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Agricultural Valorization of Treated Effluent from Korhogo Wastewater Treatment Plant

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Authors' contributions

This work was carried out in collaboration among all authors. Author KYS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SB managed the analyses of the study. Author KNL managed field experiments and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The main objective is to evaluate the effluents of Korhogo's wastewater treatment plant for irrigation and fertilization in agriculture.
Study Design: Characterization of outlet treated wastewaters has been firstly done. Then their suitability for irrigation has been determined and finally their fertilizing power has been assessed.
Place and Duration of Study: Department of geosciences, Korhogo's wastewater treatment plant and laboratory. Sampling and analyses were carried out in January 2023, before agricultural field implementation started in February 2023.

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Methodology: Firstly, Physico-chemical and microbiological analyses, allowed characterization of outlet treated wastewaters. A determination of their suitability for irrigation was then done through Sodium Adsorption Ratio calculation and water classification with Diagram of Richards. An assessment of their fertilizing capacity was finally carried out using these waters for irrigating and fertilizing crop plots (3x2 m), and consisting of determining firstly their biodegradability index, then their nutrient contents (Nitrogen, Phosphorus and potassium), and the influence of their use on crop development and yield.

Results: The results show that several parameters meet standards for discharge of treated wastewater except total nitrogen, suspended matters and total phosphorus (67.67 mg/l, 271.33 mg/l and 18.30 mg/l). Sodium Adsorption Ratio (SAR) value=3.78 and C3S1 class indicate that these treated effluents can be used for irrigation without salinization risk. As fertilizer, treated effluents brought to crops respectively 603 kg/ha of nitrogen, 162 kg/ha of phosphorus and 99 kg/ha of potassium for maize; and 368.5 kg/ha of nitrogen, 99 kg/ha of phosphorus and 60.5 kg/ha of potassium respectively for Okra. A yield of 12.2 kg of fresh maize and 3.15 kg of fresh okra was obtained for the plot irrigated by treated effluents, compared with 4.80 kg of fresh maize and 0.36 kg of fresh okra for the plot irrigated by well water.

Conclusion: This study has shown that outlet treated wastewater from Korhogo's wastewater treatment plant is suitable for crops irrigation, contains sufficient nutrients enhancing crops development and yield.

Keywords: Korhogo; treated wastewater; valorization; agriculture; maize okra.

1. INTRODUCTION

The UN's 2019 report on Food Security and Nutrition in the World, indicated the rising hunger in almost all African subregions. This makes Africa the area with the highest undernourished population, with nearly 20% according to (African Development Bank, 2020). To resolve this problem and ensure food security, it is imperative to increase agricultural production. This involves using agricultural inputs such as chemical fertilizers to improve soil fertility and agricultural productivity. However, the high cost of these inputs, combined with the significant financial lack of farmers, constitutes a major impediment to agriculture development in Africa, not to mention the adverse effects of these fertilizers on the environment, particularly on the aquatic environment. Therefore, low-cost, efficient and environmentally friendly alternatives should then be found to improve agricultural output in Africa. Thus, several studies have been carried out to improve agricultural production, precisely that of (Naitormbaide, 2012) on the impact of manure and crop residues management on soil productivity in savannahs. In the other hand, one of the most promising solutions could be found in widely available wastewaters in septic systems in most of the cities in sub-Saharan Africa (Montangero and Strauss, 2002). Indeed, self-contained sanitation facilities, such as septic tanks, latrines, public toilets, are devices that store huge amounts of sewage sludge (Strauss et al., 2003). Wastewaters are drained, transported to treatment plants where appropriate treatments are applied. At these stations, wastewaters follow several treatment steps in order to separate solid particles from liquid fraction. Solid fraction is collected and then dried to remove most of the pathogens. Liquid phase, after several so-called aerobic and anaerobic steps, is released to the environment downstream of treatment plant (Strande et al., 2018). By-products of these two treatments mentioned above, which are proven to be available throughout the year, would contain nutrients necessary for plant growth (World Health Organization, 2012). Their use in agriculture could contribute not only to improving agricultural productivity, but also to recycling water (saving on water resources) and nutrients, and above all to reduce environmental impact of these sludges (World Health Organization, 2012). In Côte d'Ivoire, the treatment of waste wastewaters has been the subject of particular attention in recent years through the construction of several treatment plants, including that of Korhogo (pilot station). By-products of wastewaters treatment which are dried sludges and treated effluents are not exploited or valorised (Kouakou et al., 2019). Treated wastewaters could be used as a fertilizer in place of mineral fertilizers used by farmers downstream the treatment plant, where okra and maize are the most grown plants along the year. However, attention should be paid on the risks of accumulation of heavy metals in plants grown on soil irrigated by wastewaters or treated wastewaters (Abdelgawad et al., 2023, Nowwar et al., 2023 and Aftab et al., 2023). It is in this context that the present study was initiated which the main objective is to show fertilizing ability of these treated effluent in agriculture and specific objectives are:

- Characterize treated wastewaters from Korhogo's wastewater treatment plant;
- Determine their suitability for irrigation;
- Assess their fertilizing capacity in agriculture.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Water and data analysis

Two types of measurement were carried out: in-situ measurements (temperature, pH and conductivity) and laboratory measurements (phosphates, nitrates, nitrites, dissolved matters...). Measurements of pH and temperature were carried out using a multi-parameter HACH 1000 apparatus. Electrical conductivity was measured with a portable 3310 SET1 conductivity meter. A HACH/DR 1900 spectrophotometer was used to analyze chemical parameters in the laboratory. Microbiological analysis results have been done by the laboratory of National Sanitation and Drainage Office (ONAD). Data analysis hardwares includes SAR/Conductivity cross-index table of Richards and Origin 8.0 software.

2.1.2 Agricultural site implementing materials

Two vegetal species were used in this study as shown in Fig. 1. First plant used is a variety of okra (*Abelmoschus esculentus*) F1 RAFIKI hybrid from Technisem structure. This variety growing cycle is between 3 and 4 months. Second plant is an improved maize variety (*Zea mays*) called N'GOUACHIA, which has a growing cycle about 55 days.

2.2 Methods

2.2.1 Characteristics analysis of treated wastewaters from Korhogo Station

Three sampling campaigns for physico-chemical and microbiological analyses were carried out in January (dry period), before agricultural site implementation in February. Water sampling was carried out at aerobic tank exit. Two types of measurement were carried out: in-situ measurements (temperature, pH and conductivity) and laboratory measurements (phosphates, nitrates, nitrites, suspended matters…). Methods of physico-chemical and microbiological analysis of parameters are summarized in Table 1.

2.2.2 Determination of treated wastewater suitability for irrigation

Determination of treated wastewater convenience for irrigation was based on the capacity of soil salinization and alkalinisation by these treated wastewaters according to results of pH, conductivity and Sodium Absorption Ratio (SAR). The SAR is calculated from equation 1 below, proposed by (Richards, 1954). The SAR/Conductivity cross-index was used to determine treated effluents class based on Table 2.

Equation 1: $$\boldsymbol{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Fig. 1. Okra and Corn Seeds

Table 1. Parameters and methods of treated effluents analysis

Parameters	Method references	Methods
PH	NFT 90-008	Electrochemical measurement with HACH multi-parametric probe glass electrode.
Conductivity	AFNOR 90-031.	Portable conductivity meter type 3310 SET1 associated with a diving electrode.
Temperature	NFT 90-100	Measurement by a HACH multi-parametric probe.
Phosphates	NF EN ISO 6878	Phosphorus determination by the ammonium molybdate spectrometric method.
Ammoniums	NFT 90-015-2	Formation in alkaline medium of an indophenol-type compound and spectrometric measurement at 630 nm.
Nitrates	ISO 7890-3	Formation of sodium paranitro-salicylate, colored yellow and spectrometric measurement at 415 nm.
Nitrites	NFT EN 26777	Formation in acidic medium of a purple colored complex and spectrometric measurement at 543nm.
Suspended matters	NF EN 872	Glass fiber filtration and gravimetry
Total Phosphorus	NF EN ISO 6878	Decomposition and determination of phosphorus by the ammonium molybdate spectrometric method.
Total Nitrogen	NF EN 25663	Decomposition and dosage of nitrogen.
COD	ISO 15705	Determination of chemical oxygen demand (closed tube method)
BOD_5	METHOD Oxi Top	Mercury-free respirometric measurement.
TOC	NF EN 1484	Oxidation by combustion and dosage by infrared spectrometry.
Fecal coliforms	NF EN ISO 9308-1	Fecal coliform count.
Helminth eggs	SAF Method	Use of the sodium-acetate-acetic acid-formaldehyde solution.
Calcium	AFNOR T90-016	Calcium determination – EDTA titrimetry method
Magnesium	AFNOR T90-003	Determination of total magnesium concentration
Sodium	Flame spectrometer	Heating metal ions in a sample to detect silty emissions using a detector
Potassium	Flame spectrometer	Heating metal ions in a sample to detect silty emissions using a detector

NF: French Norm, EN: European Norm, ISO: International Organization for Standardization, AFNOR: French Association of standardisation

Table 2. Water classes based on SAR/Conductivity cross-index

RAS/Conductivity	Indication
C1S1	Water usable for most crop species and soil
C1S2	Usable water for most crop species soil must be well drained and leached
C1S3	soil must be well prepared, well drained, well leached, addition of organic matter relative Na content can be improved by the addition of gypsum
C1S4	Water difficult to use in poorly permeable soils soil must be well prepared, very well drained and leached, addition of organic matter relative Na content can be improved by the addition of gypsum
C2S1	Water suitable for plants with a slight salt tolerance
C2S2	Water suitable for plants with a slight salt tolerance Coarse or organic soil with good permeability
C2S3	Water suitable for plants that have some salt tolerance Coarse, well-prepared soil (good drainage, good leaching, addition of organic matter)

RAS/Conductivity	Indication
	Periodic addition of gypsum may be beneficial
C2S4	Water generally not suitable for irrigation
C3S1	Water suitable for plants that have good salt tolerance Well-prepared soil (good drainage) Periodic monitoring of salinity changes
C3S2	Water suitable for plants that have good salt tolerance Coarse or organic soil with good permeability, good drainage Periodic monitoring of salinity changes Periodic addition of gypsum may be beneficial
C3S3	Salt tolerant species Very permeable and well-drained soil
C3S4	Water not suitable for irrigation
C4S1	Water not suitable for irrigation under normal conditions Can be used if the species has good tolerance to salinity and the soil is particularly well drained
C4S2	Water not suitable for irrigation under normal conditions Can be used if the species has very good tolerance to salinity and the soil is particularly well drained
C4S3	Water not suitable for irrigation
C4S4	Water not suitable for irrigation

2.2.3 Assessment of treated wastewater fertilizing capacity

Fertilizing capacity was determined by assessing treated effluents biodegradability, calculating nutrient content (nitrogen, phosphorus and potassium) delivered to crops through watering with treated wastewater and evaluating the effect of treated effluents of treated effluents on crops vegetative development and yield.

Treated effluents biodegradability of was determined through the coefficient K, which is COD/BOD_5 ratio (Rodier, 2009) and value of C/N ratio. According to (Bordet, 2007), level of biodegradability is defined according to values of coefficient K indicated below:

$K<2,5$ readily biodegradable effluents;
$3<K<5$ moderately biodegradable effluents;
$K>5$ effluents which is difficult to biodegrade.

(Giroux and Audesse, 2004) define C/N as an indicator of organic matter evolution degree, i.e. its ability to decompose more or less rapidly in soil. A high C/N ratio indicates slow decomposition rates of organic matter, while a low C/N ratio suggests rapid decomposition rates.

$C/N < 15$: Nitrogen production, the rate of decomposition increases, peaking at a C/N ratio of 10.

$15 < C/N < 20$: need for nitrogen covered to allow good decomposition of the carbonaceous material.

$C/N > 20$: Not enough nitrogen to allow carbon decomposition (there is competition between uptake by plants and reorganization of organic matter by soil microorganisms, this is the phenomenon of “nitrogen hunger”). Nitrogen is then taken from the reserves of the soil. Mineralization is slow and only releases a small amount of mineral nitrogen to the soil.

Nutrient contents (nitrogen, phosphorus and potassium) in treated effluents were calculated using formula in Equation 2. The found values were then compared to the CNRA recommendation.

Equation 2: $\mathbf{T} = \frac{\mathrm{Cm\ x\ V\ x\ n}}{\mathrm{S}} \mathrm{x}\ N$

T : Nutrient content of Nitrogen, Phosphorus or Potassium (mg/m2)
Cm: Average concentration of each nutrient (N, P, K) supplied to the plant.
V: Volume of watering can
n: Number of watering tower provided to plants per day.
S: Area under cultivation
N: Number of days in the culture cycle

Effect of using treated effluents on crops vegetative development and yield was evaluated through field experiments. Two plots have been set up with a log area of 6 m2. Each plot was watered either by well water (usually used by farmers as water for vegetable crops) or by water from treated effluents. Experiments were carried out on two crops, maize and okra. Maize and okra seeds were planted directly by hand on ridges made with hoe. Distance between lines was 75 cm and 40 cm between seed holes, resulting in 48 seed holes on a ridges. Watering was done twice a day, manually using a watering can of 15 L. Size of each plant was measured weekly during 9 weeks from date of sowing. Plants were treated 3 times throughout the crop cycle with insecticide ‘kapaas’ to control pests.

2.2.4 Statistical analysis

The Statistical analysis has been done with Origin 8.5. For physicochemical parameters, samples data were entered in the software. Then Mean and Standard Deviation were generated. One-way ANOVA test was done to get F Value, Prob>F and R-Square in order to state whever the population means are significantly different or not. For growth kinetics of corn and okra irrigated with treated influents and well water, average maximum heights of plants were determined by generating characteristics of the Nonlinear Curve with Slogistic3 method.

3. RESULTS AND DISCUSSION

3.1 Characteristics Analysis of Treated Wastewater from Korhogo’s Station

The results of physico-chemical parameters analyses (Table 3) show that pH values (between 8.31 and 9.47) comply with WHO recommended standards (between 6.5 and 9.5) for discharge and reuse of treated effluents. These values, similar to (Alhou, 2007 and Abdelbasset et al., 2002) results, would promote easy dissolution of nutrients contained in treated effluents according to (Canna, 2010, Lambert, 2000 and Carrier, 2003).

Conductivity values range from 1593 µS/cm to 1998 µS/cm with a mean value of 1740.27 µS/cm. These results meet standards for discharge of treated effluents and reuse for agriculture, and are similar to those found by (Passy, 2007 and Khamis, 2015) for treated wastewaters in Ouagadougou.

For suspended matters, values range from 124 mg/l to 530 mg/l with a mean of 271.33 mg/l. These results exceed WHO recommended values for discharge of treated effluent and for reuse in agriculture. Average is higher than the results of (Amadou et al., 2011) for domestic treated wastewater in the city of Niamey (141 mg/l). This high value of suspended matters may be due to algal growth in aerobic tank before effluent discharge. This development may be due to high phosphorus levels in treated wastewater (Kouakou et al., 2019). Such value of suspended matters could affect receiving medium and cause clogging phenomenon of soil, leading to a reduction in the amount of available soluble nutrients for plant roots (Abdelbasset et al., 2002). Also, it could have adverse consequences for crops because clogging means a reduction of pores in the soil which are spaces used for roots and liquids.

COD, TOC, BOD_5, Na+, Ca2+, and Mg+ mean values are respectively 413 mg/l, 77.20 mg/l, 131 mg/l, 209.63 mg/l, 278.33 mg/l, 129.83 mg/l. These results are consistent with WHO treated wastewater discharge standards. However, mean values for total nitrogen, nitrates, nitrites, ammonium and total phosphorus exceed WHO standards (50 mg/l for nitrogen, 50 mg/l for nitrates, 50 mg/l for nitrites, < 2 mg/l for ammonium and 15 mg/l for total phosphorus). These parameters had mean values of 67.67 mg/l, 186 mg/l, 10.77 mg/l, 27.20 mg/l, and 18.30 mg/l, respectively.

Statistical analysis (Table 3) shows that deviations are high and at level 0.05 sample means are significantly different through the ANOVA test, with F=64.99 and Prob>F=0. These values mean that composition of treated wastewater varies significantly from day to day. This could be explained by the difference in wastewater characteristics from diverse septic tanks. Other reason could be the applied treatment which does not depend on physico-chemical and microbiological content of wastewaters entering in Korhogo station.

Excessive amount of nitrogen could have adverse environmental impacts. On the one hand, high content of nitrogen can cause groundwater contamination in highly permeable soil and delay the maturation of certain crops (Faby and François, 1997).

High phosphorus content results in the proliferation of algae (green color) in finishing tank (Benamar and Boultouak, 2016) and aquatic plants downstream. This can affect development of aquatic wildlife (Lakte, 2006, Sou et al. 2008). For microbiological analysis (Fig. 2), results show a total coliform content of 3.03 10^6 CFU/100 ml, fecal coliforms content of 7.73 10^4 CFU/100 ml and E. Coli content of 1.06 10^4 CFU/100 ml. These results are higher than standards, which are 1000 CF/100 ml for these various germs (World Health Organization, 1989). These values are similar to results of (Louaguenouni, 2017) on monitoring treated wastewater quality of BARAKI treatment station for agricultural reuse. According (World Health Organization, 1989), reuse of such treated wastewater for agriculture, from a bacteriological point of view, must be done carefully.

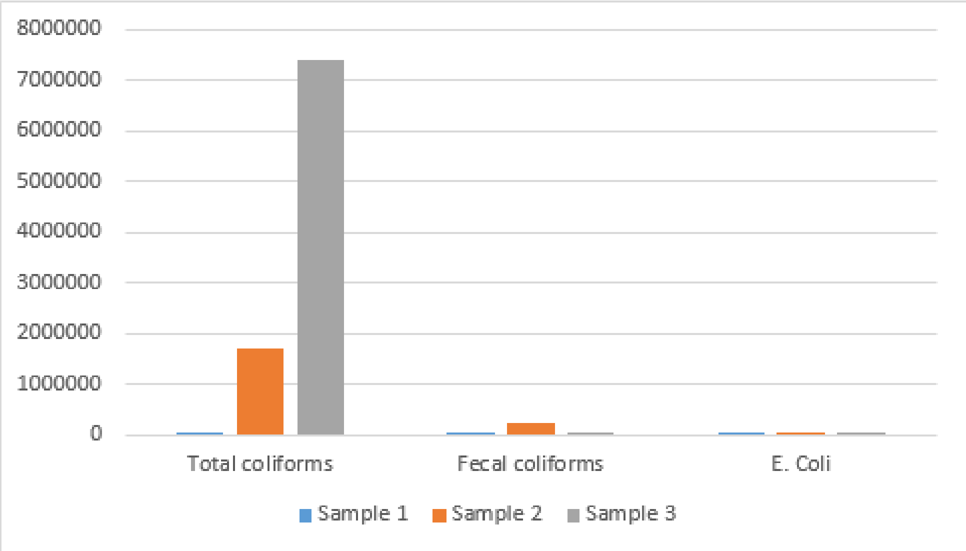

Fig. 2. Microbiological analysis

Table 3. Statistical analysis of physicochemical parameters

	Sample Size	Mean	Standard Deviation	SE of Mean	
Nitrites	3	10.772	9.55987	5.51939	
pH	3	8.90333	0.58046	0.33513	
Conductivity	3	1740.26667	224.29708	129.49798	
T°	3	25.46667	2.72091	1.57092	
Suspended matters	3	271.33333	224.73392	129.75019	
Ammonium	3	27.2	22.27375	12.85976	
Total Nitrogen	3	67.66667	50.73789	29.29353	
Phosphates	3	24.76667	20.47592	11.82178	
Total Phosphorus	3	18.3	5.24214	3.02655	
COD	3	413	172.37459	99.52052	
TOC	3	77.2	50.21195	28.98988	
BOD_5	3	131	18.52026	10.69268	
Na+	3	19	9.64365	5.56776	
Ca2+	3	12.01	7.54787	4.35776	
Mg2+	3	13.33333	11.15049	6.43774	
K+	3	11.66667	1.52753	0.88192	
	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	15	8.36E+06	557657.347	64.99279	0
Error	32	274569.438	8580.29495		
Total	47	8.64E+06			
	R-Square	Coeff Var	Root MSE	Data Mean	
	0.96822	0.51606	92.62988	179.49283	

At the 0.05 level, the population means are significantly different

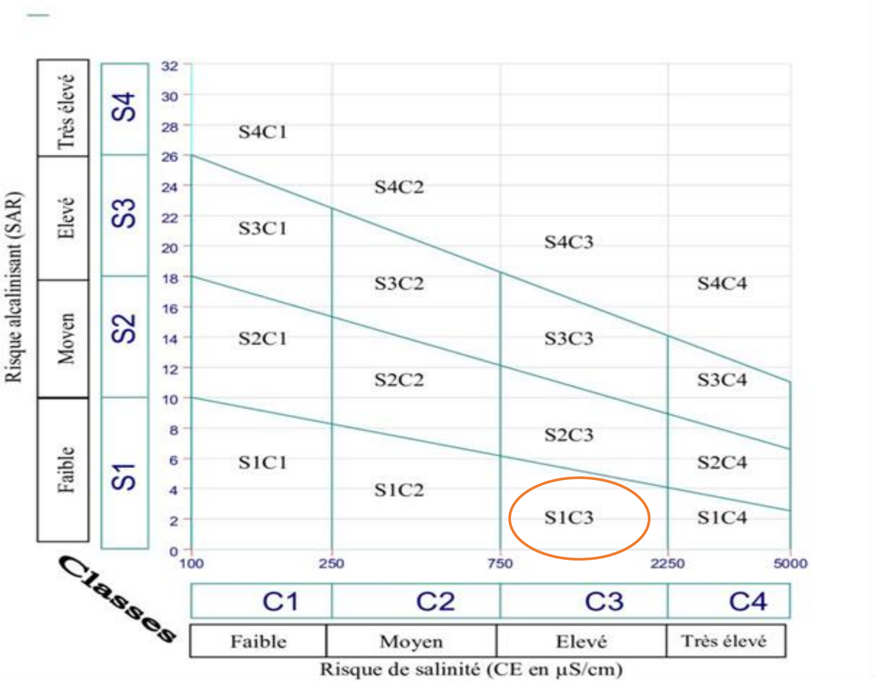

Fig. 3. Irrigation water classification diagram (Richards, 1954)

3.2 Ability of Treated Effluents for Irrigation

Based on results presented above, pH between 6.5 and 9.5 and conductivity not exceeding 3000 µs/cm, it appears that wastewaters used in the present study would not present any risk of soil salinization (Kakou, 2021). They could therefore be applied as irrigation water, according to the standard for agricultural reuse of treated waste water. However, average SAR value of 3.78 (between 3 and 9 meq/l) indicates that treated wastewater has a minor restriction. Sodium Adsorption Rate describes amount of sodium in excess in relation with calcium and magnesium cations that can be tolerated in irrigation water (Bouaroudj and Kadem, 2014). Finally, S1C3 class determined according to Richards diagram (Fig. 3), which is a combination of SAR and conductivity, shows that these treated wastewaters could be used without special control for irrigation of crops moderately tolerant to salts, on well-drained or well-permeable soils. However, quality of an irrigation water can only be established according to the soil that receives it and the crop to be grown (Rodier, 2005).

3.3 Assessment of Treated wastewater Fertilizing Capacity

Fertilizing capacity was assessed according to 3 parameters: nutrient content (N, P, K), biodegradability (K and C/N) and effect of treated wastewater use on crop development and yield.

3.3.1 Treated effluent biodegradability and nutrient content

Average biodegradability index (COD/BOD_5) of treated wastewaters from Korhogo is 3.15. This result, between 3 and 5, means that treated effluents are moderately biodegradable (Louaguenouni, 2017). Mean value of C/N ratio obtained is 1.14. This value, which is less than 15, shows that the organic matter contained in treated effluents could degrade rapidly and produce significant quantity of nitrogen during its decomposition (Giroux and Audesse 2004). More rapid the decomposition is, more plant needs are met in real time. This would allow for good growth and yield. When C/N is high than 15, organic matter would decompose more slowly in soil. Inputs of nitrogen would then be required to cover the requirements in order to allow a good decomposition of carbon material (Jean et al., 2011).

For treated wastewater used in this study, amounts of nutrients (N, P, K) provided (Table 6) are 61200 mg/m2 or 612 kg/ha nitrogen, 16200 mg/m2 or 162 kg/ha phosphorus and 10800 mg/m2 or 108 kg/ha potassium, respectively for okra. For maize, 37400 mg/m2 or 374 mg/ha nitrogen, 9900 g/m2 or 99 kg/ha phosphorus and 6600 mg/m2 or 66 kg/ha potassium. Average nutrient content (N, P, K) is well above standards recommended by CNRA. According to CNRA's technical data sheet, 250 kg/ha of NPK is required to grow okra (10-18-18). For maize, 250 kg/ha of NPK (15-15-15) is required. This is equivalent to 25 kg/ha nitrogen and 45 kg/ha phosphorus and potassium for okra. For maize, this corresponds to an intake of 37.5 kg/ha of each of the 3 elements. These high levels of nutrients, provided by treated wastewaters, are expected to have a negative impact on plants through toxicity and may cause plants death (Lakte, 2006). However, in the case of the present study, plants developed normally. This situation could be explained by well-drained soil leading to an infiltration of some provided nutrients according to (Fox et al., 2007) or the degradation of accumulated organic matter and nutrients in soils (Shah et al., 2024). This study revealed the existence of microorganisms in different qualities of soils having complex nature that were irrigated by wastewater. (Shah et al., 2020) works also show that *T. viride* comprises the higher inhibitory response towards several soil-borne infectious and pathogenic fungi that harm economically important food crops.

3.3.2 Effect of the use of treated effluents on vegetative development

Effect of the use of treated effluent on crop development and yield was assessed based on germination rate and time, plant size during growth, and harvest yield. On maize plot irrigated with treated effluents, germination rate was 95% (Table 5), compared with a germination rate of 82.5% for the plot irrigated with well water. For okra, a germination rate of 87.5% on the plot watered with the treated effluent was obtained, compared with a germination rate of 85% for the plot treated with well water. Germination rate fluctuates between 82.5% and 95%, which indicates good quality of grains (references). Furthermore, it should be noted that germination rates are slightly higher on plots watered with treated effluents and a much longer germination time for plots watered with well water. In fact, maize and okra grains started germinating on 4th day on plot irrigated with treated wastewaters, contrary to those of plot irrigated with well water, where 6 to 7 days were required for germination. This indicates that treated effluents would contain elements favouring rapid germination of seeds compared to well water. These results are consistent with those reported by (Goalbaye, 2014). with a time of 3 to 4 days between maize grains sowing and emergence. According to (Maybelline and Maiga 2012), germination of maize (emergence) takes place between the 4th and 8th days. For okra, this emergence takes place between 7 and 10 days after sowing (Fondio et al., 2007).

Fig. 4 shows evolution of the average height of maize (a) and Okra (b) plants on ridge watered with treated effluents and ridge irrigated with well water. For maize, it should be noted a difference in size of approximately 3 cm at 2 weeks after sowing, reaching a difference of approximately 36 cm after 9 weeks of sowing. This difference is in favor of plants watered with treated effluents. For okra, the difference in size is about 1.5 cm at 2 weeks after sowing, reaching a difference of about 32 cm at 9 weeks of sowing, also in favor of plants watered with the treated effluents. These results indicate that treated effluent would improve plant growth compared to well water. This is consistent with results of (Shah et al., 2022) where domestic wastewater and Lyari wastewater significantly improved the germination (%) and growth of *A. esculentus* and *P. vulgaris*. Studies of (Basheer et al., 2022) also revealed the impacts of agricultural waste amendments like alfalfa, rice husk and wheat straw on the growth of *A. esculentus*. Fig. 4 also shows representative curves of maize and okra plants growth kinetics, with a correlation coefficient above 99.3%. These curves are Slogistic3 sigmoid type and are expressed by equation 3. These graphs have a threshold at Y=a (Fig. 5), representing average maximum size that corn and okra plants can reach before flowering period. Fig. 6 shows plants height at 6 weeks. In the present study, as shown in Table 6, maize average maximum height is respectively about 234 cm for plants watered with treated effluents and about 195 cm for plants irrigated with well water. These results are consistent with works of (Diallo et al., 2016 and Goalbaye et al., 2019), on certain varieties of maize with average stem heights between 1.5 and 3 m in height. For okra, average maximum height (Table 6) is respectively approximately 90 cm for plants watered with treated effluent and approximately 15 cm for plants irrigated with well water. These results, in particular for plants watered with treated effluents, are in accordance with works of (Fondio et al., 2007), according to which height of okra varieties would generally be between 50 cm and 2.50 m.

3.3.3 Effect of the use of treated on crop yield

At the end of the experiment, 3.15 kg of okra were harvested from ridge irrigated with treated wastewater, compared with 0.36 kg from ridge irrigated with well water. Harvest on ridge irrigated with treated wastewater is about 9 times higher than that on ridge irrigated with well water (Fig. 7). For maize, 12.2 kg of fresh ears were harvested on ridge where treated wastewater was used for irrigation, compared with 4.80 kg on ridge where well water was used, with a superiority ratio of 2.50. This improvement in production on ridge irrigated with treated effluent could be explained by the presence of sufficient nutrients in these waters (Naika et al., 2005). These results are consistent with those of (Lakte, 2006), which studied fertilizing ability of treated wastewater for vegetable crops in Burkina Faso (Loumbila commune).

Table 4. Nutrient contents (N, P, K) provided by treated effluents

	Experimental values		CNRA values	
	Okra	**Maize**	**Maize**	**Okra**
Nitrogen (Kg/ha)	374	612	37,5	25
Phosphorus (Kg/ha)	99	162	37,5	45
Potassium (Kg/ha)	66	108	37,5	45

Table 5. Germination rate of Maize and Okra

	Germination rate %	
	Treated wastewater	**Well water**
Maize	95	82.5
Okra	87.5	85

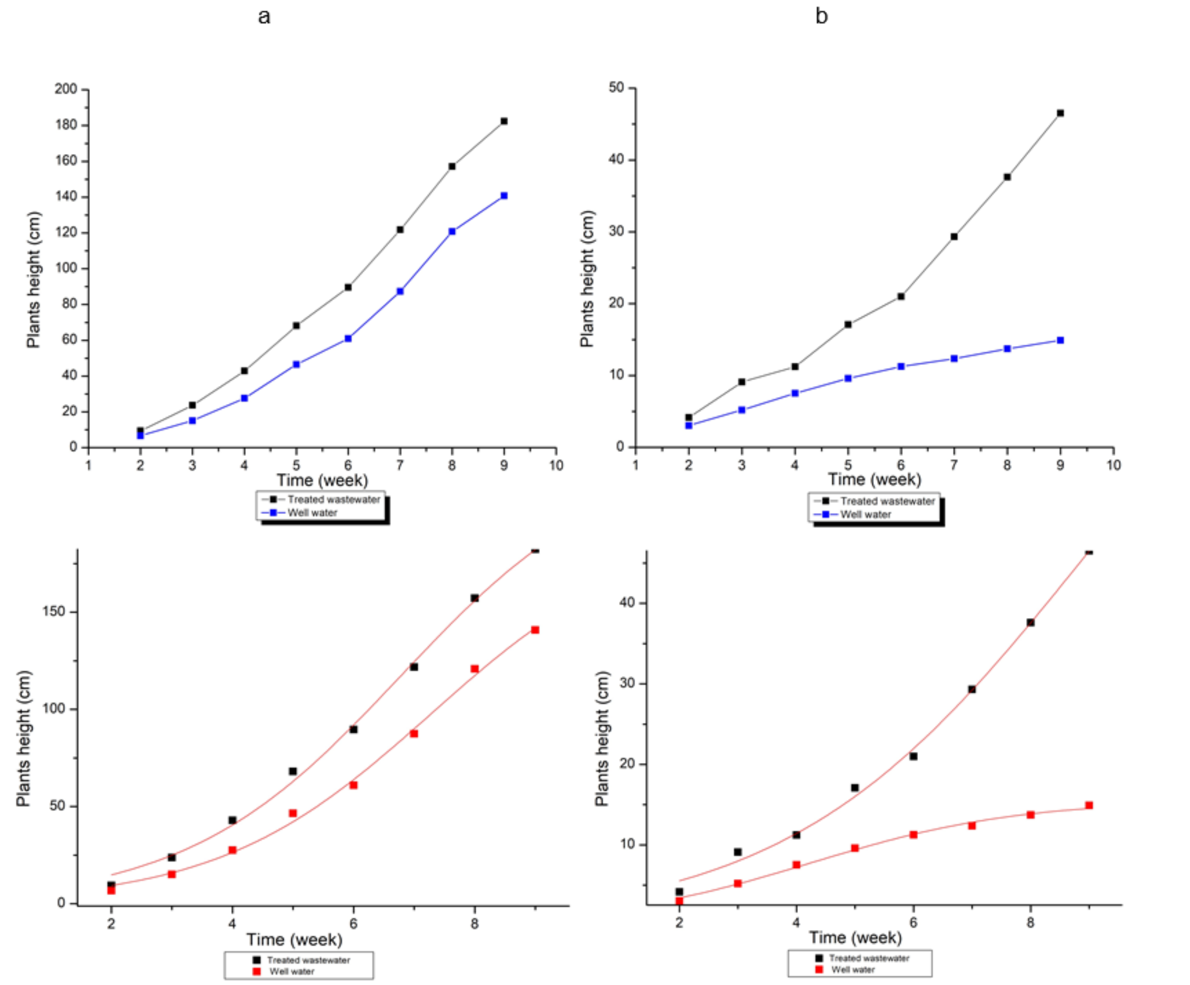

Fig. 4. Growth kinetics of maize (a) and okra (b) irrigated with treated influents and well water

Equation 3: $y = \frac{a}{1+be^{-kx}}$

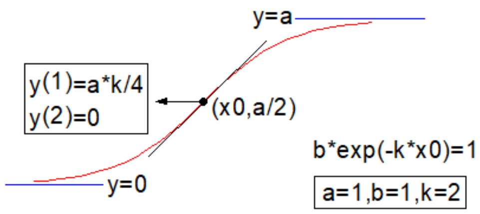

Fig. 5. Determination of the average maximum height of corn and okra plants

Fig. 6. Okra and corn plants at 6 weeks

Fig. 7. One-day harvest from plots irrigated with treated effluent (top) and well water (bottom)

Table 6. Statistical Analysis of Growth Kinetics of corn and okra

		a		b		k		Statistics	
		Value	**Standard Error**	**Value**	**Standard Error**	**Value**	**Standard Error**	**Reduced Chi-Sqr**	**Adj. R-Square**
Corn	Treated wastewater	234.098	17.126	45.469	7.432	0.563	0.045	15.528	0.996
	Well water	195.443	19.272	61.531	11.302	0.566	0.05	11.088	0.995
Okra	Treated wastewater	90.390	19.521	33.937	4.132	0.398	0.041	1.038	0.995
	Well water	15.519	0.566	10.927	1.736	0.564	0.051	0.131	0.993

4. CONCLUSION

The present study has shown that treated domestic wastewater contains sufficient nutrients to be an alternative to mineral fertilizers used in vegetable crops downstream of wastewater treatment plant of Korhogo, along the discharged treated water flow bed. Analyses revealed compliance of majority of physico-chemical and microbiological parameters with WHO standards for treated wastewater discharge, except total nitrogen, nitrates, nitrites, ammonia, dissolved matters and total phosphorus which have average values slightly above standards. Richards diagram, which classifies irrigation water by relating SAR to conductivity, assigned class C3S1 to treated effluents. These waters can therefore be used without any particular control for the irrigation of crops that are moderately tolerant to salts, on well-drained or well-permeable soils. Assessment of fertilizing capacity through COD/BOD_5, C/N ratios and NPK content shows that organic in these waters is rapidly degrading and treated effluents contain sufficient nutrients to support better crop growth and productivity. The use of treated waters from Korhogo wastewater treatment plant, as irrigation water, leads to an improvement in crops development, particularly about germination, growth and yield, with a productivity approximately 7 times compared to well water.

In terms of perspective, it would be interesting carried out further studies in order to:

- Analyze treated effluents and well water, and study significantly their irrigation suitability over a long period, even a year, with regular weekly or monthly campaigns;
- Carry out a comparative study using treated effluents and chemical fertilizers on large plots to confirm the results obtained, and analysis heavy metals accumulated in plants irrigated by treated wastewater to assess the nutritional.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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