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Impacts of Anthropogenic Activities on Water Quality of Ouangolodougou Dam, Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The population growth, the expansion of villages and towns and several human activities put an increased pressure on water resources, leading to an exponential deterioration in the water quality of these resources. The main objective of the present study was to assess the impact of human activities on water quality of the Ouangolo dam. This study firstly investigated the characterization of water quality of the dam, through the analyses physicochemical parameters and determination of water quality and organic pollution indices. The sampling and analyses were carried out during rainy season in September 2021 and the second during dry season in January 2022. Then a survey was carried out in the dam's environments in order to identify and localize human activities which are supposed to pollute the water of this resource. The results revealed the average values of following parameters: pH (6.9), electrical conductivity (124.83 µS/cm), iron (1,4 mg/L), arsenic (0,11 mg/L), BOD_5 (8,8 mg/L), NH_4^+ (0,67 mg/L), pesticides POP (0.002 mg/L) and POH (0.001 mg/L).

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The water quality indice indicates values of 94.81 and 147.66 respectively for rainy and dry season, while organic pollution indice has values of 3 and 3.33 respectively for rainy and dry season. Results also showed that Agricultural practices in dam immediate perimeters are the main source of pollution (49%), followed by artisanal activities (27%) and households (24%). This study has shown that human activities (precisely agriculture) represent the most important source of pollution of the water from the dam of Ouangolo. It is thus important to raise awareness among the population around the dam on dangers about this situation.

Keywords: Ouangolodougou; dam water; anthropogenic activities; pollution; water quality.

1. INTRODUCTION

In the 1970s, Côte d'Ivoire began building several small multi-use dams in the north to cope with water shortages caused by climate change. These small reservoirs, including the one in Ouangolodougou and Korhogo, are used in general for several purposes such us hydro-agricultural (irrigation), pastoral (watering), hydraulic, hydrological (Aka et al. 2007), or treated to supply drinking water to the population (Odoulami et al. 2020). However, over time, these infrastructures undergo various pressures related to the anthropization of landscapes, precisely agriculture, industry, rapid urbanization and population growth (Cecchi et al. 2009 , Cecchi 2007 , Stevens 2022). Indeed, these pressures, with a socio-economic nature coupled with natural processes (soil erosion, precipitation, evaporation, run-off of river waters) lead to a significantly degradation of the quality of these water resources (Aw et al. 2011), posing serious problems for the population (Agassounon et al. 2012), in particular the difficulty of treatment at drinking water treatment plants (Ghachtoul et al. 2005). In the other hand, polluted water resources are linked to several public health issues. It is therefore very important to maintain an undeniable quality of these water resources in order to preserve the environment and the health of populations (Foto et al. 2011). A non-exhaustive but precise knowledge of anthropogenic activities inducing a qualitative degradation of water resources would constitute a non-negligible basis for their protection and preservation. This study was initiated with the main objective to assess the impact of human activities on the quality of the dam's water, through physicochemical parameters analyses and identification of human activities linked to dam's water pollution.

2. MATERIALS AND METHODS

2.1 Material

Data collection material: The material used for data collection involves a survey sheets to collect geographical and household information. Plastic bottles with a capacity of 1,5 L have been used for sampling. Samples were transported in a cooler containing a cold accumulator. A device GARMIN Etrex 10 for collecting location GPS data.

Analysis equipments: Equipments used for analysis include a multi-parameter device for in situ measurement of pH, temperature, dissolved oxygen, conductivity, suspended solids and turbidity. Laboratory analyses have carried out by using HACH/DR 1900 spectrophotometer, glassware and laboratory consumables. Statistical data processing has been realised with STATISTICA 7.1 and EXCEL. The software QGIS 3.18 has exploited for map designing.

2.2 Methods

The following flowchart (Fig. 1) summarises the methodology design of the present study.

2.3 Collection and Analysis

Water analysis: The first sampling was carried out during rainy season in September 2021 and the second during dry season in January 2022. In each season, four samples were taken at different depths of the dam (surface, medium and depth). Samples collected were subsequently stored in a container with a cooler at 4°C before being transported to the laboratory for chemical analysis.

Some parameters such as pH, temperature, electrical conductivity and dissolved oxygen were measured in situ using a multi parameter. Analyses of other parameters were carried out in SODECI laboratory by using a HACH/DR 1900 spectrophotometer. It concerns chemical oxygen demand (COD), the biological oxygen demand (BOD_5), nitrate (NO_3), nitrite (NO_2-), ammonium ($NH4^+$), metals such as dissolved iron (Fe), manganese (Mn), total phosphate ($PO4^{3-}$), lead (Pb), arsenic (As), cyanide (CN), mercury (Hg), organohalogenated (POH) and organophosphorus (POP) pesticides, and carbamates (CAR). Analyses were according to specific methods in Table 1.

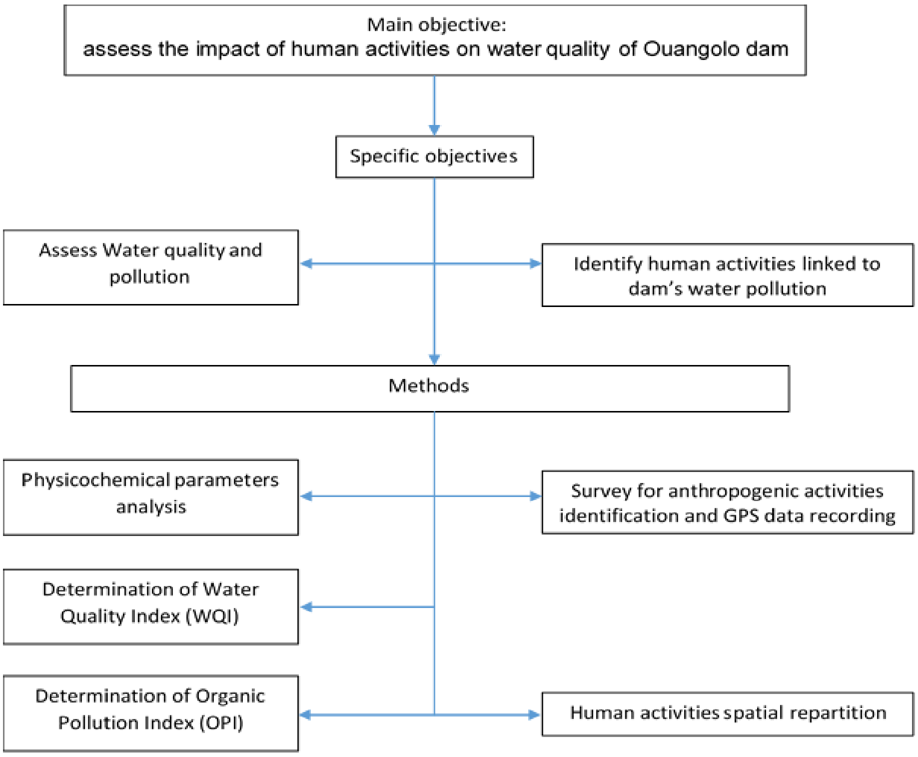

Fig. 1. Summary of study design

Table 1. Parameters Analysis Methods

Parameters	Unit	Methods
pH		ISO 10523 V 2008
Temperature	°C	Pt 100
Conductivity	µS/Cm	ISO 7888 V 1985
Dissolved Oxygen	%/mg/L	ISO 5814 V 2012
COD	mgO2/L	Tubes fermés
BOD_5	mgO2/L	Respirometric
Nitrates	mgNO3-	ISO 7890-3 V 1988
Nitrites	mgNO2-	Diazotation
Cyanides	mg/L	Pyrazolone-pyrine
Iron	mg/L	AAS ContrAA 700 (Flamme)
Manganese	mg/L	ISO 15586 V 2003
Lead	mg/L	ISO 8288 V 1986
Arsenic	µg/L	ISO 17378-2 V2014
Mercury	µg/L	ISO 12846 V 2012
Ammonium	mg/L	NF T90-015-2 V2000
Total Phosphorous	mg/L	ISO 6878 V 2004
Organohalogenated pesticides	µg/L	EN NF ISO V6468-97
Organochlorinated pesticides	µg/L	EN NF ISO V 11369-97
Carbamates	µg/L	EN NF ISO V11369-97

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

2.4 Statistical Data Analysis

The statistical approach is based on Standard Principal Components Analysis, which can be used to interpret results of physicochemical parameters to determine the likely origin of mineral pollutants that could degrade water quality (Dakouri 2021, Kambiré et al. 2014, Ahoussi et al. 2017). All analyzes (descriptive statistics, correlation matrix, eigenvalues of the correlation matrix and factorial plans) were performed using STATISTICA 7.1 software.

2.5 Determination of Water Quality Index (WQI)

The WQI was calculated using the weighted arithmetic index method proposed by (Yidana and Yidana 2010). Eight important parameters (pH, OD, CE, T° C., BOD_5, PO_4^{3-}, NH_4^+ and NO_3^-) were retained for this purpose. In this approach, a numerical value called the relative weight (Wi), specific to each physico-chemical parameter, was first calculated using the following equation:

$$Wi = \frac{k}{Si} \quad \text{with} \quad k = \frac{1}{\sum_{i=1}^{n} (1/Si)}$$

Wi: relative weight
k = constante de proportionnalité
n : le nombre de paramètres
Si : maximum value of surface waters standard for (Table 2) of each parameter (mg/L) without pH, Temperature and electrique conductivity.

Then, a quality rating scale (Qi) was calculated for each parameter by dividing the concentration by the norm of that parameter and multiplying the whole by 100 as in the followi ng equation:

$$Qi = (\frac{\text{Ci}}{\text{Si}}) \times 100$$

Qi : Quality rating scale for each parameter
Ci : Concentration of each parameter (mg/l)

Then, the overall water quality index was calculated by the following equation:

$$WQI = \frac{\sum_{i=1}^{n}(Qi \times Wi)}{\sum_{i=1}^{n} Wi}$$

Finally, Table 3 was used to determine dam water quality class.

Table 2. Drinking water guidelines (WHO 2017)

Parameters	Units	WHO guideline
Temperature	°C	25
Conductivity	µS/cm	2000
Turbidity	NTU	5
pH	-	6,5<pH<8,5
NO_3^-	mg/L	50
NO_2^-	mg/L	3
SO_4^{2-}	mg/L	250
PO_4^{3-}	mg/L	5
F^-	mg/L	1,5
Cl^-	mg/L	250
Na^+	mg/L	≤150
Mg^{2+}	mg/L	50
Ca^{2+}	mg/L	100
NH_4^+	mg/L	≤0,5
Fe^{2+}	mg/L	0,3
K^+	mg/L	≤12

Table 3. Water type and possible use according to WQI (Aher et al. 2016)

WQI class	Water type	Possible use
0 – 25	Excellent quality	Drinking water, irrigation and industry
> 25– 50	Good quality	Drinking water, irrigation and industry
> 50– 75	Bad quality	Irrigation and industry
> 75– 100	Very bad quality	Irrigation
> 100	Non-potable water	Appropriate treatment required before use

Table 4. Organic pollution index classification (Chahboune et al. 2012)

Classes	NH_4^+ (mg/l)	BOD_5 (mgO2/l)	PO_4^{3-} (µg/l)	IPO	Organique Pollution
5	< 0,1	<2	< 15	4,6 – 5,0	Null
4	0,1 – 0 ,9	2,1 – 5	16 – 75	4 – 4,5	Weak
3	1 – 2,4	5,1 – 10	76 – 250	3,0 – 3,9	Moderate
2	2,5 – 6	10,1 – 15	251– 900	2,0 – 2,9	Strong
1	> 6	> 15	< 900	1,0 – 1,9	Very strong

2.6 Determination of Organic Pollution Index (OPI)

Organic pollution index (OPI) of dam water was determined using method proposed by (Chahboune et al. 2012). The principle is to first divide the values of the polluting elements (ammonia, BOD_5, and phosphates) into 05 classes, with average contents of these three parameters obtained during laboratory analyzes. Then, determine corresponding class number for each parameter using arithmetic mean proposed by Leclercq (Table 4). Finally, overall organic pollution index of dam water was determined through arithmetic mean of pollution classes of all parameters.

2.7 Identification of Human Activities Concerning the Dam Water Pollution

A survey was carried out and consisted in submitting a questionnaire to actors in different fields of activity but also in houses around the dam. The objective was to investigate the factors likely to pollute dam water (agricultural, artisanal, industrial activities, and the management of household waste and municipal wastewater), according to dam's water quality and pollution assessment. During this survey, coordinates details of visited sites were recorded using GPS. Through CSV format of EXCEL, QGIS 3.18 was used to generate a map of these various activities. Mapping of anthropogenic activities in the dam watershed was done. The agricultural sites are marked by squares of green colors. Blue diamonds show the presence of handicraft activities. Blue arrows and red crosses indicate respectively the flow of water towards the dam and the presence of household waste.

3. RESULTS AND DISCUSSION

3.1 Physico-Chemical Parameters

Results show that pH ranges from 6.1 to 8.2 with a mean of 6.9 in the WHO range (6.5 to 8.5). This shows a less aggressive nature of the dam's waters. Temperatures range from 22.57 to 30.4°C, with an average of 26.57°C, which is close to the WHO guide value (25°C). Electrical conductivity values ranged from 82.3 to 152.11 µS/cm with a mean of 124.83 µS/cm, are lower than the WHO average (2000 µS/cm). This means that the water in the dam is weakly mineralized. In the two campaigns, pH did not show any significant difference, temperature was slightly higher in the rainy season while conductivity remained higher in the dry period (Table 5). These values differ from the results found in Lobo (Daloa) waters that are used for human consumption with conductivity ranging from 192.3 µS/cm to 316 µS/cm (Ahoussi et al. 2019). This difference may be due to a dissimilarity of natural factors such as climate, vegetation, geology and also activities carried out in the vicinity of resources. pH values at the Ouangolo Dam could also be explained by the presence of bicarbonates which have a buffering capacity in water or by the degradation of organic matter (Akil et al. 2014). As for the temperature, the variation of (22.57 to 30.4° C.) would be related to the temperature of the region. For example, high water temperatures (> 30 °C) are thought to be due to sunshine in the outer layers during the rainy season. As a factor in modifying the chemical and biological properties of water by acting on its density, on the solubility of gases, on the dissociation of dissolved salts, and on biochemical and biological reactions (Makhoukh et al. 2011, Akil et al. 2014), this high value could affect the organoleptic properties of water. In fact, this could explain the drop in conductivity in rainy period.

Variation of NO_3^- (0.32 to 1.6), NO_2^- (0.04 to 0.1), OD (0.7 to 7.94) and $PO4^{3-}$ (0.1 to 0.42) remains as large but in accordance with WHO standards. Mean concentrations of BOD_5 (from 3.8 to 16) and NH_4^+ (from 0.1 to 2.7) are respectively 8.8 and 0.67 mg/L, which are higher than WHO guide values (5 mg/L for BOD_5 and 0.5 mg/L for NH_4^+). Based on BOD_5 average value and according to (Kapepula et al. 2015), dam's water quality would be poor. These results are similar to those of (Mehounou et al. 2016). for surface waters near cotton production areas of Aplahoué in Benin. Seasonal mean of COD values (between 5.86 and 30.7) is near to the limit of required standard (20 mg/L). The high values of these parameters reflect a high organic contents in dam waters. This could be related to the discharge of municipal wastewater that is drained by runoff. It could also be due to nitrogen-based fertilizers used in crops farm around the dam. Concentrations of these 3 chemical parameters (NH_4^+, DBO_5 and DCO) vary according to season and are higher in dry period (Fig. 2). This could be explained by the fact that, during dry periods, there is not only an intensification of crops farm around the dam (intensive use of chemical fertilizers), but also during this period, municipal effluents that are discharged into this resource are more concentrated.

3.2 Metal Trace Elements

Fig. 3 shows that contents range from 0.18 to 3.29 mg/L for iron (Fe) and from 0.03 to 0.21 mg/L for arsenic (As), respectively with a mean of 1.4 mg/L and 0.11 mg/L. These values are far above the WHO guideline values of 0.3 mg/L for iron (Fe) and 10 µg/L for arsenic (As). This occurrence of heavy metal contamination in surface water maybe due to the exponential increase in human population, the proliferation of industrialization, and the expansion of agricultural activities (Hama et al. 2023, Xu et al. 2022). In the absence of industrial activities in this area, the origin of arsenic could be attributed to agricultural activities or municipal effluent discharges into the dam (Ahoussi et al. 2013, Mohod and Dhote 2013). In addition, the high iron concentration could be attributed to the transport by run-off (high content in the wet and dry seasons) of weld and cutting debris from scrap metal shops. Heavy metals in environment pose a real public health risk to populations because exposure to heavy metals has been linked to chronic and acute toxicity, which develops retardation. The neurotoxicity can damage the kidneys, lead to the development of different cancers, damage the liver and lungs. Bones can become fragile. There are even chances of death in case of huge amount of exposure (Singh et al. 2022). In addition, contaminated water with heavy metal ions like Cr (VI), Cd (II), Pb (II), As (V and III), Hg (II), Ni (II), and Cu (II) is responsible for several health issues in humans, like liver failure, gastric and skin cancer, mental disorders, harmful effects on the reproductive system (Zhang et al. 2023) and potentially even malignancies (Singh et al. 2024). Heavy metals (persistent toxicants) pollution of aquatic ecosystems, can lead to environmental problems and subsequently infect food chains (Dhriti and Mahendra 2021).

Table 5. Water quality physic parameters

	Temperature (°C)	pH	EC (µS/cm)
Rainy season	29.925	7.425	99.025
Dry season	23.2175	6.375	150.6275

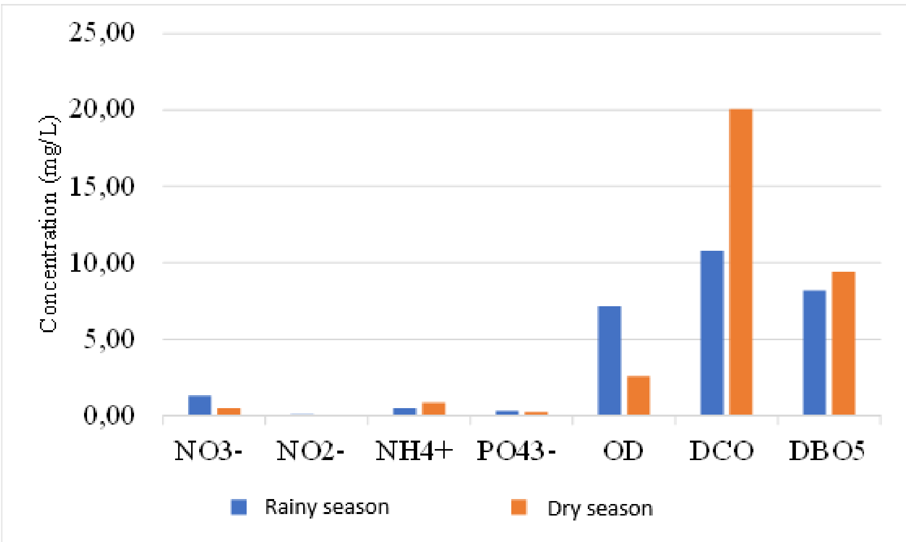

Fig. 2. Graphical representation of water quality chemical parameters

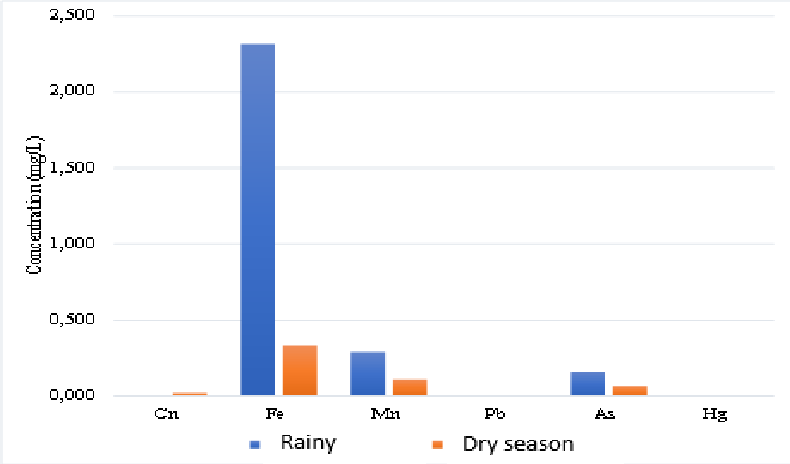

Fig. 3. Heavy metals contents of dam's water

3.3 Pesticides

Studied pesticides are organohalogen (POH), organophosphorus (POP) and carbamate (CAR). POHs and POPs have mean values respectively of 0.002 mg/L and 0.001 mg/L, above WHO standard for pesticides (0.1 µg/L), and have high concentrations in both wet and dry seasons (Fig. 4), with the lowest pesticide concentrations dry seasons. Similar results have been found by (Lakhili et al. 2015). Indeed, this could be the result of pesticides (to control pests) that are drained during the rainy season and that remain persistent in the dam water during the dry period. Due to the use of this resource as drinking water, attention should be paid to pesticides level or focusing on the necessity of comprehensive monitoring and regulatory measures to protect aquatic ecosystems (Ngoa et al. 2024) because several pesticides are not able to be completely removed by conventional Drinking Water Treatment Plant was; thus, advanced treatment systems need to be considered to safeguard the health of the community in future (Elfikrie et al. 2020). In addition, once pesticides reach water bodies, they can impact the whole ecological food chain, since other animals, including humans, feed on aquatic animals that may be contaminated (Kruć-Fijałkowska et al. 2022). The widespread occurrence of pesticides such as chlorpyrifos poses the largest risk for macroinvertebrates (Oltramare et al. 2023). Another concern is the mixing of pesticides. Indeed, pesticides are mixed in water bodies, in which case the mixture may be more toxic than any one single compound (Oltramare et al. 2023). Long-time exposure to the low concentration of pesticides had resulted in non-carcinogenic health risks (De Souza et al. 2020).

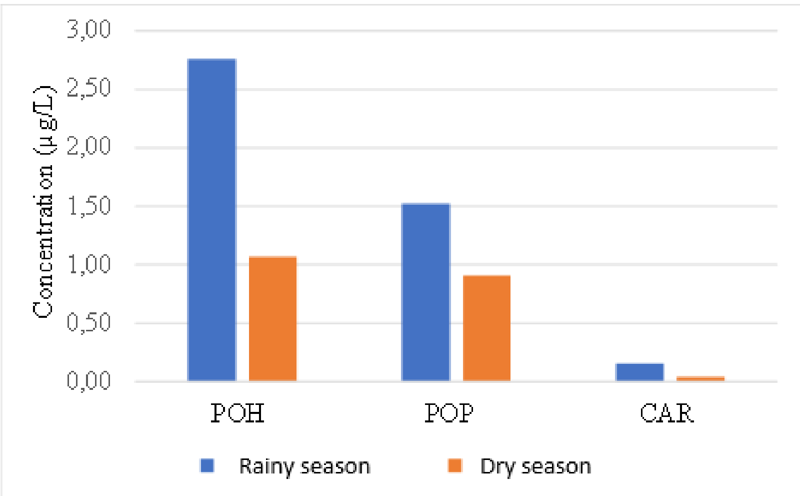

Fig. 4. Pesticides contents of dam's water

Statistical data analyses: Standard Principal Component Analyzes in Table 6 shows the correlation between the parameters taken two by two. Excellent correlations of (-0.95) between T°C and CE, (-0.9) between CE and POH, (0.9) between T°C and (NO_2^-, NO_3^-), then between Fe and (NO_2^-, NO_3^-). There is a very strong correlation of (0.8) between pH and (NO2-, NO3-, Fe), between T°C and (Fe, As), (-0.8), between CN and (T°C NO_2^-, NO_3^-), (0.8) between CN and (CE, Pb), between POH and As, between CBT and Mn (0.8). Strong (-0.7) correlations between T°C and COD, between Fe and CE, between CN and (POH, POP), between CE and CAR, (0.7) between pH and (T°C, As, PO_4^{3-}), between COD and Hg. Between NO_3^- and (POH, CAR), Mn and CAR, and between CAR and (POH, POP). Negative correlations between parameters would mean that these parameters evolve in an antagonistic manner. Indeed, when the temperature rises, this would lead to a decrease in the EC, COD and cyanide content in dam's water. The correlation between CE and Fe, POH shows that these two parameters are very active in the mineralization of dam water. Correlations of T°C with NO_2^-, NO_3^- and POH would mean that the increase in temperature directly leads to an increase in the content of NO_2^-, NO_3^- and POH. The relationship between POH and As, POP and Fe and NO_2^-, NO_3- also means that these elements are involved in the mineralization of the dam water.

Table 7 shows that the axes F 1, F 2 and F 3 express respectively 49.33%, 15.70% and 12.13% of the total variance of the data with respective eigenvalues equal to 8.88, 2.82 and 2.18. These three factors, expressing more than half of the cumulative eigenvalues (77.17%) are therefore sufficient to analyze the factorial designs.

Analysis of the results of the F1xF2 factorial plan (Fig. 5) shows that this plane expresses 65.03% of the cumulative variance. The factor F1, the most important (49.33%) is determined by two groupings of parameters. The first, in its negative part, is composed of NO2-, NO3-, T°C, POH, Mn, CAR, Fe, pH and As and the second in the positive plane is determined by Hg, DCO, CN and CE.

These groups, marked by a combination of ions and physical parameters, reflect a mineralization of the dam water. This mineralization is mainly related to anthropogenic activities. The presence of nitrate NO_3-, POH and CAR indicates pollution of surface origin. This pollution could be caused by the continued use of chemical or organic fertilizers in agricultural production, septic tanks, animal manure and municipal effluents.

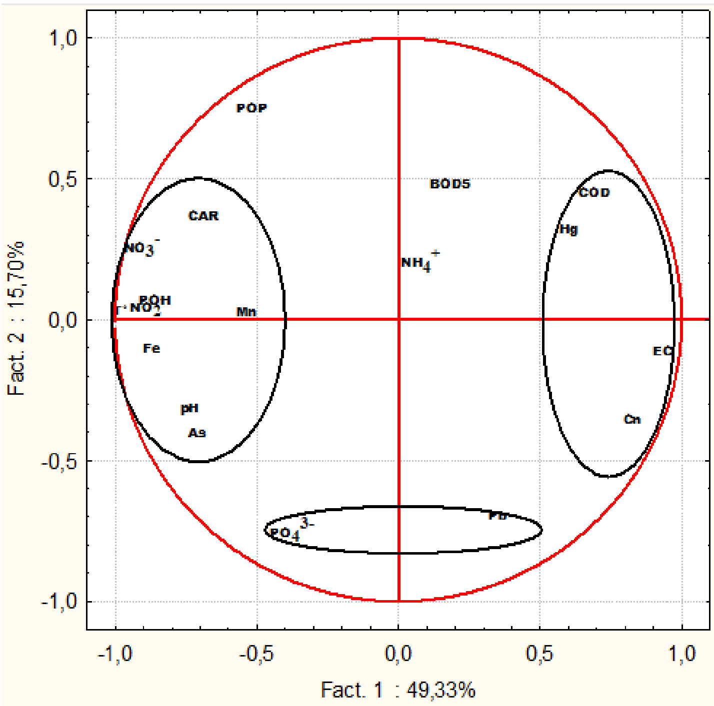

Fig. 5. F1xF2 Factorial plan

Table 6. Parameters correlation matrix

	pH	**T°C**	**EC**	**COD**	**BOD_5**	**NO_3^-**	**NO_2^-**	**Cn**	**Fe**	**Mn**	**Pb**	**As**	**Hg**	**NH_4^+**	**PO_4^{3-}**	**POH**	**POP**	**CBT**
pH	1																	
T°C	**0.7**	1																
EC	-0.5	**-0.95**	1															
COD	-0.4	-0.7	0.7	1														
BOD_5	0.1	-0.2	0.3	**0.8**	1													
NO_3^-	**0.8**	**0.9**	**-0.8**	-0.5	0.1	1												
NO_2^-	**0.8**	**0.9**	**-0.8**	-0.5	-0.1	**0.8**	1											
Cn	-0.5	**-0.8**	**0.8**	0.4	0.02	**-0.8**	**-0.8**	1										
Fe	**0.8**	**0.8**	**-0.7**	-0.5	-0.04	**0.9**	**0.9**	-0.6	1									
Mn	0.3	0.5	-0.5	-0.2	0.1	0.5	0.2	-0.2	0.4	1								
Pb	-0.2	-0.4	0.4	-0.1	-0.3	-0.5	-0.4	**0.8**	-0.2	0.04	1							
As	**0.7**	**0.8**	-0.6	-0.6	-0.2	0.5	0.6	-0.6	0.5	0.3	-0.1	1						
Hg	-0.5	-0.6	0.5	**0.7**	0.4	-0.5	-0.4	0.3	-0.5	-0.3	-0.3	-0.5	1					
NH_4^+	-0.1	-0.1	0.2	-0.2	-0.2	0.1	-0.3	0.03	-0.3	-0.01	-0.1	-0.2	-0.5	1				
PO_4^{3-}	**0.7**	0.4	-0.2	-0.5	-0.3	0.2	0.3	-0.01	0.5	0.3	0.3	0.6	-0.2	-0.2	1			
POH	0.5	**0.9**	**-0.9**	-0.5	-0.03	**0.7**	0.6	**-0.7**	0.6	**0.7**	-0.3	**0.8**	-0.5	-0.1	0.3	1		
POP	-0.002	0.5	-0.6	-0.3	-0.1	0.6	0.4	-0.7	0.3	0.3	-0.6	-0.1	-0.3	0.4	-0.4	0.4	1	
CBT	0.2	0.6	**-0.7**	-0.3	0.01	**0.7**	0.5	-0.4	0.6	**0.8**	-0.1	0.1	-0.4	-0.05	-0.1	**0.7**	**0.7**	1

Table 7. Eigenvalues of correlation matrix

	Eigenvalues	Eigenvalues %	Cumulation	Cumulation %
F1	8,88	49,33	8,88	49,33
F2	2,83	15,70	11,71	65,03
F3	2,18	12,13	13,89	77,17
F4	1,57	8,73	15,46	85,90
F5	1,10	6,12	16,56	92,02
F6	0,89	4,92	17,45	96,94
F7	0,55	3,06	18	100

The factor F2 (15.70%) is characterized by a grouping of Pb and $PO4^{3}$-. These two elements would be in the dam because of human activity and lead pollution. When used as an anti-knock agent in vehicle engine fuels, it is directly contaminated by stormwater runoff from surrounding garages. The two axes can therefore be assimilated to a degree of organic and metal pollution.

The statistical unit space of the F1xF2 factor plan (Fig. 6) shows four (4) parameter grouping classes. Class 1, which contains three samples from campaign 1 (area, average level 1 and background), groups together samples with high concentrations of Fe, Mn and As. It therefore summarizes natural and anthropogenic pollution. Class 2, marked by the sampling of the average level 2 of campaign 1, indicates a high concentration of POPs. This pollution is linked to agriculture. Class 3 comprising three samples from season 2 (surface, average level 2 and background) is governed by a high concentration of COD and Hg. This reflects domestic pollution. Finally, Class 4, which states that the sampling of the average level 1 of marketing year 2 records the highest concentrations of Pb.

Thus, Results of Standard Principal Component Analyzes highlighted contribution of anthropogenic activities to the mineralization of dam water. Indeed, Runoff and evaporation of mineral fertilizers and pesticides used by farmers, run-off of residues from informal sector, atmospheric fallout and discharge of domestic waste and municipal wastewater would be the real pollution sources of dam water. Studies have clearly shown importance of anthropogenic activities in surface waters mineralization (Syafrudin et al. 2021).

3.4 Level of Dam Water Quality and Pollution

Tables 8 and 9 successively determine the level of water quality and pollution of Ouangolodougou dam's water. After the calculation of the global WQI quality index using the results of physico-chemical analyzes and the standard values of the WHO standard of drinking water, the water quality class of the dam is determined for the two sampling seasons (Table 8). Thus, the values 94.13 and 147.66 determined, describe the dam as very poor quality in rainy periods and undrinkable in dry periods. These are consistent with those of (Vital et al. 2018) concerning the evaluation of surface water contamination and its impacts on health in the mining districts of Kambélé and Bétaré-Oya. The deterioration in quality is mainly anthropogenic in relation to agricultural activities through leaching of soils with high fertilizer content and urban wastewater discharges (Kim et al. 2023). Seasonal qualitative variation has been widely reported in the literature by (Yao et al. 2020). Indeed, the high value of the WQI in dry periods is due to the fact that during this period, the water level drops while the municipal effluents remain large and concentrated in the dam. These results are consistent with those of (Talhaoui et al. 2020, El Hmaidi et al. 2020).

The results of analyzes of the pollution indicator parameters (NH4 +, BOD5 and PO4 3-) were used to determine the pollution class of the dam (Table 9). The results show that organic pollution remained moderate over both periods. This means that the resource is subject to high levels of organic matter (BOD_5) and phosphate. Discharges of wastewater from the city's effluents increase the content of these parameters and contribute to the degradation of the water quality of the dam (Anoh et al. 2017). However, the values 3 and 3.33 indicated justify that the pollution is slightly high in the rainy season than dry. At this time, run-off water may increase the organic load of the water.

3.5 Anthropogenic Activities in Dam Watershed

The main activities identified during the survey, based on information gathered and observations

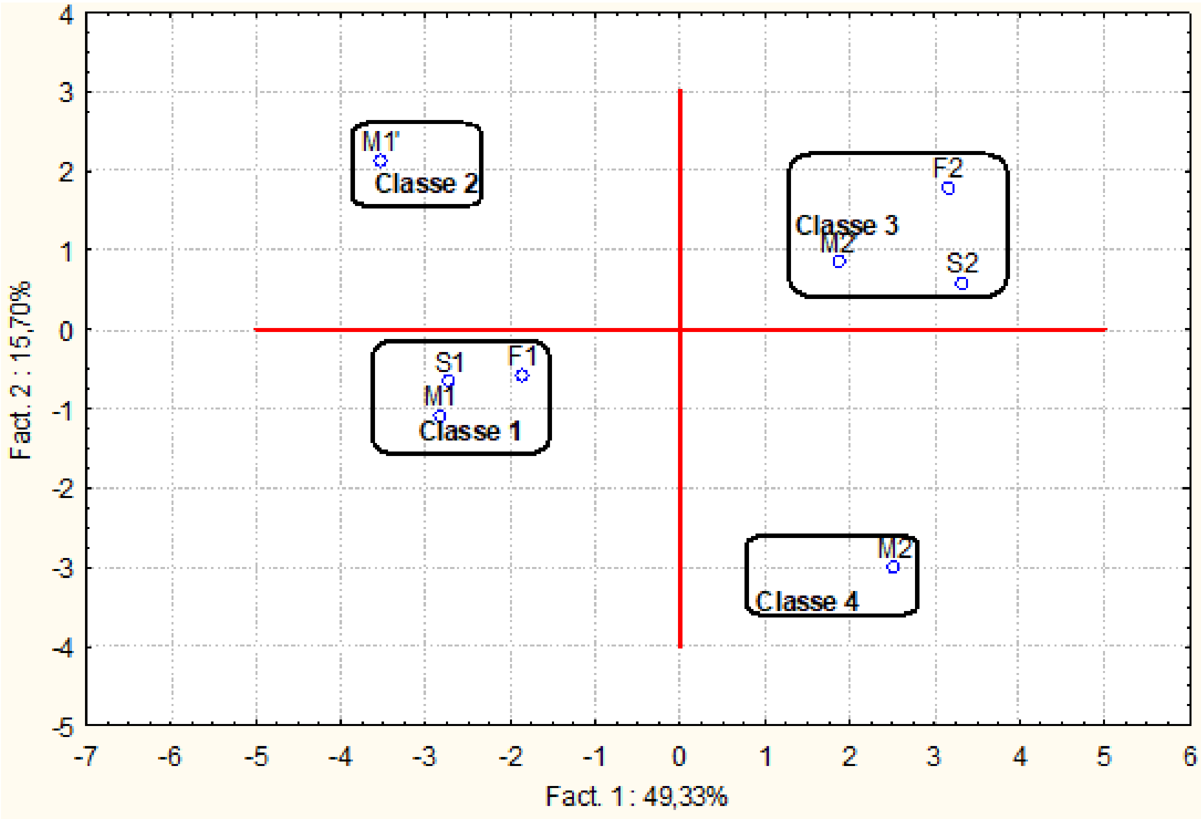

Fig. 6. Statistical units space of F1xF2 factorial plan

Table 8. Water Quality Index of Ouangolo dam

				Rainy season		**Dry season**	
Parameters	**(Si)**	**1/Si**	**Wi**	**Qi**	**WQI**	**Qi**	**WQI**
pH	8,5	0,1176	0,0435	87,35	94,81	75	147,66
T(°C)	25	0,0400	0,0148	114,70		92,87	
EC (µs/cm)	2000	0,0005	0,0002	4,95		7,53	
DO (mg/L)	8	0,1250	0,0462	89,74		32,16	
NH_4^+ (mg/L)	0,5	2,0000	0,7399	98,00		172	
NO3- (mg/L)	50	0,0200	0,0074	2,59		0,99	
PO43- (mg/L)	5	0,2000	0,0740	6,70		4,8	
DBO_5 (mg/L)	5	0,2000	0,0740	164,00		188	
	TOTAL	2,703	1				
	k	0,370					

made on the ground, were agriculture, grazing and handicrafts. Market gardening in agriculture (Figs. 7 a and b), is mainly carried out in dry season using of mineral and organic fertilizers (animal debris) as fertilizers and chemicals for plant protection treatment (Fig. 7 c), which increases organic and mineral pollution of dam water.

Craft includes informal sectors such as car and motorcycle garages, welding and metal-working workshops, vulcanization workshops, etc. Actors in these sectors use different products such as engine oils, fuel, welding and scrap cutting residues in performing their activities. All the waste and residues fromthese activities are dumped on the ground and carried away by run-off to canals draining in dam direction. In addition, flocks (Fig. 7 d) have been seen coming to drink daily, dropping the faeces near or into the dam water. There is also a lack of sanitation and no available protection perimeter, resulting in domestic sewage and solid waste (household waste) being introduced into the dam water.

Table 9. Water Pollution Index of Ouangolo dam

	Rainy season			Dry season		
Parameters	**Means**	**Classes**	**WPI**	**Means**	**Classes**	**WPI**
NH_4^+ (mg/L)	0,49	4	3	0,86	2	3,33
BOD^5 (mg/L)	8,2	3		9,4	3	
PO_4^{3-} (µg/L)	335	2		240	3	

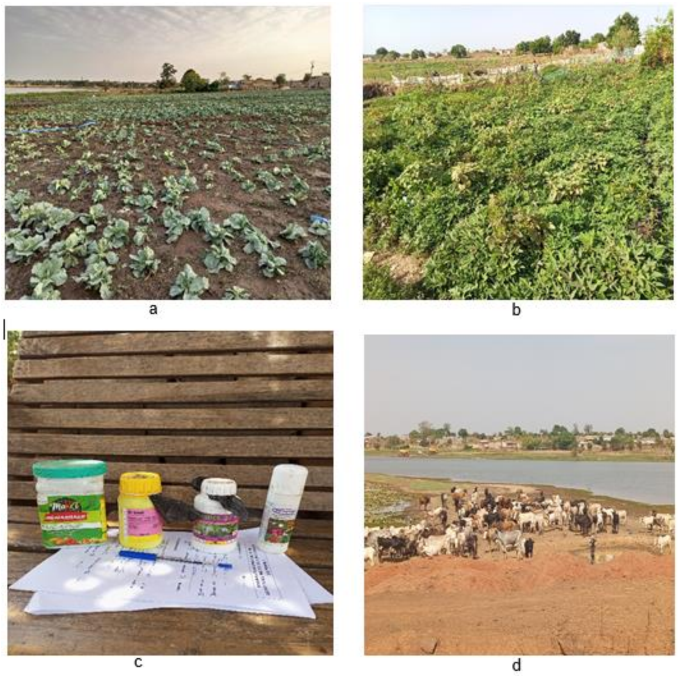

Fig. 7. Agricultural activities around the water of Ouangolo dam

Fig. 8. Household loads around the water of Ouangolo dam

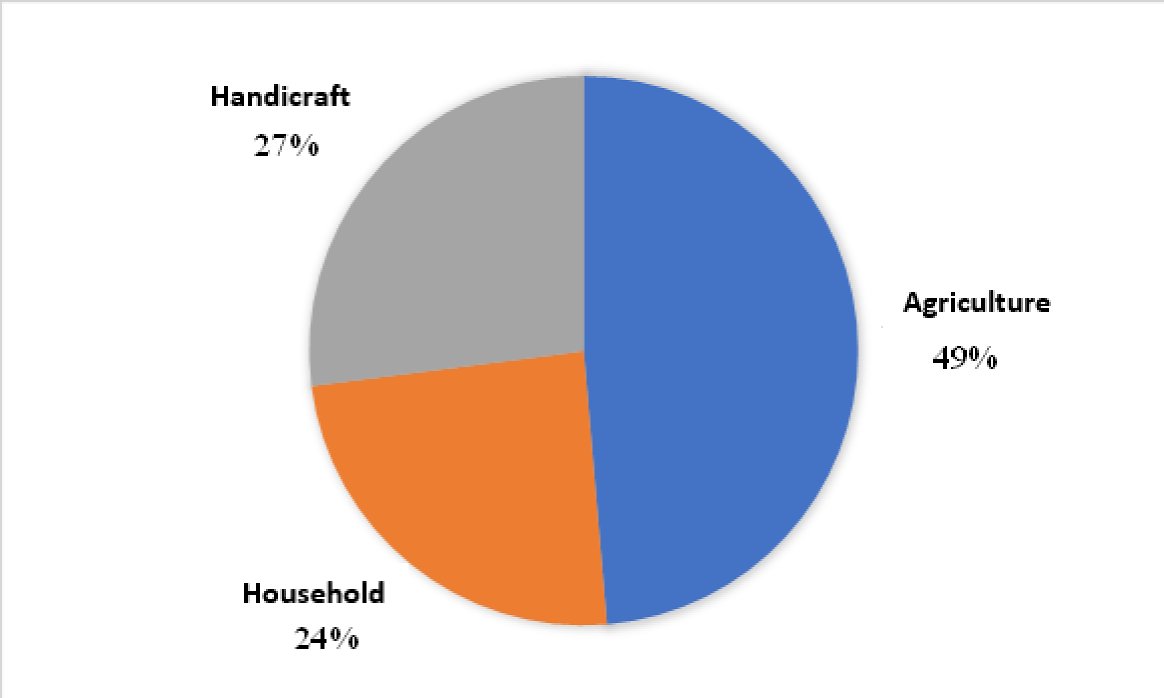

Fig. 9. Proportion of major sources of water pollution

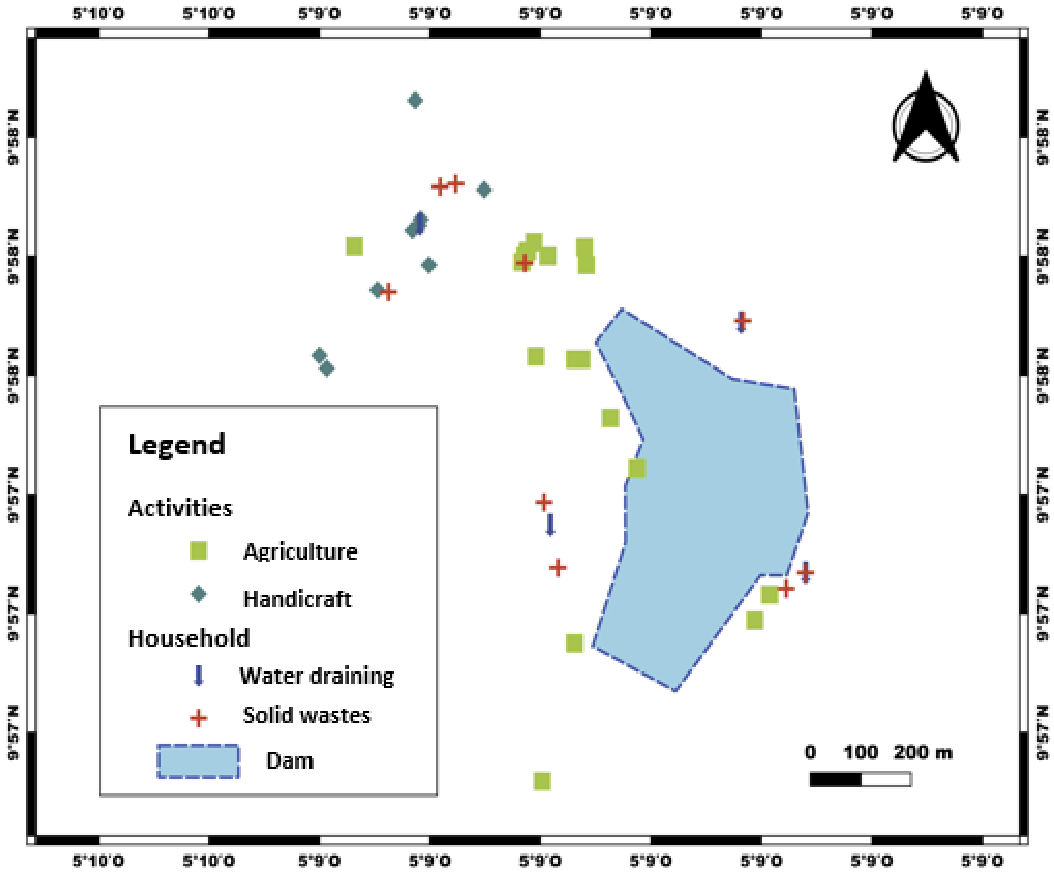

Fig. 10. Anthropic activities repartition in the watershed of Ouangolo dam

Indeed, three main drainage channels were observed during the surveys (Figs. 8a and b). Concerning household waste, it is either dumped by local residents into dam environment or transported from the city by runoff water (Fig. 8c). All these household loads, coupled with climatic phenomena such as temperature and rainfall, increase the aquatic flora of the dam and could be the cause of the eutrophication phenomenon observed in Fig. 8d.

Fig. 9 below shows proportion of the three major sources of human pollution observed in the environment near the reservoir. Based on the survey results, agriculture consists the main source of pollution of dam water (49%). Other sources of pollution are craft activities (27%), and domestic waste and waste water (24%).

Fig. 10 shows all the activities identified in the geographic surveys. There is a concentration of activities (agriculture, handicrafts, water and household waste) in the northwest part of the dam. These observations were also made by (Anoh et al. 2017) at the Drébot Lake in Gagnoa where activities, such as farming (market gardening), overgrazing, watering of large livestock, household waste landfills around the lake and drainage of household wastewater from nearby residents to this reservoir, pose risks of pollution of that water intended for consumption (Anoh et al. 2017). studies of (Goman et al. 2017) also have shown that grazing activities and intensive agriculture on the lake shores are the degradation causes of this water quality. Works of (Gohourou et al. 2019), in the others hand, indicated that informal activities, such as carpentry, catering, bag washing, car garages and sale of charcoal, the source of surface water pollution by producing waste that is discarded directly by the absence of communal collection. Domestic wastes within water perimeter are other cause of surface waters pollution after decomposition and/or percolation (Brou et al. 2018). This poses a danger to the ecosystem and biodiversity, such as the mortality of many aquatic species or species whose habitat is linked to the aquatic environment, with the consequent limitation of animal and plant life.

4. CONCLUSION

This study showed that water of Ouangolodougou dam is characterized by a mean temperature of 26.57°C and a high content of BOD_5 (8.8 mg/L), NH_4^+ (0.67 mg/L), POP (0.001 mg/L), POH (0.002 mg/L), Fe (1.2 mg/L) and As (0.11 mg/L). These mean values are higher than the WHO drinking water guidelines. The assessment of the quality and pollution level leading to classify this resource as very poor quality in rainy periods (WQI = 94.81) and not suitable for drinking in dry periods (WQI = 147.66) with moderate pollution (3 ≤ IPO < 3.9). This state of degradation is directly linked to human activities, such as production of household waste, discharge of municipal wastewater, agriculture in the perimeter of the watershed and handicrafts, are the real sources of pollution and degradation of the quality of these waters. The contribution of agriculture to this degradation is linked to the crop protection products and fertilizers that farmers use to grow crops successfully. In order to reduce the pollution and maintain the quality of this water, it is imperative to raise awareness of the household waste proper management through the creation of landfills and the recycling of household waste. It also necessary to establish some training stage for farmers in order to rationally using of fertilizing and pesticides products. Municipal wastewaters should be collected and treated prior to discharge. Protective perimeters should be established to retain coarse solid wastes. Further studies should be done on microbiological aspects and aquatic life pollution consequences.

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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