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Geospatial assessment of the surface waters and identification of the incidence of typhoid fever: correlation via the tools GIS

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Abstract

Oueds Fez and Sebou northeast of the city the city of Fez are affected by different sources of pollution, likely to cause human waterborne diseases. This work aims -a priori- at the identification of geographical relationship between the pollution of surface waters and the distribution of the water-related incidence of Typhoid Fever infection, by examining the risk factors influencing them. Based on this analysis, we have spatially mapped the various parameters followed by statistical treatment. The spatial mapping of the incidence of Typhoid Fever infection, as well as physico-chemical and bacteriological analysis of the different sites studied during the year 2016, compared to the Moroccan standard of surface water quality, show that the District with the highest incidence rate of this disease is AIN KADOUS, which represented more than 71% in 2016. According to this geographic distribution, this neighborhood is close to one of the most polluted sites water courses of the East-north of the city. Indeed, the quality results prove that they are contaminated by the majority of surface water quality indicators used, namely Electrical Conductivity, turbidity, Biological Oxygen Demand, Chemical Oxygen Demand, total phosphorus, nitrates, ammonium and high microbial presence by fecal coliforms. This study revealed the need for constant monitoring in places where environmental degradation is caused by the not regulated sewage discharges coming from the city of Fez. This can have adverse effects on the health of the population and the aquatic life of Oued Sebou.

1. Introduction

The natural reserves of soft surface waters, accessible to humans, do not exceed 0.3% of the total area covered by water on our planet [1]. Otherwise our country, these reserves are among the most precarious in the world. More than half of these resources are concentrated in the Northern Basins and the Sebou Basin, one of the largest rivers in Morocco, which annually receives huge amounts of polluted wastewater from adjacent cities. For several years, the city of Fez has contributed to the degradation of this river with a high volume of wastewater [2], up to 57 million m³ / year, including sewage discharge from various activities [3],particularly olive oil industry and handicrafts, evacuated without any preliminary pre-treatment. Therefore, the STEP-Fez, inaugurated at the end of November 2014 [4],was dedicated to pre-treatment of these discharges, which have several adverse effects on the balance of aquatic environment characteristics and the health of populations.

When these compounds are in the aquatic environment, it favors the formation of complex mixtures that can cause problems to the health and well-being of humans as well as the organisms that use it [5]. Organisms inhabiting areas influenced by effluent discharges can suffer DNA damage, and humans using polluted water are at risk of similar genotoxic effects and of developing cancers [6].

Assessing environmental risk also requires systems that reflect, quantitatively and qualitatively, the exposure effects. Organisms that are in direct contact with contaminated environmental compartments are well suited for inclusion in such systems [7].Several studies have been conducted on the properties of water in Oued Fez and Sebou River [8,9]. Most of these studies detected a surface water contamination in both water courses downstream from Fez, related to the demographic growth and the accelerated progress of the vital social and economic sectors of agriculture and industry in this region [10].

Typhoid fever is a severe multi-systemic illness caused by Salmonella entericaserovar Typhi (Salmonella Typhi) and is characterized by classic prolonged fever. The reservoir of S. Typhi is human. Typhoid fever is usually contracted by the ingestion of fecal contaminated food or water [11]. Typhoid fever outbreaks, associated with dirty and contaminated water, are continuously reported throughout the world, especially in developing countries [12]. Typhoid fever results in an estimated 216,000–, 600,000 deaths annually, with almost all cases occurring in developing countries[13,14].

Prior to the start of the WWTP, which became operational at the end of 2014, the reduction of water-borne diseases during the last years is explained by improvements in socio-economic conditions, personal hygiene, introduction of food security measures [15], and endeavours deployed by the government in this area.

Disease maps are useful tools to identify the geographical distribution of the disease incidence. The development of geographic information systems (GIS) over the last three decades has provided a powerful tool to examine spatial patterns, and is commonly used in public health and epidemiologic research [16]. Combined with Global Positioning System (GPS), GIS has been widely used in environmental protection projects [17]. To achieve this, we opted for a geographic repartition that allowed us to have a thorough data base, which has proven effective in several studies [18,19], in this paper, we use GIS methodologies to evaluate (via spatiotemporal monitoring, the physicochemical and bacteriological quality of the surface waters and the geographical distribution of the incidence rates of typhoid fever) the spatial patterns of typhoid fever, with a view to ensuring water security for the purposes of sustainable development and public health.

2. Material and Methods

2.1. Study area

Surface waters of the periurban Oued Fez and the Sebou River the city of Fez were impacted by the discharge of sewage and contaminated water sources, likely to cause water-borne diseases of public health importance [20]. When we draw on the main aims of this study and the geographic location of the area, the study area includes:

Fez Prefecture: located in the northern part of Morocco, In Fez-Meknes Region. It is bordered by the Provinces of Sefrou, Taounate and MoulayYaacoub and characterized by hydrology based on Oued Fez, running from West to East, starting from its springs in Ras El Ma till Oued Sebou.

In the *north*-East*of the city of Fez* located the activated sludge WWTP is 10 km from Fez, on the territory of the rural commune of All Kansara, located on the hills to the north-East of Fez, in Fez-Meknes Region.

Sebou River is one of the largest Moroccan rivers, stretching over 600 km from its source in the Middle Atlas to the Atlantic Ocean. This river plays a vital role in supplying its watershed area with water for drinking, irrigation as well as for industrial uses. It originates in the Middle Atlas mountain range in 2030 m of altitude, and flows over 600 Km into the Atlantic Ocean. Its watershed, located at the North-West of Morocco between parallels 33° -35°north latitude and 4° 15'-6° 35' West longitude, stretch over nearly 40,000 Km². It is bordered to the north by the southern front range of the RifMountains, to the south by the Middle Atlas, to the east by Fez–Taza corridor, and the Atlantic Ocean from the West. The city of Fez is responsible for 40% of the total impact on water quality of Sebou River[21]. The canning and yeast factories also represent a non-negligible contribution of organic pollution of Sebou River[10].

Oued Fez is the main water body in Morocco crossing the city of Fez, with a SW-NE direction, crossing the city of Fez and its old Medina on a 24-km stretch, before joining Sebou River. It takes its source from the big source (Ras al-Ma), where it is fed by very important sources (Ain Ras El Ma, Atrous, Bergama, Sennad…) [22]. All of Fez's sewage is flushed directly into nearby watercourses. This includes industrial effluents generated by many industries, including tanneries[23]., oil mills, metal works, pottery and wastewater from the textile industry, which is rated as the most polluting among all industrial sectors[24], using various pollutants (e.g. degradable organics, surfactants, metals and dyes) [25], which induces serious degradation of quality.

Therefore, considerable amounts of chemicals, among which are chromium and ammonium in addition to organic matter, are present in the river [26,27]. The sub-basin of Fez alone seriously contributes to this pollution [28] (Figure. 1).

2.2. Sampling sites

In the rural area of Al Kansara, field visits enabled us to identify the number of water points and their nearby environment of periurban Oued Fez and Sebou of Fez; The sampling was done on a seasonal basis of 2016 were taken in stable hydrological conditions, at five sampling sites (Table. 1). The geographic locations of these points are shown in (Figure. 2).

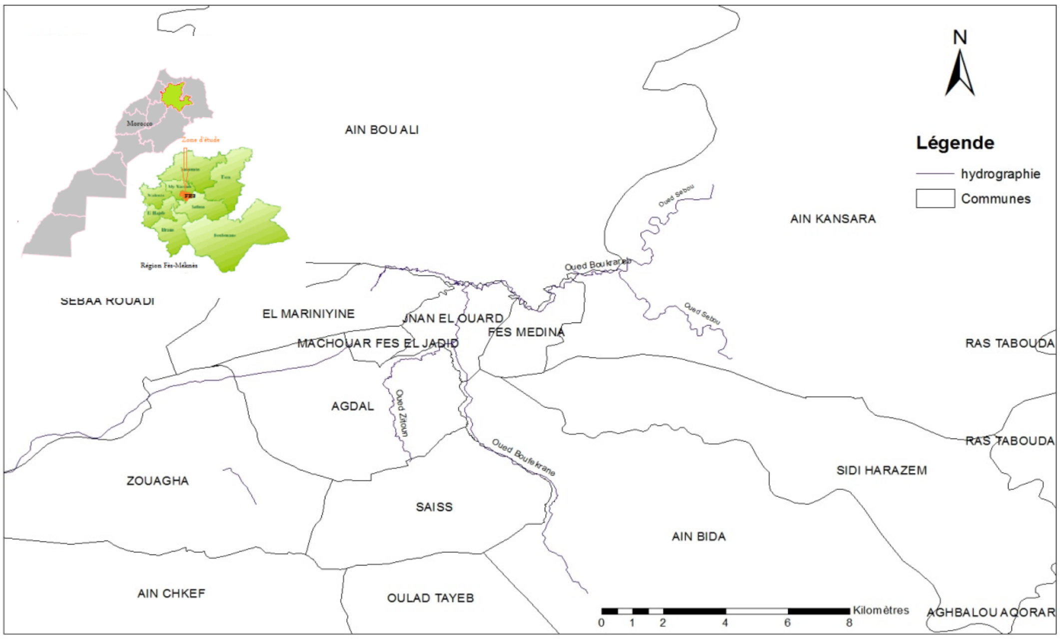

Figure 1: Overview of the study area, different districts of the city of Fez with Oued Fez and Oued Sebou

Table 1: Geographic coordinates of the five sampling sites

Sites	Locality	Geographic coordinates	
		Longitude	Latitude
S1	Upstream the discharges of Fez before the WWTP.	4 ° 55' 50,0" W	34 ° 04' 49,0 "N
S2	Before the confluence (Oueds Sebou-Fez)	4 ° 56' 13,8" W	34 ° 04' 43,1 "N
S3	Located in the confluence (Oueds Sebou-Fez)	4 ° 55' 13,9" W	34 ° 04' 34,3 "N
S4	Located in Sebou downstream of the confluence (Oueds Sebou-Fez)	4 ° 54' 53,1" W	34 ° 04' 49,0 "N
S5	Located in Sebou upstream the confluence (Oueds Sebou-Fez)	4 ° 55' 04,0" W	34 ° 04' 10,2 "N

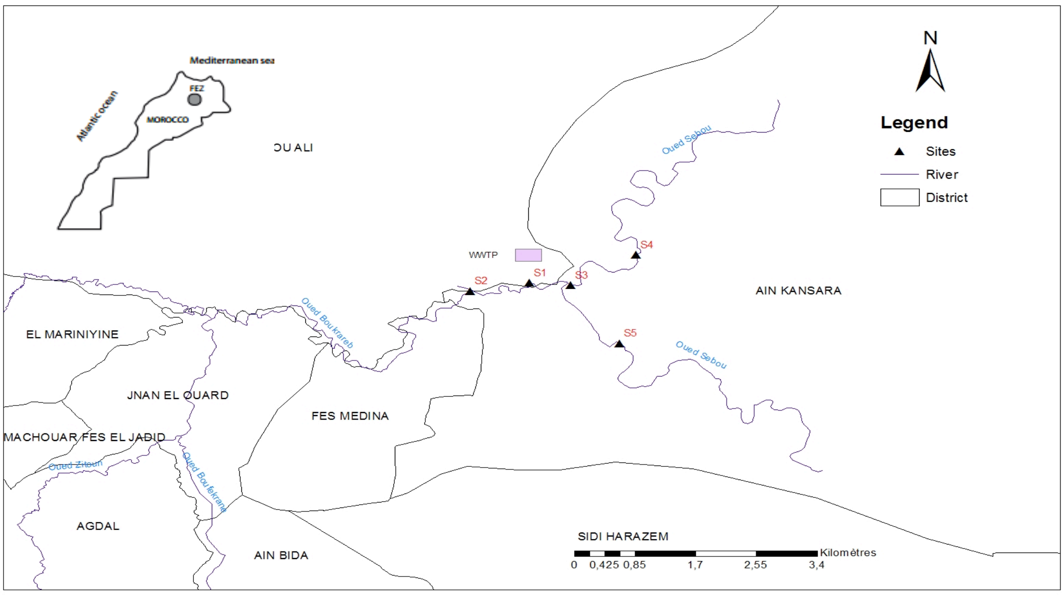

Figure 2: Location of sampling sites in the Sebou River and Oued Fez

3. Methodology

3.1. Analytical procedure

3.1.1.Physicochemical parameters

Grab samples were manually collected at approximately 20 cm below the water surface, using 1 L, 0.5 L and 0.25 L flasks of high-density polyethylene (HDPE).

The flasks were thoroughly cleaned and rinsed with distilled water. At the time of in-situ sampling, the previously washed flasks were rinsed three times with river water before sample collection [29]. Samples were carefully labelled and transported from the sampling site to the laboratory.

The tests were performed in situ, according to the methods described by Rodier [30] for Physicals measurements parameters (Temperature, pH, Dissolved Oxygen DO and Electric Conductivity EC), with a multi-probe (Consort C561 Portable) calibrated before each campaign, and the Turbidity with a turbidimeter Type (HACH-Model 2100P).

Chemical tests concerned the following elements: Nitrates NO_3^-, Total Phosphorus TP, Biological Oxygen Demand BOD_5, Chemical Oxygen Demand COD, Total Nitrogen TN ,Ammonium, Chlorides and Sulphates, analyzed in a laboratory and were performed according to 9th edition DUNOT standards by Rodier [31]. Water samples were tested in compliance with the appropriate Moroccan standards [32]. (Table. 2)

Table 2*:*Grid to evaluate the physico-chemical parameters of the Moroccan surface water quality of the river[32].

Class 5	Class 4	Class 3	Class 2	Class 1	Units	Parameters
Very poor	Poor	Average	Good	excellent		
35<	30-35	25-30	20-25	20>	°C	Temperature
<6.5ou>9.2	.5ou>9.2	8.5-9.2	6.5-8.5	6.5-8.5		pH
3>	3-1	5-3	7-5	7<	$mgO_2.L^{-1}$	Dissolved oxygen
>3000	2700-3000	1300-2700	750-1300	<750	$\mu s.cm^{-1}$	Conductivity at 20 °C
>100	70-100	35-70	35-70	<15	NTU	Turbidity
>25	10-25	5-10	3-5	<3	$mgO_2.L^{-1}$	BOD_5
>80	40-80	35-40	30-35	<30	$mgO_2.L^{-1}$	COD
>1000	750-1000	300-750	200-300	<200	$mg.L^{-1}$	Chlorides
>400	250-400	200-250	100-200	<100	$mg.L^{-1}$	Sulfate
-	>50	25-50	10-25	≤10	$mg.L^{-1}$	Nitrates
-	>3	2-3	1-2	<1	$mg.L^{-1}$	Kjeldahl nitrogen
>8	2-8	0.5-2	0.1-0.5	≤0.1	$mg.L^{-1}$	Ammonium
>3	0.5-3	0.3-0.5	0.1-0.3	≤0.1	$mg.L^{-1}$	Total Phosphorus

Bacteriological parameters

The counting indicator bacteria of fecal contamination FC is realized by the method of multiple tube fermentation MPN, using special statistical tables (Mac Crady).

Water samplers used for bacteriological tests were taken in compliance with the protocol as described below: Sampling was performed using borosilicate glass vials carefully pre-cleaned with distilled water.

The cleaned and rinsed vials were then sterilized in an autoclave at 120 °C, and pressured at 120 kg/cm^{-2} for 30 minutes. Water samples were tested in compliance with the appropriate Moroccan standards [32]. After storing water samples each in an appropriate 500 mL vial, they were labelled and conserved in a cooler at a maintained temperature between 0 and 4 °C. Then, they were transferred to the laboratory with a sampling sheet indicating all required data, mainly the sampling site and date, as well as sanitary conditions in the sampling sites (Table. 3).

Table 3: Grid to evaluate the Bacteriological parameters of the surface water quality of the river [32]

Class 5	Class 4	Class 3	Class 2	Class 1	Units	Parameters
Very poor	Poor	Average	Good	Excellent		
-	>20000	2000-20000	20-2000	≤20	/100 mL	Fecal Coliforms

GIS

The Geographic Information System (GIS) is the combination of five essential components: data; software: hardware; human resources; procedure and standards. The first step in developing a GIS project is the collection of databases from hospitals and health Centers, with regard to the information system for waterborne disease, were mapped using the 'select by location' function.
Spatial series maps were established using Geographic Information Systems (GIS) to introduce the spatial changes in the morbidity rates of typhoid fever.
This was achieved after grouping geographic coordinates with different analyzes into an Excel table, which was then transformed into CSV file readable by the QGIS software 8.2, in order to realize the maps, to have a spatial ftion of the water quality studied, geo-referenced by the GIS tools, in geographical coordinates of Lambert Conic Conform (Merchich Morocco).
In parallel with that the microbiological and physicochemical analyses were integrated into the GIS in order to elaborate quality maps for studied parameters.

3. Result and Interpretation

Physico-chemical parameters

The results of the physico-chemical mean values are represented in figures below, according to the quality GRID for each sampling site. According to the Decree of Moroccan Standards, which sets the surface water quality standards (MSSW) [32] (Table. 4).

Table 4: Results of global physicochemical parameters analysis, according to the Moroccan standards of quality, concerning the classification of surface waters

Sites					Units	Parameters
S1	S2	S3	S4	S5		
25,1	25	22,3	23,6	20,2	°C	Temperature
6,3	7,5	7,6	7,2	7,1		pH
3,7	4,2	5,5	5,8	6,0	$mgO_2.L^{-1}$	Dissolved Oxygen
70,4	42,5	38,9	50,3	14,4	NTU	Turbidity
2187	2314	1001	967	800	$\mu s.cm^{-1}$	Conductivity at 20 °C
26,7	22,6	20,3	8,9	4,9	$mgO_2.L^{-1}$	BOD_5
41,3	36,4	38,1	31,8	32,3	$mgO_2.L^{-1}$	COD
751	243	213	201	102	$mg.L^{-1}$	Chlorides
144	163	108	44	34	$mg.L^{-1}$	Sulphates
28	32	8	9,7	8,5	$mg.L^{-1}$	Nitrates
6,9	2,6	1,1	1,1	1,7	$mg.L^{-1}$	kjeldahl Nitrogen
2,33	1,18	0,61	0,13	0,21	$mg.L^{-1}$	Ammonium
0,81	0,78	0,4	0,34	0,26	$mg .L^{-1}$	Total phosphorus

Temperature has an influence on many physical, chemical and biological processes [33]. In the study area, it was noticed that there were no great temperature variations from one site to another. The values obtained are between 22.1 °C as minimal value and 24.5 °C as maximum value recorded at the level of the Sebou River, and

25.3 °C as minimal value and 26 °C as maximum value recorded at the level of Oued Fez. This temperature is deemed favorable to the development of bacteria, parasites, mosquito larvae and other microbial germs. The confirmed values (<30 °C) rank these waters within the range of good quality.
The *pH* of water affects most of water chemical and biological mechanisms. It can also be influenced by acid precipitation, biological activity and certain industrial releases [34]. No significant variations were noticed in water pH values in the sites object of study with a minimum of 6.46 in S1, due to the presence of high organic matter contents, and a maximum of 8.3 in S4. The obtained pH values are acceptable and meet Moroccan directives on the classification of surface waters.
As for Dissolved Oxygen, it's one of the most sensitive parameters of pollution. Indeed, a DO level that is too high or too low can harm aquatic life and affect water quality. The obtained values of Dissolved Oxygen are acceptable and meet Moroccan directives on the classification of surface waters. They are between 3.6 $mgO_2.L^{-1}$ as minimal value and 6.2 $mgO_2.L^{-1}$ as maximum value. Usually one can rank these waters within the range of good quality.

Turbidity is the measurement of water clarity. The obtained values of the turbidity between 8 and 70 NTU; indicating that the river water had moderately polluted quality according to Moroccan directives on the classification of surface waters, The highest values were recorded during the winter season in S1 and during summer in stations the confluence. Usually one can rank these waters within the range of average quality. (Figure. 3)

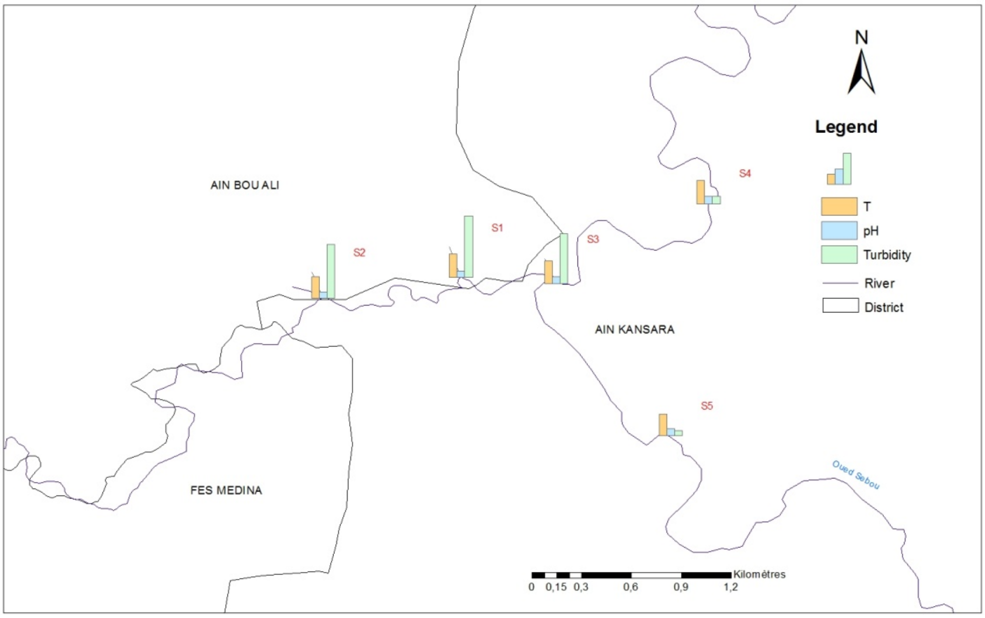

Figure 3: Spatial variation of temperature, turbidity and pH in different sampling sites water in the Sebou River and Oued Fez

Electric conductivity indicates water capacity to conduct an electric current; therefore, it represents the mineralization rate of water [35]. In the sites selected for the study, conductivity was significant in S1 and S2 oscillate between 2000 and 2400 $\mu s.cm^{-1}$, and weak in S3, S4 and S5. According to Moroccan surface water classification, they obtained values (<2700 $\mu s.cm^{-1}$) position these waters within the range of good quality (Figure. 4).

Biological Oxygen Demand BOD_5 is conducted over a five-day period. It's ranged from 50 and 70 $mgO_2.L^{-1}$ for sites 1 and 2, while the values of S3 and S4 Sites oscillate between 9 and 40 $mgO_2.L^{-1}$.

Chemical Oxygen Demand COD is used for determining waste concentration[36], his contents in natural waters are in the order of 30–45 $mgO_2.L^{-1}$. Compared to Moroccan surface water standards, the majority of samples show a moderately polluted quality, especially in summer.

Nitrates can be toxic to the human body; their presence in significant quantity decreases water quality. In this case, the average concentration of NO_3^- is in the order of 9–40 mg.L-1. Most of the samples were well below the level of 25 mg/l; the excessive value in S1 water may be attributed to agricultural and household activities, and positions these waters in the range of average quality(Figure. 5). *Aimed at chlorides,* are largely spread in nature, generally in the form of sodium and potassium salts (NaCl) and (KCl). They are often used as a pollution index. Content in chlorides is at its good in site S1, as well as in the other sites. These positions these waters in the range of good quality.

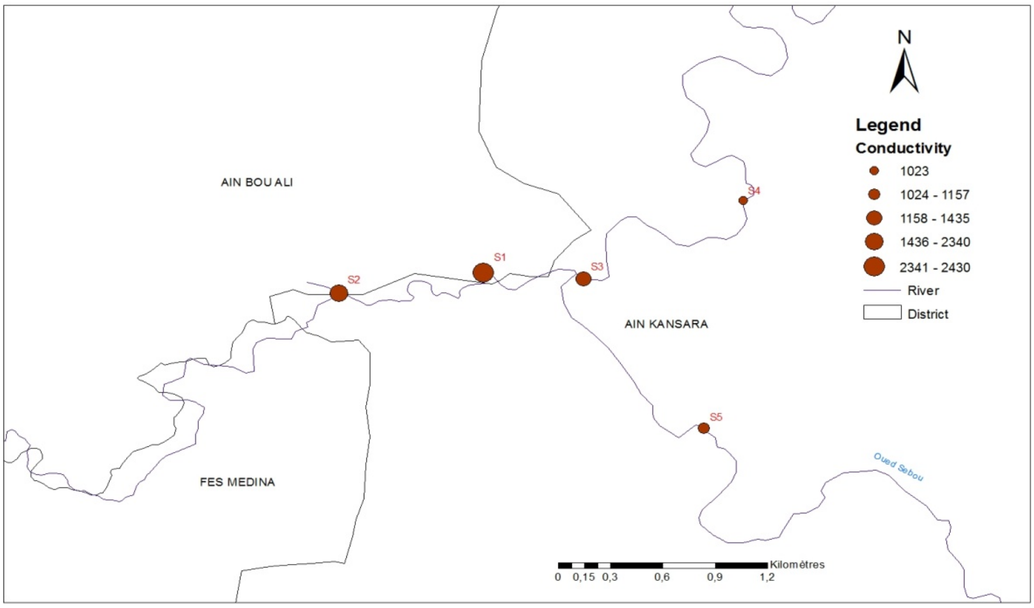

Figure 4: Spatial variation of Conductivity in different sampling sites water in the Sebou River and Oued Fez

Concerning *sulfate*, the values of this parameter in studied waters vary from 55, 55 and 479, 2 mg.L-1. High contents of this parameter are noticed in polluted waters. The high contents may also be attributed to agricultural activities; it positions these waters in the range of poor quality.

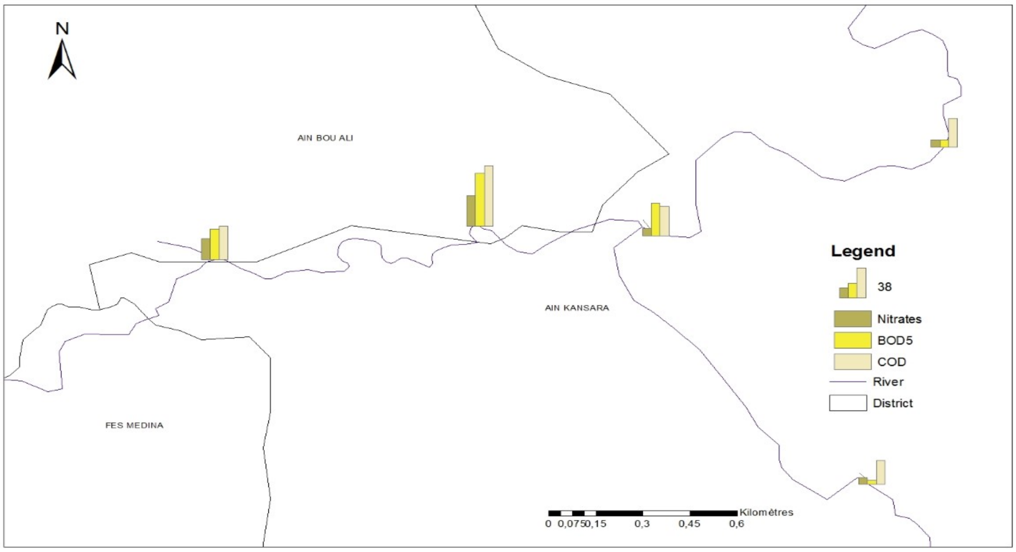

Figure5: Spatial variation of Nitrates, BOD_5 and COD in the different sampling sites water in the Sebou River and Oued Fez

for *TN*, the studied samples presented a high concentration in site 1, which positions these waters in the range of poor quality; whereas waters in sites S3, S4 and S5 are weak and present acceptable content in TN, meeting the Moroccan surface water directives.

Ammonium constitutes the product of the final reduction of nitrogenous organic substances and inorganic matter in waters and soil. It also originates from living organisms' excretion and waste reduction, as well as biodegradation, in addition to the household, industrial and agricultural origins. This element is present in low rates in sites S3, S4, S5. Knowing that *TP* are primarily the result of the household, agricultural and industrial activities, and also of agricultural run-off in lands with phosphate fertilizers content, in Oued Fez (S1, S2), the maximum values obtained position these waters in the range of poor quality especially in summer, whereas S3, S4 and S5 present acceptable content meeting the Moroccan surface water directives (Figure. 6).

Figure 6: Spatial variation of NTK, Ammonium and TP in different sampling sites water in the Sebou River and Oued Fez

Bacteriological Results

The results of the bacteriological mean values are represented in figures below, according to the quality GRID for each sampling site. According to the Decree of Moroccan Standards, which sets the surface water quality standards (MSSW) [23] (Table. 5).

Table 5: Results of global bacteriological parameters analysis, according to the Moroccan standards of quality, concerning the classification of surface waters

Sites					Units	Parameters
S1	S2	S3	S4	S5		
3195299,5	162420,5	205760,5	117664	954,25	/100 mL	Fecal Coliforms

Results obtained show that the sampling sites S1, S2, S3, S4 have presented high concentration rates of Fecal Coliforms. This can be explained by a very important human activity in the neighboring area, and a human or animal fecal pollution. In conformity with Moroccan classification, they obtained values position these waters in the range of poor bacteriological quality. OuedSebou S5 presented a minimum value of Fecal Coliforms. The regulatory framework of surface water ranks OuedSebou water in the range of good quality.
The entirety of surface and waste waters in Fez might engender a detrimental impact on the lives and health of the fauna and flora, and cause the transmission of several water-borne infectious and parasitic diseases, mainly: typhoid, viral hepatitis, and food intoxication, due to the consumption of market gardening products.
The micro-organisms content in the water of Oued Fes seem to undergo a gradual growth from upstream to downstream, due to fecal contamination of the Oued waters, resulting from industrial effluents. The quality of spring waters is very good for micro-organisms. The S 5 sites have on excellent quality and the most polluted sites are sites 1 and 2.Generally, according to the classification only some points have a good quality to excellent.In this regard, a physico-chemical pre-treatment of these effluents is absolutely necessary to reduce the harmful effects of this pollution (Figure.7).

Incident Typhoid fever

Since Typhoid Fever are waterborne diseases supervised by the Ministry of Energy, Mines, Water and Environment of Morocco, the study tried to focus on the survey of geographic distribution, While drawing on the geographic location of the area of study considering the coverage of quality periurban river the city of Fez (Al Kansara area), taking into account that patients from the region of Alkansara go to Fez Health Centers. The data will serve as a reference study for other waterborne diseases. Finally, it will be employed for the establishment of GIS Decision Support System which will assist decision makers in assessing and monitoring the water pollution. The geographic distribution map of the typhoid fever disease notification rate with the population of Fez during the year 2016, with the distribution of different districts in 2016, for Fez.In fact, this distribution shows that the District with the highest incidence rate of this disease more than 71% in 2016, is the closest one to the water course of the polluted sites East-North of the city of Fez. Indeed, close to the perimeters of discharges of industrial effluents and reuse of wastewater in agriculture, and boroughs experiencing a popular condensation (Figure. 8).

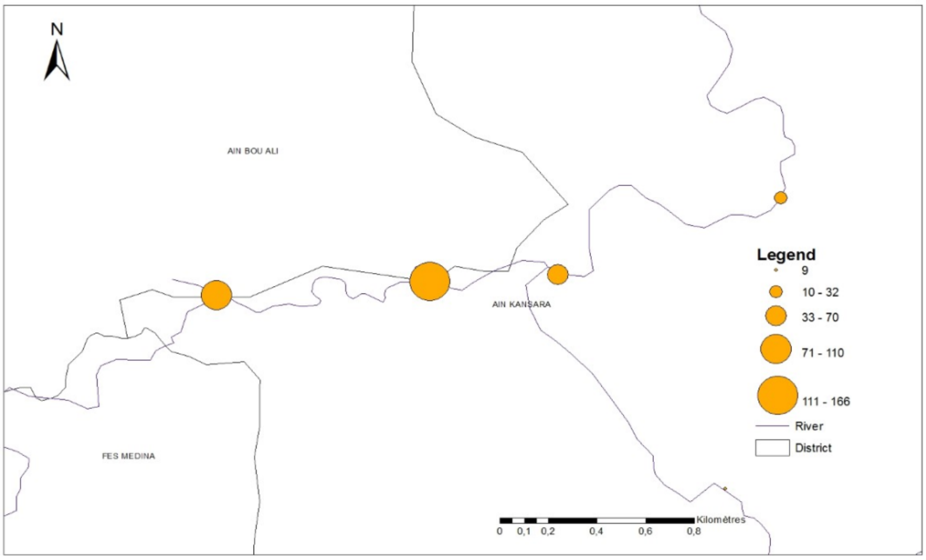

Figure 7: Spatial variation of FC in the different sampling sites water in the Sebou River and Oued Fez

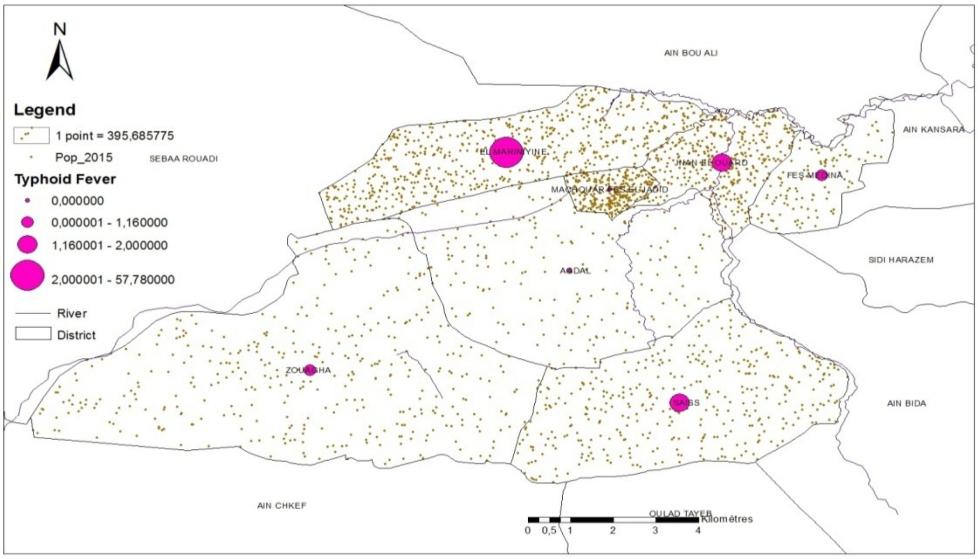

Figure 8: Spatial variation of Typhoid Fever and population of different districts of Fez City during 2016

As far as typhoid fever in concerned, the rate in the prefecture of Fez is equal to 80% of the annual incidence at the Region Fez-Boulemane, which represents the third highest rate of this waterborne infection at the national level. Which is ranked second after the region of Meknès-Tafilalt at the state level [37].
The spatio-temporal monitoring of the polluting load of the waters shows that the existing tributaries to the East-North of the city, going as far as the section of OuedSebou a strong chronic pollution of organic and phosphoric origin.The mapping of typhoid fever, for the same period, are very high, which indicates that Ain Kadous area is the first responsible for the spread of these epidemic and waterborne diseases in the city of Fez.

Correlation matrix

The linear correlations obtained for the variables studied are reported in Table 4, whose critical values of Bravais-Pearson's rate represented for a $p < 0.05$. Examination of the correlation matrix in this table shows the existence of positive correlations up to 0.759 and negative correlations reaching -0.837.
The incidence rates of typhoid fever, at the level of the various districts obtained for the year 2016, are negatively correlated with the bacteriological quality with a rate of $r = -0.685$. The meaning of this correlation

explains that the incidence of diseases increases. With poor bacteriological quality. We also notice a good correlation with the location parameter.
The global bacteriological quality (GBQ) of the wadis is negatively related to the popular density (-0.837 *), whereas the overall physico-chemical quality (GPH-CHQ) of the surface waters is strongly linked to the number of industries with a similar rate. at (-0.820 *). So we can say that the rise in the number of people and industry seriously diminishes the overall quality of the waters. This is in connection with anthropogenic inputs and areas that are heavily populated.

Table 6: Statistical analysis of correlations according to the criteria of Bravais-Pearson

	TF	Density	Number of industries	GPH-CHQ	GBQ	Location
TF	1	-	-	-	-	-
Density	0,039	1	-	-	-	-
Number of industries	-0,361	0,759	1	-	-	-
GPH-CHQ	0,040	-0,489	**-0,820***	1	-	-
GBQ	-0,685	**-0,837***	0,476	0,747	1	-
Location	0,685	-0,502	0,278	0,733	0,604	1

*the values in bold are highly significant

Geographical correlation

The correlation between disease incidence and surface water pollution was developed through GIS maps (Fig. 9) and Pearson's statistical analysis; allow us to highlight the various factors involved, namely:
- The proximity to Oued Fez downstream, which is considered the most polluted and the industrial zones (mainly the Doukkarat and AinNokbi districts.
- The Overlappling of agricultural areas, especially near the El Merja zone known for its vegetables irrigated by wastewater;
- The high population density, with the highest rate in Fes El Medina district where it exceeds 33%, and rates equivalent to 15.8% and 15.9% successively for the district El Mérinides and Jnane El ward in the Fez city.

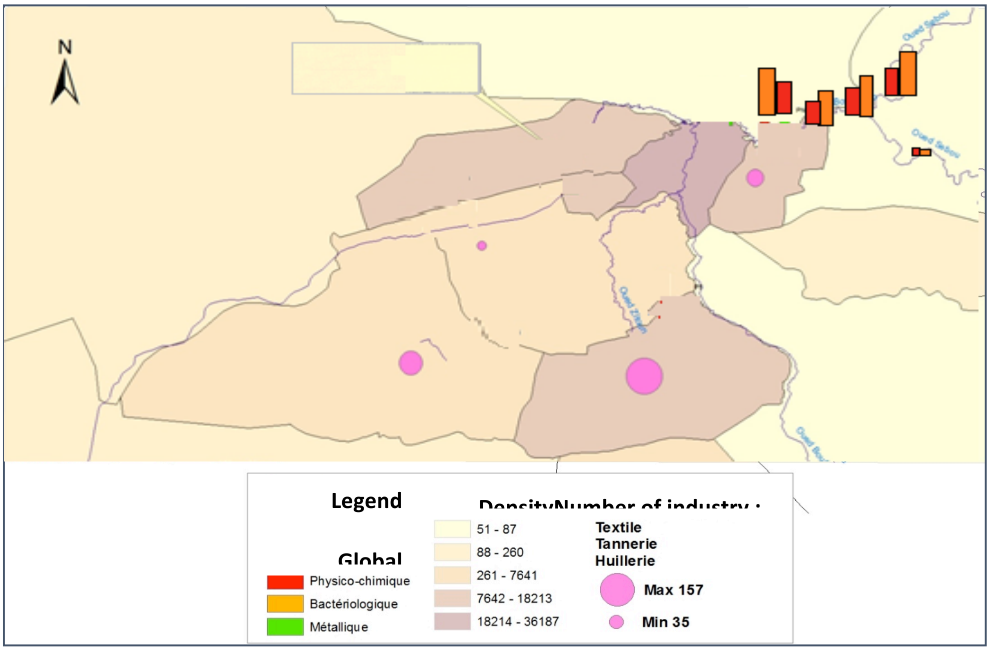

Figure 9: Geographic distribution of the different parameters with the incidence of disease

Conclusion

Water quality is assessed with respect to different types of pollution, which are characterized by groups of parameters of the same nature or the same effect on aquatic environments.
Overall, the spatial evaluation of the physicochemical quality shows us that Oued Fez is more polluted than OuedSebou; the same applies for the bacteriological quality because the contamination persists with the flow of Oued Fez leaving OuedSebou downstream of the confluence; whereas the site n° 5, which is not mixed with the

water of Oued Fes, remains of good quality. The S 5 sites have on excellent quality and the most polluted site is site 1.
This study concerning as well the geographic distribution of typhoid fever with respect to this surface water pollution. The intention was to demonstrate the utility of a geographic information system GIS in this context. The SebouRiver, upstream from the confluence, showed a low-pollution status. the highest incidence rate of this disease more than 71% in 2016, is the closest one to the water course of the polluted sites East-North of the city of Fez. Indeed, close to the perimeters of discharges of industrial effluents and reuse of wastewater in agriculture, and boroughs experiencing a popular condensation
This work aims -a priori- at the identification of geographical relationship between the pollution of surface waters and the distribution of the water-related diseases' incidences, by examining the risk factors influencing them. Based on this analysis, we carried out spatio-temporal assessments of the polluting load of surface waters downstream from Oued Fes to OuedSebou (Al Kansara rural area).
After that, we have spatially mapped the various parameters of the environmental and epidemiological data to correlate them with the geographical distribution of the pathological infection incidence caused by the deterioration of the water quality.
The correlation between disease incidence and surface water pollution was developed through GIS maps and Pearson's statistical analysis; allow us to highlight the various factors involved, namely:
- The proximity to Oued Fez downstream, which is considered the most polluted and the industrial zones (mainly the Doukkarat and Ain Nokbi districts.
- The Overlappling of agricultural areas, especially near the El Merja zone known for its vegetables irrigated by wastewater;
- The high population density, with the highest rate in Fes El Medina district where it exceeds 33%, and rates equivalent to 15.8% and 15.9% successively for the district El Mérinides and Jnane El ward in the Fez city.
The analysis indicates that surface water located in Sebou upstream the confluent (OuedSebou and Oued Fez) and around the wastewater treatment plant is suitable for drinking, agricultural and industrial use. In general, it is not harmful to human beings, whereas some samples need pretreatment before use.
This study aims at enabling:
- Epidemiological researchers and water treatment authorities to forge scientific cooperation ties on mutually agreed projects that respond to national research priorities in both fields; In order to combat the most declared waterborne diseases, and carry out awareness programs near the most polluted streams.
- The assessment of concentration levels for other pollutants (e.g. pesticides, etc.) to obtain a more complete picture of the pollution problem, which could lead to the introduction of treatment technologies.
- Work towards multidisciplinary research in the field of epidemiology and quality management of wastewater treatment.
- Make computer contacts link the quality of treatment of the studied waters with the reduction of the rate of the most frequent waterborne diseases. Indeed, it is a system that plays an important role in monitoring the preservation of population health and the quality of the aquatic environment.
- Thus, there is an obligation to implement tertiary treatment and to choose the process (s) that are most suitable for the desired reuse and the quality of the effluent at the station exit.
The assessment system presented in this work is a model, in the form of a decision support tool that aims to facilitate the exploitation and processing of data to enable the management of water-borne diseases generated by quality surface water.

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