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Contribution of End Member Mixing Analysis Model to Characterize the Sources Responsible for Urban River Water Quality: Case of Houet River in Burkina Faso

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Abstract The study focused on the assessment of sources responsible for an urban river's water quality. To do the analysis, water samples were collected from three sources. The first source was rainfall, the second source was a Wastewater Treatment Plant (WWTP) which releases pre-treated wastewater in the river, and the third source was the river itself at upstream and downstream parts from the WWTP discharge point in the river. The results of the chemical analysis performed on those water samples showed that the water discharged from the WWTP into the river has a poor physico-chemical quality and high microbiological pollution. However as expected, water samples of rainfall were of good quality. Water samples from the river revealed the presence of microbiological flora (total coliforms, fecal coliforms, Escherichia coli and fecal Streptococci) and chemical elements such as ammonium (NH_4^+), manganese (Mn), nickel (Ni) with high concentrations values than those recommended for irrigation waters as defined by World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations. However, parameters like temperature (T°), hydrogen potential (pH), electrical conductivity (EC), total dissolved solids (TDS), suspended solids (SS), chemical oxygen demand (COD), biological oxygen demand (BOD5) ortho-phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), sodium (Na^+), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), zinc (Zn^{2+}) and iron (Fe^{2+}) are in line with the reference values for irrigation. Furthermore, water mixing analysis model "End Members Mixing Analysis (EMMA)" based on principal component analysis (PCA) of physico-chemical parameters of the pre-treated wastewater from the WWTP discharged into the river, the rainfall, and the river collected at upward of WWTP junction discharge point in the river has been developed. The results show that the wastewater pre-treated by the WWTP and discharged into the river contributes to 13.72% of the river water chemistry compared to 33.64% for rainfall and 52.64% for river water before its junction with WWTP. This study revealed that during rainy season, Houet river has high concentrations of NH4+, metallic trace elements (Mn, Ni) and significant microbiological pollution due to (i) the discharge into the river of incomplete treated wastewater coming from the WWTP (ii) but also to the river itself, which minor bed is the depository of urban and domestic wastes. It is true that the river water quality is globally good for market gardening, but to ensure its long-term quality, authorities in charge of water resources and agriculture should (i) monitor and optimize WWTP wastewater treatment efficiency, (ii) and control/limit agricultural and domestic activities with potential pollution risks alongside the river.

Keywords: *river, wastewater, chemistry, rainfall, trace elements, model*

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1. Introduction

Freshwater ecosystems are necessary for the continuity of life [1]. Their availability in quantity and quality remains vital for human survival. Unfortunately, these water resources are increasingly exposed worldwide to anthropogenic pollution from (i) agricultural practices (use of pesticides and nitrogen fertilizers, burning of cereal residues...) [2,3], (ii) pastoral (animals excrements, …) [4,5,6], (iii) industrial activities (poorly treated or untreated industrial effluents) [7,8,9]; (iv) domestic use (sewage, human excreta and feces ...) [10-16] and (v) mining [17,18,19]. These pollutions occurrence require more rigorous and efficient management of the freshwater, which represent only 2.5 % of total world freshwater resources, compared to 97.5 % of salt water [20,21].

Particularly to a Sub-Saharan African country, Burkina Faso has marginal freshwater reserves of about 8.79 billion m^3/year, placing it below the international scarcity threshold for sustainable water resources management [22].

The region of Bobo Dioulasso, the second largest in the country, has a climatic and hydrogeological context that are favorable to the formation and storage of large stocks of surface and groundwater.

It receives abundant rainfall (> 900 mm/year compared to 400-600 mm/year in the north and 600-900 mm/year in the Center) [23,24].

In terms of uses, the region's surface water resources, particularly those of the Houet River, are exploited for the urban and peri-urban irrigated agriculture. In the rainy season, the water of this river helps to sustain crop irrigation in drought spells and rainfall deficits. It, thus, supports rainfed agricultural production and secure farmers' income during dry periods [25].

In the dry season, the Houet river is intensively exploited for off-season irrigation of lettuce (15%), mint (13%), parsley (10%), cabbage (10) %, celery (9%), tomato (9%) and pepper (7%) and 28% for various other vegetables (Leaf of onion, zucchini, spinach, beetroot, pepper, cucumber, moringa, corn, ground pump) [26]. Urban and peri-urban irrigated agriculture in the region contributes to the country's economy and has a strong impact on local economic output. This activity employs one out of five of the city's active population and contributes to increase food and nutritional security for its inhabitants [25]. Unfortunately, this river is more and more threatened by pollutions due to the development of irrigation activities (market gardening) along its banks. Also, pollution of the river water is coming from wastewater released by the city's WWTP which water pre-treatment process is inefficient. This study aims to determine the contribution of the various water sources to the chemical and microbiological quality of the Houet river.

2. Overview of the Study Area

Study area is the city of Bobo-Dioulasso, capital of the Houet province, second largest city and economic capital of Burkina Faso (Figure 1). It extends over 14 km^2 and located between latitudes 11°00' and 11°30' North and longitudes 4°36' and 4°00' West. Bobo-Dioulasso is the first region of fruits and vegetables production in Burkina Faso. The town concentrates 15 % of the country's vegetable production [27]. Total surface area of the city's market garden sites is estimated at 175 ha [25]. The city is also one of the best-watered areas in the country with a South Sudanese climatic conditions [27]. The average annual rainfall and temperature are respectively between 900 mm and 1200 mm, and between 25°C and 30°C [27,28].

The city of Bobo-Dioulasso is located in the Mouhoun watershed drained by two main tributaries that are the Kou and the Houet river. These two tributaries provide water for irrigation to some market gardening areas. The Houet river, which is the subject of this study, is a tributary of the Kou, crosses the city from south to north, draining the northern sector of the city [23,24].

This river has multiple interests, in fact, it shelters of sacred catfish of Bobo-Dioulasso, irrigated market gardening and fruit growing. It also serves as a source of socio-economic activities for the riparian population, despite its high load of liquid and solid waste and pathogens [29]. The Houet river receives pretreated wastewater from the only WWTP of the city which is located in the middle of the households and about 1 km from the river (Figure 1).

3. Methodology

The Houet river water used for the irrigation of market gardening are made up of a mixing of water from different origins (reservoirs). However the use of water in agriculture must respect some standards in terms of its physico-chemical and bacteriological quality in order to be deemed healthy to the consumers [30].

To quantify these standards, the methodological approach adopted is described below.

3.1. Identification and Characterization of the Physico-chemistry of the Houet River and the Others Reservoirs

The water physico-chemistry parameters study highlight the water quality by determining their concentrations and comparing it, to the water use standards [31,32]. In addition, the water analysis gives an idea of the current state of the water, its quality and its suitability for irrigation.

The pollutant parameters to be analyzed include: hydrogen potential (pH), electrical conductivity (EC), total dissolved solids (TDS), temperature (T°); dissolved oxygen (DO); suspended solids (SS); Chemical Oxygen Demand (COD), Biological Demand (BOD5) etc., certain ions such as: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Bicarbonate (HCO_3^-), Sulphates (SO_4^{2-}), Chloride (Cl^-), Nitrate (NO_3^-), Ortho-phosphate (PO_4^{3-}), Ammonium (NH_4^+), Nitrite (NO_2^-), as well as bacteriological parameters (total coliforms (TC), fecal coliforms (FC), Escherichia coli (EC) and fecal Streptococci (ST)) and metallic trace elements (Nickel (Ni), Chromium (Cr), Zinc (Zn), Copper (Cu), Aluminum (Al), Iron (Fe) and Manganese (Mn), etc.).

In the present study, in order to assess the quality of Houet river water for agricultural uses, water samples were taken along the Houet river at 8 points, upstream and downstream of the WWTP discharge point, in August during the rainy season (Figure 3). EC, pH, TDS and T° parameters are measured in situ using an Aquaprobe AP-2000. The chemical and microbiological parameters were analyzed at the Water-Hydro-Systems and Agriculture Laboratory of the 2iE Institute and the Hydrochemical Laboratory of "Office of Mines and Geology of Burkina Faso". The determination of the concentrations of these elements have been done using the following methods (i) AFNORT 90 105 for TSS, (ii) Oxitop method for BOD5, (iii) Standard method by Spectrophotometer 890 for COD, (iv) HACH 8039 cadmium reduction method for NO_3^-, NH_4^+ et NO_2^- ; (v) HACH 8051 sulfaVer method for SO_4^{2-} ; (vi) HACH 8114 PhosVer 3 method for PO_4^{3-} ; (vii) Flame photometry for Na^+ et K^+ ; (viii) Acidimetry for HCO_3^- ; (ix) Complexometric method for Ca^{2+} et Mg^{2+} ; (x) Deep plating for microbiological parameters. Traces of heavy metals were determined by the flame atomic absorption method.

The assessment of the physico-chemistry parameters quality of the Houet river used for irrigation consisted in comparing theirs concentrations of the FAO and WHO guides values for irrigation [33,34,35].

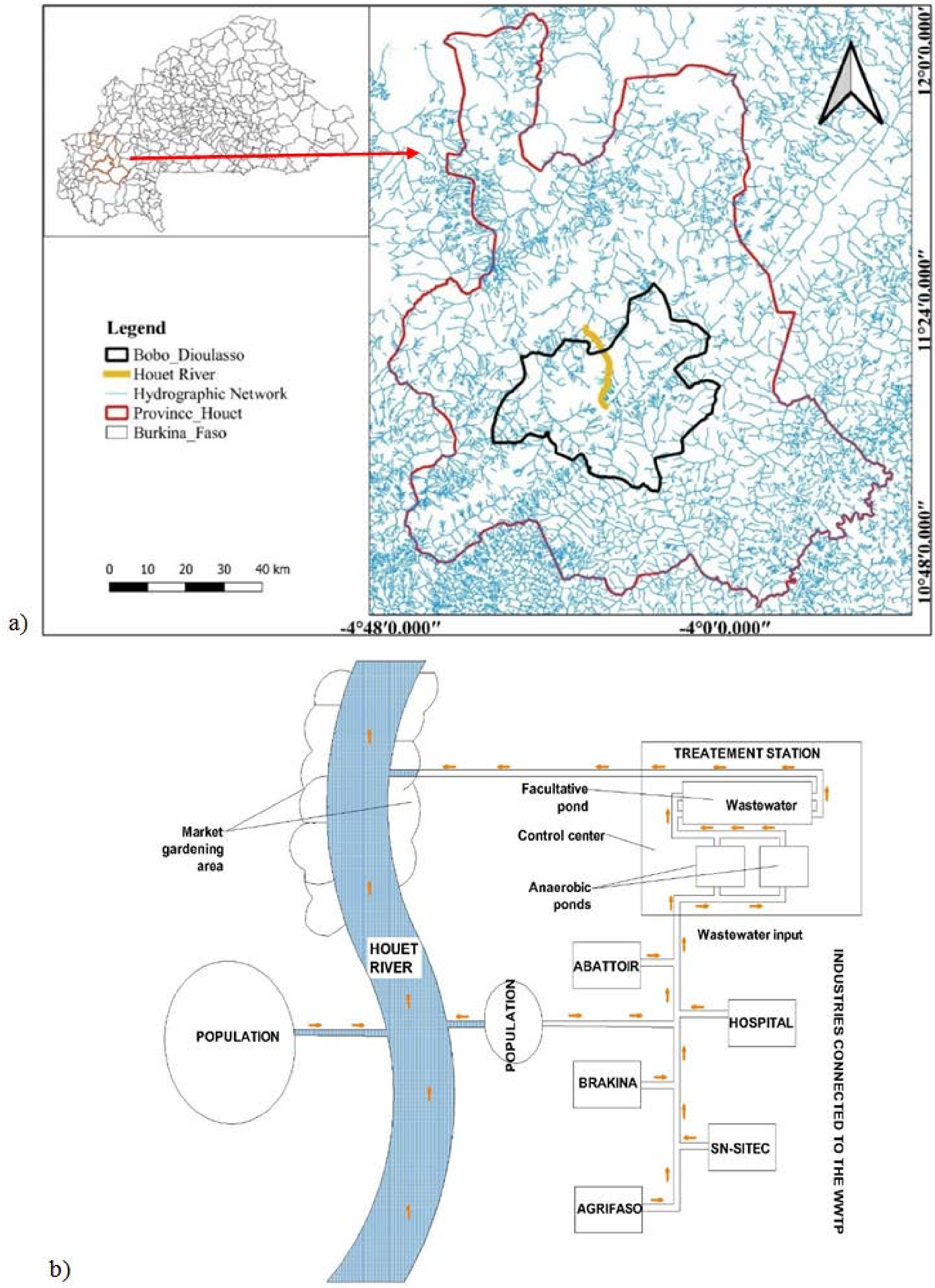

Figure 1. a) Location of the city of Bobo-Dioulasso and b) chart of Wastewater treatment unit location and interaction with Houet river

3.2. Study of Water Exchange between Groundwater and Houet river by Direct Measurements with Seepages Meters

The study of water exchange between groundwater and Houet river was based on direct measurements with seepages meters. Objective of this study is to determine the sense of water fluxes between groundwater and Houet river to ensure if the groundwater constitutes or not, a water reservoir that contributes to the river water chemistry.

To do so, the direct measurements by seepages meters in few sections of the river has been implemented. According to many authors [36,37,38], the basic concept of a seepage meter consists of enclosing and isolating a portion of the water-sediment interface of a river, with a cylinder connected at its base to a deflated plastic bag, and ventilated at the top by an aeration tube (Figure 2). The inflow of water into the bag indicates a "gaining stream" and the outflow of water a "losing stream". The exchanged water flow is calculated after a change of water volume in the collecting bag over time.

$$q_s = \frac{V_f - V_0}{t \times A} \quad (1)$$

q_s is in m/s, with V_f and V_o in m3 the final and initial volumes of water contained in the collection bag, t (s) the elapsed time, A (m2) the basal area of the main tank.

There are three possible hypotheses:

- $V_f > V_O$ and $q_s > 0$, the river gains water: "gaining river";
- $V_f < V_O$ and $q_s < 0$, the river loses water: "losing river";
- $V_f = V_O$ and $q_s = 0$, the river is in balance with the groundwater

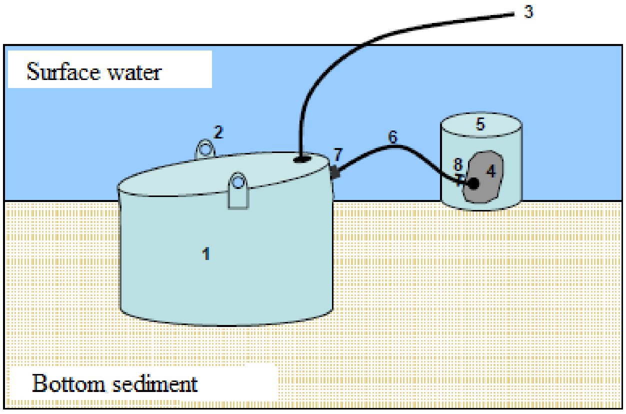

Figure 2. Simplified seepage meter model (Lee, 977)

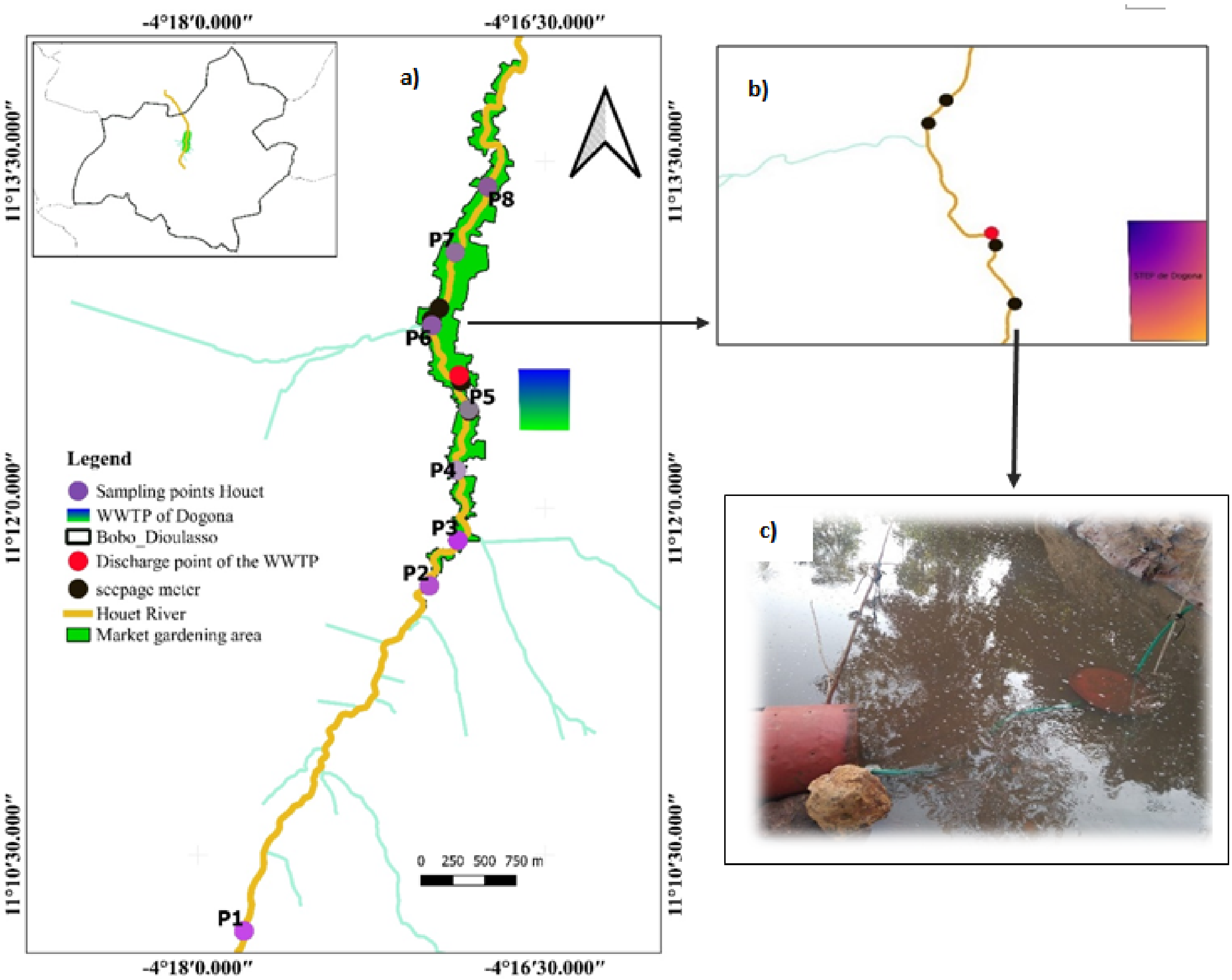

Figure 3. a) Location of the sampling points and the 4 seepage meters installed on the Houet River, b) zoom on the seepages meters points on the river, c) an example of seepage meter installed on the river

In this study, seepage meters are made from local materials according to the prefabricated design. A total of four (04) measurement sections on the Houet river were selected, two upstream and two downstream of the discharge point of the WWTP in the river. On each section, the measurements were repeated twice in order to ensure that the water exchange direction determined is correct (Figure 3).

3.2. Assessment of the Contribution of the Different Reservoirs to the Chemistry of the Houet River

The EMMA model is widely used in hydrology and quantitative hydrogeology to highlight mixing process in an environment characterized by water of different origins [39]. Based on the assumption that a water sample corresponds to the water mixing of one or more mixing components, it assumes a conservative behavior of the chemical elements used [26,40].

In this study, the EMMA method is applied as described by precited authors . It is based on the equation below:

$$\sum_{i=1}^{n} f_i = 1$$

$$\sum_{i}^{n} f_i \times C_{1,i} = C_k$$

$$\sum_{i}^{n} f_i \times C_{k,i} = C_k ; Avecf_i \geq 0$$

Where fi is the fraction of each mixing component i defined. C_{1i} and C_k are the observations of the first and second principal components for each of the mixing poles i

The methodology applied is as follows:

- The main water reservoirs which discharge into the Houet river until the point of discharge of the WWTP have been identified (WWTP, rain water, Houet river itself, and potential groundwater emergences flowing into the river).
- Potential exchange between shallow groundwater and Houet river have also be assessed.
- The collection and analysis of physico-chemical parameters of water samples from the identified reservoirs;
- Principal component analysis (PCA) method has been applied on the chemical analysis results. In fact, principal component analysis is used as a coordinate space to define the poles that define the mixing pattern of the modelled dataset and thus allows to reduce the number of data to be manipulated;
- From this equation, the concentrations of the conservative natural tracers are used simultaneously in matrix form to estimate a single value for f_i, in order to assess the relative contribution of each component to the river chemistry. If the obtained values for f_i are negative, the determined system is re-solved with the negative f set to zero. Once the values for f_i are obtained, the results are presented and commented on.

4. Results

4.1. Physico-chemistry and Microbiological Parameters

Table 1 presents the results of physico-chemistry parameters of the 8 samples from the Houet river (before and after junction to the WWTP), rainfall and pretreated wastewater of WWTPWWTP. For the Houet river, the results show high temperature values ranging from 27.7°C to 29.93°C. At very high temperatures, the plant is less able to absorb oxygen from the water, this can lead to an increase in the formation of mould (such as pythium) and harmful bacteria [46]. The pH is slightly neutral to basic with values between 7.12 and 7.73, the EC has values between 416 µs/cm and 604 µs/cm. In addition, the TDS values range from 270 mg/l to 392 mg/l confirming the trends observed in the EC, the two parameters explaining each other. The EC and TDS values show an increase in concentrations from point 6 to point 8 located on the Houet river after the discharge point of the WWTP. This is consistent with the findings of other authors who found that EC and TDS concentrations are high in the Houet river downstream of the WWTP discharge point [47,48].

All the values of the physical parameters measured (EC, pH, T°C, TDS) meet the FAO and WHO requirements for water use concentrations for irrigation. As for, the organic pollution (TSS, COD and BOD5) and mineral chemical parameters (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, NO_3^{-}, PO_4^{3-}, NH_4^{+}et NO_2^{-}), the Table 1 shows in general, the low concentrations values. They are lower than the WHO and FAO guidelines for water used for irrigation.

The presence of ammonium in surface waters is an excellent indicator of water pollution by organic discharges of agricultural, domestic (fecal pollution) or industrial origin [49,50,51].

Thus, the high concentration of ammonium in the river can probably be attributed to anthropogenic pollution from agricultural activities in the study area by the recurrent use of fertilizers, open defecation and discharge of pretreated wastewater from the WWTP. The results of the microbiological analyses recorded in Table 1 show a significant presence of bacteria (total coliforms, fecal coliforms, Escherichia coli, fecal Streptococci) with very high concentrations varying from 10^4 to 10^9 CFU/100ml and higher than the FAO standard (2000 CFU/100ml), which indicates that these waters are unsuitable for irrigation, household needs and even consumption. Use of these waters for irrigation purposes can lead to contamination of plants by micro-organisms, which can be found on the surface of the plants during growth or harvest and on the soil [52]. In fine, the concentrations of the metallic trace elements in Table 1 show the anomalous values of manganese and nickel in samples 2 and 4, while the concentrations of the remaining elements respect the standards established by the FAO for irrigation. According to these authors [53,54], the high manganese and nickel can be explained by the presence of leaching of a geological cover of ferralitic type and/or soils rich in organic fertilizer.

Table 1. Results of physicochemical, microbiological and trace metal analyses

Parameters	Houet River								WWTP		Rain	Guide value for irrigation	
	Before connection with WWTP					After connection with WWTP							
	P1	P2	P3	P4	P5	P6	P7	P8	Input	Output		WHO	FAO
T (°C)	27,7	28,3	29,93	28,7	28,28	28,7	29,2	29,3	30,7	26,83	-	18 - 40	40
pH	7,8	7,12	7,72	7,35	7,39	7,64	7,67	7,73	8,93	8,16	-	6,4 – 10,5	6,5 – 9,0
CE (µs/cm)	416	494	530	434	397	590	604	600	3515	1753	-	2000	-
STD (mg/l)	270	321	330	282	259	383	392	390	2284	1139	-	-	-
MES (mg/l)	37	84	57	47	120	61	55	66	268	94	25	150	-
DC0 (mg O2 /l)	31	52	47	79	33	70	62	60	1109	505	13	150	-
DBO5 (mg O2 /l)	10	30	30	40	20	30	30	40	380	60	5	50	-
NO_3^- (mg/L)	12,4	8,9	6,7	7,3	7,8	8,6	6,6	2,5	140	85	2,6	50	< 30
NO_2^- (mg/L)	0,012	0,009	0,023	0,028	0,014	0,015	0,009	0,003	1,3	1,2	0,2	1	-
NH_4^+ (mg/l)	1,2	6,5	5,3	5,8	4,6	7,6	6,7	6,1	72	20	0,38	1	-
PO_4^{3-} (mg/l)	0,5	2,37	0,85	1,16	1,01	1,05	1,06	1,05	77	73	0,2	5	-
K^+ (mg/l)	17	19,2	19,2	16,5	13,1	16	14,5	16	33	26	0,5	-	-
SO_4^{2-} (mg/l)	28	25	23	19	17	30	26	24	4900	1100	0	250	-
Ca^{2+} (mg/l)	43,2	49,2	48	38,4	37,6	42,8	40,4	43,2	28	21,6	1,6	500	-
Mg^{2+} (mg/l)	5,04	0,72	1,2	4,08	2,16	1,2	2,16	3,84	6,48	2,64	0	200	-
Na^{2+} (mg/l)	27	57,5	53,8	43	35	79,5	75,8	77	795	350	1	300	-
Cl^- (mg/l)	68,07	64,07	70,08	60,07	64,07	74,08	70,08	74,08	460,51	280,31	18,02	-	< 355
HCO_3^-(mg/l)	118,3	174,5	146,4	152,5	128,1	197,6	201,3	204,9	1201	662	9,76	-	< 519
Cd (mg/l)[1]	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-	0,01
Pb (mg/l) [1]	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	-	5
Mn (mg/l)	7,2	7,92	7,06	6,23	5,52	6,22	6,59	6,69	7,69	6,72	0,09	-	0,2
Zn (mg/l)	0,03	0,05	0,05	0,08	0,06	0,04	0,06	0,03	0,13	0,11	0,04	-	2
Ni (mg/l)	0,09	0,24	0	0,25	0,13	0,05	0,09	0,11	0,12	0,04	0	-	0,2
Cr (mg/l) [1]	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	0,1
Fe (mg/l)	0,97	0,38	0,94	0,03	0,19	0,64	0,47	0,88	0,63	0,68	0,72	-	5
Cu (mg/l) [1]	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	0,2
Total coliforms (UFC/100ml)	5,08 10^{8}	5,8 10^{8}	4,24 10^{8}	2,54 10^{9}	1,37 10^{9}	2,07 10^{9}	1,16 10^{9}	2,2 10^{9}	1,97 10^{10}	1,74 10^{10}	-	-	-
Faecal Coliforms (UFC/100ml)	6 10^{7}	2,53 10^{8}	3,13 10^{9}	2,38 10^{9}	2,52 10^{9}	1,73 10^{9}	1,75 10^{9}	1,75 10^{9}	1,10 10^{9}	5 10^{6}	-	2000	2000
Escherichia coli (UFC/100ml)	10^{6}	3,6 10^{7}	5,3 10^{7}	1,39 10^{8}	4,4 10^{7}	6 10^{7}	2,9 10^{7}	4,3 10^{7}	5,4 10^{8}	2 10^{6}	-	-	-
Fecal Streptococci (UFC/100ml)	10^{4}	1,1 10^{6}	2,7 10^{6}	3 10^{5}	9 10^{5}	9,5 10^{5}	3 10^{5}	7 10^{5}	9,64 10^{8}	3,2 10^{8}	-	2000	2000

[1]Detection level (D.L) [56].

Table 1 also shows, the physico-chemistry parameters analysis of the rainfall and pretreated wastewater released by the WWTP. The concentrations of T°, pH, EC, TDS, Ca^{2+}, Mg^{2+} of pretreated wastewater released by the WWTP are lower than the WHO recommendations while the COD, BOD5, PO_4^{3-}, NH_4^+, NO_2^-, Na^+, HCO_3^- and Cl^- have very high values. As for the metallic trace elements, only the concentrations of Manganese do not respect the standards values. The presence of total coliforms (TC), fecal coliforms (FC), Escherichia coli (EC) and fecal Streptococci (FSC) indicate a high level of fecal contamination of the water discharged by the WWTP.

In contrast to the WWTP discharges, all the parameters analyzed from rainfall samples show concentrations under standards values for irrigation. According to a study conducted by [55] during the dry season on the WWTP and another by [47] in 2020 at the end of the rainy season on the WWTP and its industrial effluents, the poor performance of the WWTP is explained by the poor quality of the effluents of the industrial units connected to it, the lack and poor maintenance of the WWTP.

4.2. Study of Water Fluxes between the Groundwater and Houet River

The results obtained in terms of water fluxes exchanged between the underlying groundwater and the Houet river are presented in the Table 2. The results show that in upstream and downstream of the considered WWTP discharge point in the river, the river loses water to the benefit of groundwater. The flows of water lost are approximately –3,2 10^{-3} m/d and –1,6 10^{-3} m/d respectively. The objective of this test was to determine the direction of flow exchange between these two reservoirs.

The results show that the water transfer is from the river to the groundwater, the Houet river is drained by shallow aquifer during the rainy season. According to these results, during this period the river at downstream of the WWTP is fed by (i) the pre-treated wastewater released by the WWTP; (ii) the rainfall (iii) and the river itself (at upstream of his junction with the WWTP, at point 5 in the Figure 2). As for the "underlying groundwater" reservoir, the results of the seepage meters confirm the river is drained by the groundwater.

Indeed, the shallow aquifer cannot be considered as a reservoir whose water resource contributes to the chemistry and water quality of the Houet river.

Table 2. Results obtained on the 4 functional seepage meters

Points	Number of measures	qsmin (m/j)	qsmoy (m/j)	qsmax (m/j)
Seepage 1	2	-0,0033	-0,0022	-0,0011
Seepage 2	2	-0,0048	-0,0042	-0,0035
Seepage 3	2	-0,0034	-0,0018	-0,0002
Seepage 4	2	-0,0019	-0,0013	-0,0008

4.3. Assessment of the Contribution of the Different Reservoirs to the Chemistry of the Houet River

4.3.1. Principal Component Analysis (PCA) of Physico-chemical Parameters

The Houet River downstream to WWTP point is fed by the three reservoirs mentioned above. Thus, for the application of the EMMA model of these three (3) sources of water from the river are retained as End Members, while the water at point 6 downstream to WWTP discharge point in the river constitutes the Mixing water.

The application of the PCA on the results of the analysis of the physico-chemical parameters of the water samples of the selected mixing components allowed to select according to the Kaiser criterion the first two (2) PC1 and PC2 representing 94.6% of the information of our data and are sufficient to translate exactly the information sought [57]. The results of the PCA components are presented in Table 3.

Table 3. Principal Component Analysis informations

	PC1	PC2
Eigen values	12,76333	4,26352
Variability (%)	70,9	23,7
% Cumulative	70,9	94,6
Houet river P5	-0,95691	2,60219
Rain	-3,2478	-2,2455
Output. WWTP	5,10122	-0,8541
Houet River P6	-0,89651	0,49741

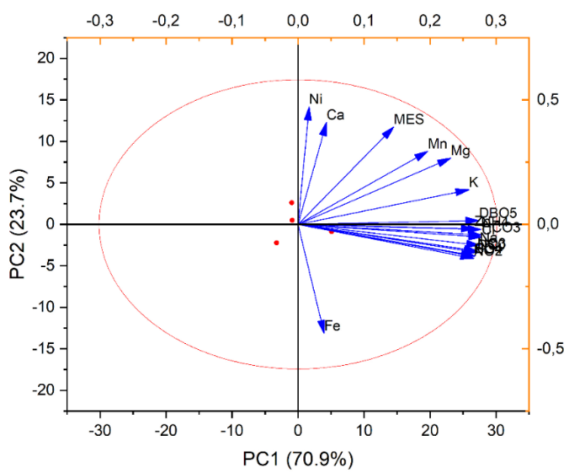

Figure 4. Projection of physico-chemical parameters on the PC1*PC2 plan

The Figure 4 gives an illustration of the variability of the data which is expressed by the factorial plane PC1*PC2.

4.3.2. Application of the EMMA Model

The first two main components of the PCA were chosen for the application of the EMMA for the assessment of the contribution of the three (03) reservoirs identified to the Houet river water chemistry. Next, the assessment of the contribution of each end member was calculated. This resulted in solving the concentration balance equation based on three mixing poles using Excel software.

The contribution of these three reservoirs: rainfall, Houet river flow from upstream of the WWTP discharge point, and pre-treated wastewater from the WWTP is represented in Table 4.

Table 4 shows that the WWTP contributes at 13.72% at the Houet river water chemistry. The contribution of rainfall and water from the Houet River upstream of the WWTP discharge point is estimated at 33.64% and 52.64% respectively.

Table 4. Contribution of different reservoirs to the Houet river chemistry

Reservoirs (Houet river water sources)	Individual contribution (%)
Rainwater	33,64 %
River water upstream of the WWTP discharge	52,64 %
Water discharged from the WWTP	13,72 %

5. Discussion

The results of the analyses of the physico-chemical, microbiological and metallic trace elements of the Houet river show that the concentrations of NH_4^+, Mn and Ni are anomalous and the existence in the waters of fecal coliforms, Escherichia coli and fecal streptococci at high levels. The results show that these anomalous concentrations vary from one section to another on the river. This could be explained by the leaching of the bedrock of the river bottom whose geology is different [58], direct discharges of domestic wastewater and some industries into the river, the leaching and drainage of irrigated land in the easement strip of the river, to which various fertilizers and pesticides are applied, as well as discharges of WWTP water whose pretreatment is not completed [26,47,48]. During 2010 year, the city of Bobo-Dioulasso produced nearly 100,000 tons of waste [59]. In addition to this domestic waste, there is industrial waste and waste from medical care activities or infectious risks. Most of this waste, which is poorly treated or not treated at all, is dumped on the ground due to non-existence of an efficient collective sewage system. This situation represents a real and potential risk of contamination of surface and groundwater.

As for the WWTP, its functioning is incomplete, as it does not have a maturation unit to refine and disinfect the wastewater and sludge from the anaerobic and facultative ponds [26]. Its anaerobic and facultative ponds are not functioning properly. Solid wastes were observed on the surface of the anaerobic pond and were related to the malfunctioning of the screening and grit removal devices.

As for the facultative pond, the water has a pink coloration and a significant amount of sludge on the surface. This is due to the proliferation of rhodophyceae and purple bacteria with a reduction in sulfates [26,55]. Some pollutions of metallic trace elements and bacteria of perennial rivers released by domestics wastes and industrials effluents had been analyzed and diagnosed on rivers in Ivory Coast [54,60,61,62,63], Algeria [64-70] in Liban [71-75]. The values of physical parameters such T°, pH, EC and TDS of the Houet river are similar to those found in other studies in the Houet river before its junction with the WWTP [48,76]. The current measurements in rainy season are much lower than dry season values found by these authors due to the dilution of Houet river by the rainfall.

According to [48], the occurrence of organic pollution parameters TSS, COD and BOD5 of the Houet river is due to the fact that large amounts of waste are found on the banks of the river, as well as frequent traces of defecation along the river during the dry season.

During the rainy season, this large quantity of pollutants is washed into the river, degrading its quality and contributing to the increase in the organic load. The variations in organic pollutant concentrations are similar to those found in the Massili river in Burkina Faso, which is the main receptacle for almost all industrial wastewater (treated or not) from the city of Ouagadougou, during the rainy season. The concentrations of Fe^{2+}, Zn^{2+} and mineral nutrients analyzed (Cl^-, SO_4^{2-}, NH_4^+, NO_2^-, PO_4^{3-}, NO_3^-) are higher than those found on the Houet river. As for microbiology, the substances and concentrations found reflect the strong presence of fecal matter. In fine, Houet river water can be used for irrigation, but the presence of metallic trace elements requires special attention and monitoring of the waters of all reservoirs.

The EMMA model used shows the contributions of different sources that may be responsible of the chemical quality of Houet river water. The Houet river itself before its junction of the WWTP contributes significantly to its chemistry and quality. The contribution of pretreated wastewater which is released by the WWTP may be more pronounced during the dry season where anthropogenic activities (brick making, gardening, dish washing, etc.) and irrigation activities along the banks are more important.

6. Conclusion

Present study of the Houet river water quality, has shown that its quality remains intrinsically linked to the reservoirs that feed it, notably the wastewater pretreated and released by the WWTP, the rainfall and the river itself. Even if the physico-chemical quality is in-line and remains acceptable regarding to the standards purposed by WHO and the FAO, the presence of TME such as manganese, nickel, iron and zinc requires a regular monitoring of Houet river and specifically the WWTP discharges.

Microbiological analysis indicated high microbial contamination suggesting also adequate management of human feces littering both sides of the river banks. The application of the EMMA model showed that the WWTP contributes about 13.72% to the chemistry of the Houet river. The pretreated wastewater by the WWTP being continuously released into the Houet river would induce over time a regular variation of the physico-chemical and microbiological parameters of the river, which could reduce its quality for market gardening. However, by improving sanitation in the city of Bobo-Dioulasso, it will be possible to control and reduce the unhealthy effluents released into the Houet river and the underlying aquifer which drains it and thus reduce their negative impact on their quality.

Author Contributions

Investigation, Methodology, D.L.Z., S.É.S.G. and C.H.M.M.; Conceptualization, Formal analysis, Data curation, Software, Draft preparation, Visualization, Writing—original draft, Writing—review and editing D.L.Z., S.É.S.G., C.H.M.M and K.M.A.A; Validation, Supervision, S.É.S.G. and C.H.M.M; K.H. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

Not applicable.

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Conflicts of Interest

The authors declare no conflict of interest.

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