteria, which they are released to sewer systems in urban areas and propel the global public health crisis of antimicrobial resistance (WHO, 2021).

In most developing countries, such as Morocco, HWW is usually discharged into urban sewerage systems with little or no pre-treatment. This imposes a significant burden on municipal WWTPs, which are not usually designed for the unique and concentrated wastes contained in HWW (Chabuk et al., 2017). In addition, the quantity and quality of HWW are highly variable over time, responding to daily hospital work (e.g., interventions, care for patients, cleaning) and seasonal fluctuation (Pauwels & Verstraete, 2006). Such native variability makes it difficult to build and operate efficient treatment systems.

While the general characteristics of HWW are known, the bulk of current research offers only a snapshot in time for contamination, which restricts the progress of responsive and effective treatment systems. The recent study has shown how recent advances like IoT sensor networks and predictive deep learning frameworks have the potential for real-time monitoring and control of wastewater. For example, wastewater recycling research has documented how sensor-based integrated systems were able to efficiently convert contaminated water bodies into (Maruthai et al., 2025), and others employed machine learning to promote environmental quality within farm environments (Selvanarayanan et al., 2024). These advanced approaches, in addition to more advanced classification models (Venkatraman et al., 2025), rely on the creation of baseline pollutant dynamics. The most critical deficiency is in the description of high-resolution diurnal and seasonal HWW fluctuations in a range of geographical conditions, as required in engineering solutions to treat. Although it is known that the general trend of HWW, the bulk of current research offers only a snapshot in time for contamination, which restricts the progress of responsive and effective treatment systems. The recent study has shown how recent advances like IoT sensor networks and predictive deep learning frameworks have the potential for real-time monitoring and control of wastewater. For example, wastewater recycling research has documented how sensor-based integrated systems were able to efficiently convert contaminated water bodies into (Maruthai et al., 2025), and others employed machine learning to promote environmental quality within farm environments (Selvanarayanan et al., 2024). These advanced approaches, in addition to more advanced classification models (Venkatraman et al., 2025), rely on the creation of baseline pollutant dynamics. The most critical deficiency is in the description of high-resolution diurnal and seasonal HWW fluctuations in a range of geographical conditions, as required in engineering solutions to treat.

Although the broad outline of HWW is understood, elucidation of its temporal dynamics and correlations of its varied set of pollutants is required to formulate suitable management schemes. For unscrambling complicated patterns in high-resolution environmental data, multivariate statistical approaches like Principal Component Analysis (PCA) have emerged as dynamic tools. PCA minimizes data dimensionality, uncovering hidden relationships and structures between many variables that do not appear obvious otherwise (Helena et al., 2000; Singh et al., 2004).

The novelty of this study lies in its use of PCA to analyze a high-resolution, temporal dataset (diurnal and seasonal) to elucidate the pollution dynamics from a major North African university hospital. Thus, the current study was conducted to give a detailed physicochemical and microbiological analysis of the raw wastewater released by the Mohammed VI University Hospital Center in Marrakech, which is a top-rated health care center in Morocco. Our particular goals were: to track a broad set of indicators of pollution over four months, to use PCA to identify the major gradients of pollution and pollutant associations, and to describe temporal profiles of effluent quality, for example, diurnal and seasonal. The purpose of this research is to present site-specific critical data required for the implementation of appropriate and effective on-site wastewater management solutions.

MATERIALS AND METHODS

Study Site

Sampling took place at the Mohammed VI University Hospital Center, Marrakech, one of Morocco's largest and most complete. The samples were drawn from the hospital's principal effluent collector, to which raw wastewater coming from all hospital buildings is fed before being released into the municipal sewerage system. (Fig. 1).

Figure 1. Main effluent collector at the Mohammed VI University Hospital Center in Marrakech. (Photo by Ayoub AIT BELLA, 2022)

Sampling Campaign

The sampling process was conducted between 2022 October and 2023 January. There were sixteen individual physical sampling events to account for temporal variability. A selective sampling strategy was adopted. Grab samples were taken four times during the day at selected hours with varying activity levels: 07:00 (low), 11:00 (high morning), 16:00 (high afternoon), and 20:00 (dying).

Sample Collection, Preservation, and Transportation

The physicochemical samples were sampled in 1-liter HDPE bottles. For microbiological examination, sterile glass containers of 250 mL were employed, following aseptic practices. Samples were received directly in an electric cooler and sent to the laboratory under a controlled temperature of 4°C for immediate examination. Examination was carried out in National Center for Water and Energy Studies and Research (CNEREE) Marrakech. In order to preserve sample integrity, analyses were started within two hours for physicochemical parameters and within one hour for microbiological parameters.

Physicochemical and Microbiological Analysis

Measurements of electrical conductivity (EC), water temperature (T water), air temperature (T air), and pH were carried out in-situ at the sampling site directly with portable, calibrated meters. The rest of the laboratory analysis was done in accordance with internationally accepted standard procedures as outlined in Table 1 (physicochemical parameters) and Table 2 (microbiological parameters). Bacterial counting was done using membrane filtration technique to standards.

Table 1. Analytical Methods for Physicochemical Parameters

Parameter	Abbreviation	Analytical Method	Standard Reference
Biochemical Oxygen Demand (5-day)	BOD_5	Respirometric technique (OxiTop system) with manometric analysis following incubation at 20°C for 5 days.	(ISO, 2003)
Chemical Oxygen	COD	Potassium dichromate ($K_2Cr_2O_7$) in an acid medium - open reflux	(ISO, 1989)

Demand		followed by titration with Mohr's salt.	
Total Suspended Solids	TSS	Gravimetric technique: filtration through 0.45 μm glass fiber filter and drying at 105°C to constant weight.	(ISO, 1997)
Nitrates	NO_3^-	Spectrophotometry at 324 nm following reaction with 2,6-dimethylphenol in acid medium.	(ISO, 1986)
Nitrites	NO_2^-	Spectrophotometry at 540 nm following colorimetric reaction with sulfanilamide and N-(1-naphthyl) ethylenediamine.	(ISO, 1984)
Total Phosphorus	P-Total	Persulfate digestion to oxidize all phosphorus compounds to orthophosphates and subsequently followed by spectrophotometric molybdenum blue method at 880 nm.	(ISO, 2004)
Sulfates	SO_4^{2-}	Turbidimetric method utilizing barium sulfate precipitation and measurement of turbidity at 420 nm.	(ISO, 2007)

Table 2. Culture Media and Incubation Conditions for Bacterial Indicators

Bacterial Indicator	Abbreviation	Culture Medium	Incubation Conditions	Standard Reference
Total Coliforms	TC	Triphenyltetrazolium Chloride Tergitol 7 Agar	36 ± 2°C for 24-48 h	(ISO, 2014)
Fecal Coliforms	FC	Triphenyltetrazolium Chloride Tergitol 7 Agar	44 ± 0.5°C for 24-48 h	(ISO, 2014)
Fecal Streptococci	FS	Slanetz and Bartley Agar	37 ± 1°C for 40-48 h	(ISO, 2000)
Staphylococcus spp.	SA	Baird-Parker Agar with Rabbit Plasma Fibrinogen supplement	37 ± 1°C for 24-48 h	(ISO, 2021)

Instrumentation and Software

In-situ values (T water, pH, EC) were determined with a Hanna Instruments HI98194 portable multi-parameter meter calibrated prior to measurement. Spectrophotometric readings were taken in a Hach DR3900 spectrophotometer. Pearson correlation matrix and Principal Component Analysis (PCA) statistical tests were also conducted using SPSS Statistics v26.

RESULTS AND DISCUSSION

General Effluent Characteristics and Primary Data

The base dataset used in this research includes physicochemical and microbiological parameters from 16 individual sampling events. In the interest of maximum transparency and replicability, the full empirically gathered raw data are included below in Table 3 (physicochemical parameters) and Table 4 (microbiological parameters). This dataset is the source of all further statistical analyses.

Table 3. Raw Physicochemical Data for all 16 Sampling Events.

Code	Campaign (Month - Hour)	T air (°C)	T water (°C)	pH	EC (µS/cm)	BOD_5 (mg/L)	COD (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	P-total (mg P/L)	SO_4^{2-} (mg/L)	TSS (mg/L)
1	Oct 2022 - 7h	22.5	24.0	7.20	1900	460	690	6.8	0.5	5.20	380	500
2	Oct 2022 - 11h	26.6	25.6	7.70	2450	580	850	8.5	0.9	7.00	550	1100
3	Oct 2022 - 16h	26.0	25.0	7.90	2750	650	900	9.3	1.0	7.80	650	1500
4	Oct 2022 - 20h	23.0	24.2	7.50	2100	500	750	7.5	0.6	6.00	450	700
5	Nov 2022 - 7h	21.0	22.5	7.00	1700	420	640	6.2	0.4	4.70	320	400
6	Nov 2022 - 11h	24.0	23.8	7.60	2300	550	810	8.0	0.8	6.80	500	900
7	Nov 2022 - 16h	23.5	23.5	7.80	2500	692	925	9.0	1.2	8.13	770	3353
8	Nov 2022 - 20h	21.5	22.8	7.40	1950	470	710	7.2	0.5	5.70	400	600
9	Dec 2022 - 7h	19.6	20.5	6.90	1314	390	600	5.6	0.3	3.88	260	124
10	Dec 2022 - 11h	22.0	22.0	7.40	2000	510	760	7.3	0.6	6.10	430	750
11	Dec 2022 - 16h	22.8	22.5	7.70	2200	560	830	8.2	0.9	7.20	580	1300
12	Dec 2022 - 20h	20.0	21.0	7.30	1800	440	670	6.5	0.4	5.00	350	450
13	Jan 2023 - 7h	20.0	19.5	7.10	1500	400	620	5.8	0.3	4.30	290	250
14	Jan 2023 - 11h	21.5	21.2	7.50	2150	530	790	7.8	0.7	6.50	480	850
15	Jan 2023 - 16h	22.0	21.8	8.42	2600	670	910	9.1	1.1	8.00	720	2800
16	Jan 2023 - 20h	19.8	20.0	7.60	2050	490	730	7.0	0.5	5.80	410	550

Table 4. Raw Microbiological Data for all 16 Sampling Events.

Code	Campaign (Month - Hour)	Total Coliforms (TC) (×10^6 UFC/100ml)	Fecal Coliforms (FC) (×10^6 UFC/100ml)	Fecal Streptococci (FS) (×10^6 UFC/100ml)	Staphylococcus (×10^6 UFC/100ml)
1	Oct 2022 - 7h	7.0	4.5	1.5	1.8
2	Oct 2022 - 11h	10.0	8.0	2.5	3.0
3	Oct 2022 - 16h	12.0	9.5	3.0	4.0
4	Oct 2022 - 20h	8.0	6.0	2.0	2.0
5	Nov 2022 - 7h	6.5	3.5	1.2	1.5
6	Nov 2022 - 11h	11.0	8.5	2.8	3.5
7	Nov 2022 - 16h	15.0	12.0	4.0	5.0
8	Nov 2022 - 20h	9.0	7.0	2.2	2.5
9	Dec 2022 - 7h	6.0	3.0	1.0	1.0
10	Dec 2022 - 11h	9.5	7.5	2.3	2.8
11	Dec 2022 - 16h	13.0	10.5	3.5	4.5
12	Dec 2022 - 20h	7.5	5.0	1.8	1.8
13	Jan 2023 - 7h	6.2	3.2	1.1	1.2
14	Jan 2023 - 11h	10.5	8.2	2.6	3.2
15	Jan 2023 - 16h	14.0	11.5	3.8	4.8
16	Jan 2023 - 20h	8.5	6.5	2.1	2.2

From the initial data set, descriptive statistics were computed to provide an overview of the overall pollution profile, which is evident in Table 5. Raw wastewater from Mohammed VI University Hospital contained very high levels of contamination in all sectors. The mean BOD_5 (523 mg/L), COD (771 mg/L), and TSS (1120 mg/L) concentrations are significantly higher than the discharge limits to Moroccan surface waters specified by the country standard NM 03.8.200 (Ministry of Equipment, Transport, Logistics, and Water, 2018) (40 mg/L for BOD_5, 120 mg/L for COD, and 30 mg/L for TSS). The microbiological pollution was also high, with mean concentrations for Fecal Coliforms of 7.59×10^6 CFU/100 mL, several orders of magnitude higher than the Moroccan national quality requirement of 2,000 CFU/100 mL for surface water (Moroccan Institute for Standardization, 2006). The occurrence at high concentrations (mean 2.74×10^6 CFU/100 mL) of Staphylococcus is a direct consequence of clinical waste pollution and an enormous health risk.

Table 5. Descriptive Statistics of Physicochemical and Microbiological Parameters (n=16).

Parameter	Unit	Mean	Std. Dev.	Min	Max
T air	°C	22.5	2.2	19.6	26.6
T water	°C	22.9	1.8	19.5	25.6
pH	-	7.51	0.41	6.90	8.42
EC	μS/cm	2094	388	1314	2750
BOD_5	mg/L	523	97	390	692
COD	mg/L	771	109	600	925
TSS	mg/L	1120	988	124	3353
NO_3^-	mg/L	7.61	1.12	5.60	9.30
NO_2^-	mg/L	0.69	0.32	0.30	1.20
P-Total	mg P/L	6.22	1.30	3.88	8.13
SO_4^{2-}	mg/L	477	160	260	770
Total Coliforms	10^6 CFU/100mL	9.64	2.96	6.00	15.00
Fecal Coliforms	10^6 CFU/100mL	7.59	3.04	3.00	12.00
Fecal Streptococci	10^6 CFU/100mL	2.33	0.99	1.00	4.00
Staphylococcus	10^6 CFU/100mL	2.74	1.31	1.00	5.00

Integrated Principal Component Analysis (PCA)

A To gain an aggregate image, PCA was run on the entire dataset of 15 physicochemical and microbiological parameters altogether. The aggregate strategy proved very effective, with the first two principal components (F1 and F2) explaining a massive 95.83% of the accumulated variance (F1: 86.33%; F2: 9.50%), as indicated in the scree plot (Fig. 2). This strong explanatory power suggests that effluent quality is controlled by some important, inter-interrelating factors.

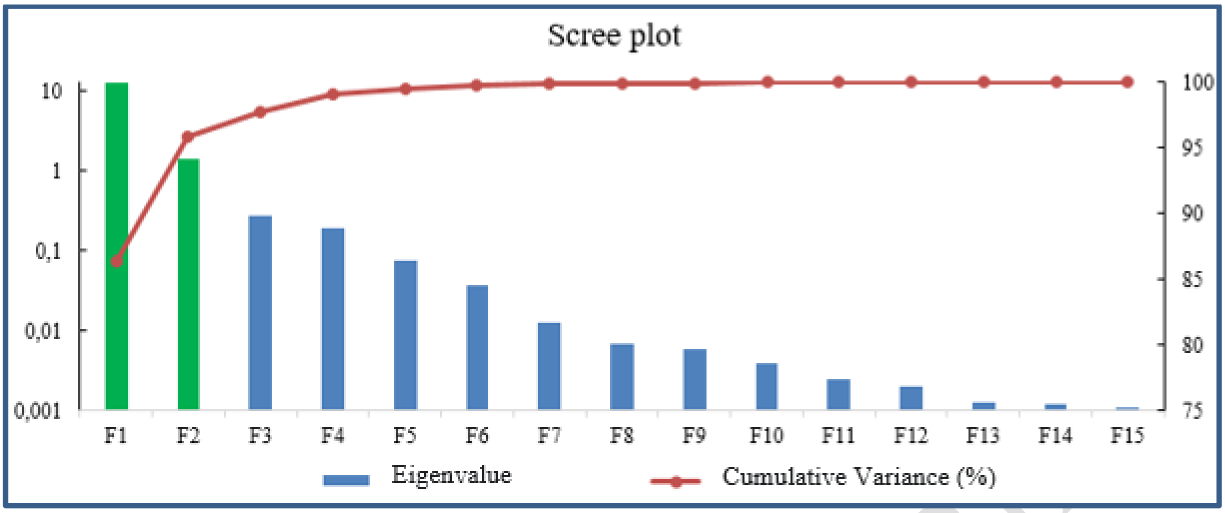

Figure 2. Scree plot of eigenvalues from the global PCA of all physicochemical and microbiological parameters.

In order to statistically confirm the meaning of these axes, factor loadings for all the variables are given in Table 6. The axes structure is explained as follows:

• F1 (86.33% of variance): A seasonal/thermal gradient. It can be seen from the correlation circle (Fig. 3), confirmed by the high positive loadings in Table 6 that F1 is highly, and positively correlated with water temperature and air temperature. All physicochemical and microbial indicators of pollution, however, have strong negative loadings on F1. This is easily seen as increased F1 scores with warmer temperatures and reduced overall pollution, a trend that is repeated over the autumnal months (samples 1-8).

• F2 (9.50% variance): This factor is an obvious world pollution gradient. It is most strongly and positively correlated with all organic, mineral, and microbial pollution indicators (BOD_5, COD, TSS, nutrients, and all bacterial counts), and this is clearly confirmed by the high positive loadings for these variables in Table 6. Thus, a high value of F2 axis, which is found for samples collected at 11:00 and 16:00, defines an interval of higher contamination on all parameters.

Table 6. Factor Loadings of Physicochemical and Microbiological Parameters on the First Two Principal Components.

Variable	F1 Loading	F2 Loading
T air	0,913	0,124
T water	0,872	0,188
pH	-0,526	0,611
EC	-0,781	0,835
BOD_5	-0,688	0,901
COD	-0,733	0,921
Nitrates	-0,772	0,915
Nitrites	-0,717	0,899
P-Total	-0,707	0,943
Sulfates	-0,651	0,93
TSS	-0,433	0,961
Total Coliforms (TC)	-0,54	0,952
Fecal Coliforms (FC)	-0,566	0,97
Fecal Streptococci (FS)	-0,534	0,968
Staphylococcus (SA)	-0,568	0,972

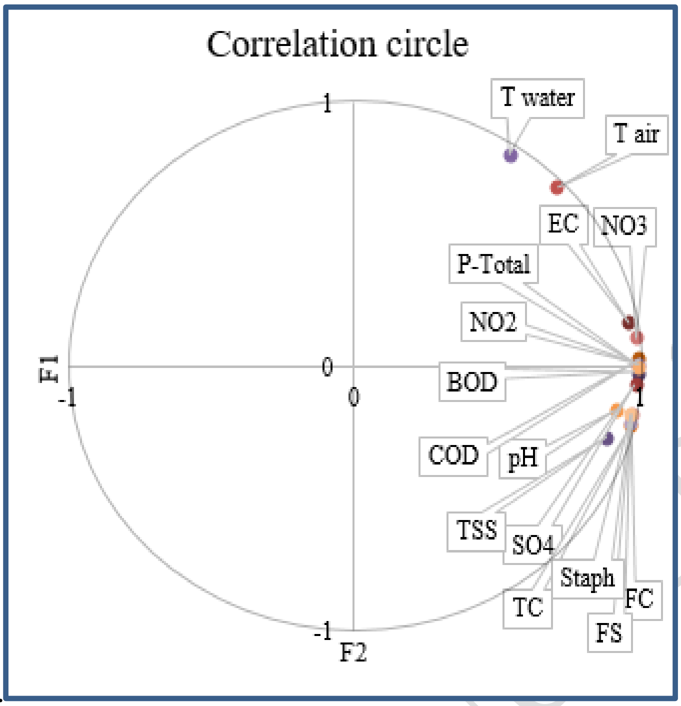

Figure 3. Correlation circle from the global PCA, showing the projection of all variables onto the F1 × F2 factorial plane.

The 16 sampling events plotted on this combined F1-F2 plane (Fig. 4) give the widest description of the effluent dynamics. The samples are uniquely separated by season (along the F1 thermal axis) and time of day (along the F2 pollution axis).

- These samples from the two peak activity times (11:00 and 16:00) all group in the top half of the plot, showing high positive scores on the F2 pollution axis.
- Low activity hours samples (07:00 and 20:00) concentrate in the lower half, as these represent low or negative scores on the F2 pollution axis.
- Their location on the F1 horizontal axis is determined by season: the warm months (October, November; samples 1-8) are to the right (positive F1), and the cold months (December, January; samples 9-16) are to the left (negative F1).

This unique pattern shows a cyclical pattern of diurnal pollution dominated by seasonal factors. High clustering of almost all the pollution variables indicate that they originate from a single source, i.e., the principal activities of patient care, diagnostic services, and sanitation of the hospital.

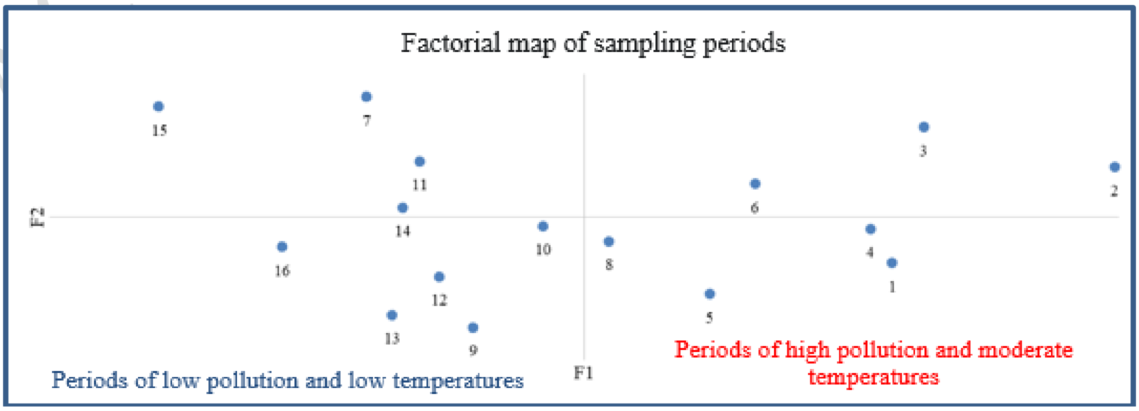

Figure 4. Factorial map showing the projection of the 16 sampling periods onto the F1 × F2 plane from the global PCA.

Environmental and Public Health Implications

The concentrations of the pollutants analyzed at the Mohammed VI University Hospital are huge even when compared with other literature from across the world, thereby making the effluent a significant source of pollution. For example, the average COD concentration of 771 mg/L and BOD_5 concentration of 523 mg/L, although in the extremely huge ranges reported across the world, are exceedingly greater than recorded in most European hospitals. In their systematic review, Verlicchi et al. (2012) cited COD concentrations of raw hospital wastewater ranging from 230 to more than 16,000 mg/L, putting our results in the higher side of the spectrum. In addition, the average TSS concentration of 1120 mg/L is highly undesirable, and this is a serious concern for traditional treatment plants. The elevated microbiological loads exactly align with Rizzo et al. (2013) concerns that urban wastewater treatment systems can act as reservoirs of antibiotic-resistant bacteria (ARB), an international public health problem highlighted by the WHO (2021). Such comparative view validates the evidence that the effluent in question should be treated with advanced, sophisticated on-site treatment in an attempt to reduce its apparent environmental and public health threat.

The high, positive values of virtually all microbial and chemical contaminants (Table 7) ensure that their existence is synergistic. Particle-rich and nutrient-rich effluent creates the perfect environment for bacterial development, as noted by Berto et al. (2009) as well. This implies that any period of high-chemical-contamination is at the same time a period of high-microbiological-risk.

The huge burdens of fecal marker loads and, in particular, Staphylococcus pose a direct and significant public health risk. The effluent poses a vehicle potential for pathogenic and antibiotic-resistant bacteria which have been discovered as being preferred in hospitals (Kümmerer, 2009). Such un-treatment effluent discharged to the municipal sewer system imposes a tremendous amount of stress on downstream WWTP (not designed to treat such targeted pollutants) and poses a critical threat to receiving water bodies. In addition, the high nutrient load (P-Total) poses a definite threat of eutrophication.

Table 7. Pearson Correlation Matrix between all Physicochemical and Microbiological Parameters (n=16).

Variables	T air	T water	pH	EC	BOD_5	COD	Nitrates	Nitrites	P-Total	Sulfates	TSS	TC	FC	FS	Staph.
T air	1														
T water	0.913**	1													
pH	0.526*	0.341	1												
EC	0.781**	0.630**	0.907**	1											
BOD_5	0.688**	0.515*	0.909**	0.949**	1										
COD	0.733**	0.550*	0.912**	0.967**	0.989**	1									
Nitrates	0.772**	0.611*	0.910**	0.983**	0.976**	0.991**	1								
Nitrites	0.717**	0.550*	0.879**	0.926**	0.987**	0.984**	0.968**	1							
P-Total	0.707**	0.535*	0.917**	0.966**	0.981**	0.996**	0.989**	0.977**	1						
Sulfates	0.651**	0.492	0.903**	0.923**	0.992**	0.979**	0.962**	0.990**	0.976**	1					
TSS	0.433	0.311	0.804**	0.755**	0.909**	0.855**	0.814**	0.905**	0.849**	0.936**	1				
TC	0.540*	0.356	0.870**	0.857**	0.947**	0.945**	0.917**	0.958**	0.956**	0.963**	0.902**	1			
FC	0.566*	0.387	0.895**	0.886**	0.947**	0.958**	0.937**	0.951**	0.971**	0.956**	0.867**	0.991**	1		
FS	0.534*	0.364	0.891**	0.869**	0.940**	0.946**	0.922**	0.948**	0.961**	0.958**	0.885**	0.994**	0.996**	1	
Staph.	0.568*	0.388	0.872**	0.870**	0.944**	0.947**	0.926**	0.958**	0.961**	0.958**	0.880**	0.996**	0.989**	0.990**	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Implications for Treatment Strategy

The heavy and highly variable pollution profile established in this research requires a site-specific, high-tech wastewater treatment plant that must satisfy the stringent needs of the effluent. Given the particular problems engendered by the effluent (i.e., highly elevated Total Suspended Solids (TSS) and microbiological contaminations, heavy organic loading, and presumably scarce space at the hospital site) a Membrane Bioreactor (MBR) system is found to be most appropriate technology.

MBR technology combines a biodegradation process with micro- or ultra-filtration and offers a complete physical barrier to suspended solids and microorganisms. MBR tackles the two most important quality problems in the effluent directly. In addition, in order to maintain a high concentration of biomass in the reactor ensures strong and effective removal of the high organic loads (BOD_5 and COD) in this research. One of the advantages of an MBR system is its relatively reduced physical space requirement relative to conventional activated sludge processes, and therefore it is particularly suited to integration into existing urbanized hospital complexes (Metcalf & Eddy, 2014). The high-quality, disinfected effluent from an MBR is also acceptable for non-potable reuse (e.g., irrigating landscaped areas), which gives additional justification for broader water resource management and sustainability objectives within hospitals (WHO, 2017). Installation of an MBR system would not only make hospital discharge nationally compliant, but also dramatically decrease the public health risk from the discharge of pathogens.

CONCLUSIONS

The present study provides a conclusive report of the untreated effluent discharged by Mohammed VI University Hospital Center, depicting a critical and sophisticated pattern of pollution. The effluent is seriously overloaded with exceptionally high concentrations of organic matter, suspended solids, and nutrients, with an extremely extensive scale of microbiological contamination, consisting of fecal indicator bacteria and Staphylococcus. The Principal Component Analysis recovered quite well a pattern of daily predictable pollution directly controlled by the maximum working hours of the hospital, modulated by a secondary thermal/seasonal gradient.

Therefore, these results affirm that the release of this raw effluent is not viable and poses a serious risk to public and environmental health. It is not only advisable but also required to be equipped with a firm on-site treatment facility. With the particular issues in question (substantial TSS, extreme microbiology loads, and high organics content), an MBR system is recommended as the best technology. Its ability to offer a complete barrier to suspended solids and pathogens, combined with its small footprint and effectiveness at degrading organic matter, directly speaks to solving the most important problems. This study offers the necessary, time-resolved data required to effectively design and operate such a system and offers an open door for the hospital to be in compliance with the environment and meet its obligation of safeguarding public health.

Acknowledgements

The authors appreciate all the participants in this research. A.B. Ayoub is appreciated for his involvement in sampling and analyzing the wastewater and preparing the manuscript. E. El Azzouzi is also appreciated for his help in interpreting the findings and preparing the manuscript. The authors also appreciate their sincere gratitude to L. Mandi, National Center for Research and Study on Water and Energy (CNEREE) Director, for the provision of access to laboratory equipment required for analysis.

REFERENCES

1. Berto, J., Rochenbach, G. C., Barreiros, M., Corrêa, A. X., Peluso-Silva, S., & Radetski, C. M. (2009). Physico-chemical, microbiological and ecotoxicological evaluation of a

septic tank/Fenton reaction combination for the treatment of hospital wastewaters. Ecotoxicology and Environmental Safety, 72(4), 1076–1081. https://doi.org/10.1016/j.ecoenv.2008.12.002
2. Chabuk, A., Al-Musawi, S., Al-Khafaji, R., & Al-Khuzaie, F. (2017). The environmental and health risks of untreated hospital wastewater: A case study in Iraq. Reviews on Environmental Health, 32(3), 269–277. https://doi.org/10.1515/reveh-2016-0062
3. Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J. M., & Fernandez, L. (2000). Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. Water Research, 34(3), 807–816. https://doi.org/10.1016/S0043-1354(99)00226-0
4. International Organization for Standardization. (1984). Water quality — Determination of nitrite — Molecular absorption spectrometric method (ISO 6777:1984).
5. International Organization for Standardization. (1986). Water quality — Determination of nitrate — Part 1: 2,6-Dimethylphenol spectrometric method (ISO 7890-1:1986).
6. International Organization for Standardization. (1989). Water quality — Determination of the chemical oxygen demand (ISO 6060:1989).
7. International Organization for Standardization. (1997). Water quality — Determination of suspended solids by filtration through glass-fibre filters (ISO 11923:1997).
8. International Organization for Standardization. (2000). Water quality — Enumeration of intestinal enterococci — Part 2: Membrane filtration method (ISO 7899-2:2000).
9. International Organization for Standardization. (2003). Water quality — Determination of biochemical oxygen demand after n days (BODn) — Part 2: Method for undiluted samples (respirometric method) (ISO 5815-2:2003).
10. International Organization for Standardization. (2004). Water quality — Determination of phosphorus — Ammonium molybdate spectrometric method (ISO 6878:2004).
11. International Organization for Standardization. (2007). Water quality — Determination of dissolved anions by liquid chromatography of ions — Part 1: Determination of bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulfate (ISO 10304-1:2007).
12. International Organization for Standardization. (2014). Water quality — Enumeration of Escherichia coli and coliform bacteria — Part 1: Membrane filtration method for waters with low bacterial background flora (ISO 9308-1:2014).
13. International Organization for Standardization. (2021). Microbiology of the food chain — Horizontal method for the enumeration of coagulase-positive staphylococci (Staphylococcus aureus and other species) — Part 1: Method using Baird-Parker agar medium (ISO 6888-1:2021).
14. Kümmerer, K. (Ed.). (2009). Pharmaceuticals in the environment: Sources, fate, effects and risks (3rd ed.). Springer. https://doi.org/10.1007/978-3-540-74664-5
15. Maruthai, S., Rajendran, S., Selvanarayanan, R., & Gowri, S. (2025). Wastewater Recycling Integration with IoT Sensor Vision for Real-time Monitoring and Transforming Polluted Ponds into Clean Ponds using HG-RNN. Global NEST Journal, 27(4), 1–11. https://doi.org/10.30955/gnj.06758
16. Metcalf & Eddy, Inc. (2014). Wastewater Engineering: Treatment and Resource Recovery (5th ed.). McGraw-Hill Education.
17. Ministry of Equipment, Transport, Logistics, and Water (METLE). (2018). Moroccan Standard NM 03.8.200 relating to liquid discharges from hospitals. Official Gazette No. 6672.
18. Moroccan Institute for Standardization (IMANOR). (2006). Moroccan Standard NM 03.7.001 Water quality – Liquid discharges – Discharge limits for the receiving environment. Ministry of Land Use Planning, Water, and the Environment.
19. Pauwels, B., & Verstraete, W. (2006). The treatment of hospital wastewater: An appraisal. Journal of Water and Health, 4(4), 405–416. https://doi.org/10.2166/wh.2006.021

20. Rizzo, L., Manaia, C., Merlin, C., Schwartz, T., Dagot, C., Ploy, M. C., Michael, I., & Fatta-Kassinos, D. (2013). Urban wastewater treatment plants as hotspots for the release of antibiotics and antibiotic-resistant bacteria into the environment: A review. Science of the Total Environment, 447, 345–361. https://doi.org/10.1016/j.scitotenv.2013.01.032
21. Selvanarayanan, R., Maruthai, S., Rajendran, S., & Gowri, S. (2024). Wastewater Recycling to Enhance Environmental Quality using Fuzzy Embedded with RNN-IoT for Sustainable Coffee Farming. Global NEST Journal, 26(8). https://doi.org/10.30955/gnj.06346
22. Singh, K. P., Malik, A., Mohan, D., & Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study. Water Research, 38(18), 3980–3992. https://doi.org/10.1016/j.watres.2004.06.011
23. Venkatraman, M., Surendran, R., Srinivasulu, S., & Vijayakumar, K. (2025). Water quality prediction and classification using Attention based Deep Differential RecurFlowNet with Logistic Giant Armadillo Optimization. Global NEST Journal, 27(1), 1–13. https://doi.org/10.30955/gnj.06799
24. Verlicchi, P., Al Aukidy, M., & Zambello, E. (2012). Occurrence of pharmaceutical compounds in urban wastewater: Removal, mass load and environmental risk after a secondary treatment—a review. Science of the Total Environment, 429, 123–155. https://doi.org/10.1016/j.scitotenv.2012.04.028
25. World Health Organization (WHO). (2017). Safe management of wastes from health-care activities: A practical manual (2nd ed.). WHO.
26. World Health Organization. (2021). Antimicrobial resistance. WHO. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.