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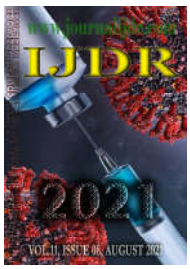

RESEARCH ARTICLE OPEN ACCESS

SEASONAL ASSESSMENT OF THE BACTERIOLOGICAL CONTAMINATION OF THE WATER OF THE KODJOBOUÉ LAGOON (SOUTH-EAST BONOUA, CÔTE D'IVOIRE)

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ABSTRACT

This study carried out on the Kodjoboué lagoon during the seasons was aimed at highlighting the bacteriological quality of this water which is the site of several activities such as fishing, navigation, swimming, etc. It was carried out in the lagoon season during the months of March, August and November 2017. Bacteriological analysis revealed Total Coliforms, Fecal Coliforms, *E.coli,* Enterococci and *Clostridium perfringens* with average loads varying respectively from 583.33 CFU/100 mL ± 548.48 to 3166.67 CFU/100 mL ± 1877.05; from 85 CFU/100 mL ± 18.03 to 616.67 CFU/100 mL ± 475.22; from 23.33 CFU/100 mL ± 5.77 to 604.33 CFU/100 mL ± 503.47; from 14 CFU/100 mL ± 5.29 to 40 CFU/100 mL ± 34.64 and from 2.66 CFU/100 mL ± 1.15 to 8.66 CFU/100 mL ± 3.05. The average fecal coliform loads obtained below the Canadian Health standard, showed that these waters were of acceptable quality for recreational and sports activities.

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INTRODUCTION

Côte d'Ivoire has the largest lagoon system in Africa which extends parallel to the shore of the Gulf of Guinea, between 2°50' and 5°25' West longitude over nearly 300 km with a total area of 1200 km^2. This lagoon system is made up of three main lagoons, namely the Grand Lahou lagoon, the Aby lagoon and the Ebrié lagoon linked together by artificial channels (Varlet, 1978 in Amani, 2012). Lagoons are shallow bodies of watere longated parallel to the coastline and isolated from the sea by a soft cord of sand and pebbles (Maanan, 2003). They are the sites of several anthropic activities such as fishing, transportation, etc... and are therefore the receptacle of different categories of effluents. As a result they are subject to enormous anthropic and natural pressures that contribute to the deterioration of their water quality. The Kodjoboué lagoon that is the subject of this study is a small lagoon, naturally influenced by the Comoé River. In this lagoon are practiced various socio-economic activities such as leisure activities, fishing, navigation, tourism etc.. It is also the receptacle for domestic wastewater, household and agricultural waste etc... Also, it should be noted that nowadays, many pathologies are linked to waterborne diseases. Thus, the waters of the Kodjoboué lagoon could contain pathogenic germs of fecal origin responsible for waterborne diseases in humans. According to the World Health Organization (WHO, 2003), 2.6 billion people in the world do not have access to drinking water and 1.8 million people, 90% of whom are children under five years old, die each year, especially in developing countries where hygiene measures and basic sanitary infrastructures are insufficient or non-existent (WWC, 2006). In addition, 80% of the causes of morbidity worldwide are waterborne (RCGE, 2000).

To our knowledge, few bacteriological studies have been carried out on the Kodjoboué lagoon.In order to make up for this deficiency, it therefore seems necessary to evaluate the bacteriological quality of these waters during the seasons (low, rainy and flood) on the basis of the search for bacteria indicative of fecal contamination such as Total Coliforms, Fecal Coliforms, *E.coli,* Enterococci and *Clostridium perfringens.*

METHODOLOGY

Presentation of the study site: The Kodjoboué lagoon is located in the village Kodjoboué in the South of Bonoua between longitudes 3°36'49.92" W - 3°33'00.78" W and latitudes 5°13'31.67" N - 5°14'56.47" N with an area of about 4.32 km^2.The coordinates of the sampling stations are in Table 1. Figure 1 shows the geographical location and positioning of the measuring stations.

Table 1.Measuring Stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Long.	438696	437827	436326	435318	435048	433837
Lat.	578626	578494	579620	578863	579403	578066

Long : Longitude ; Lat : Latitude

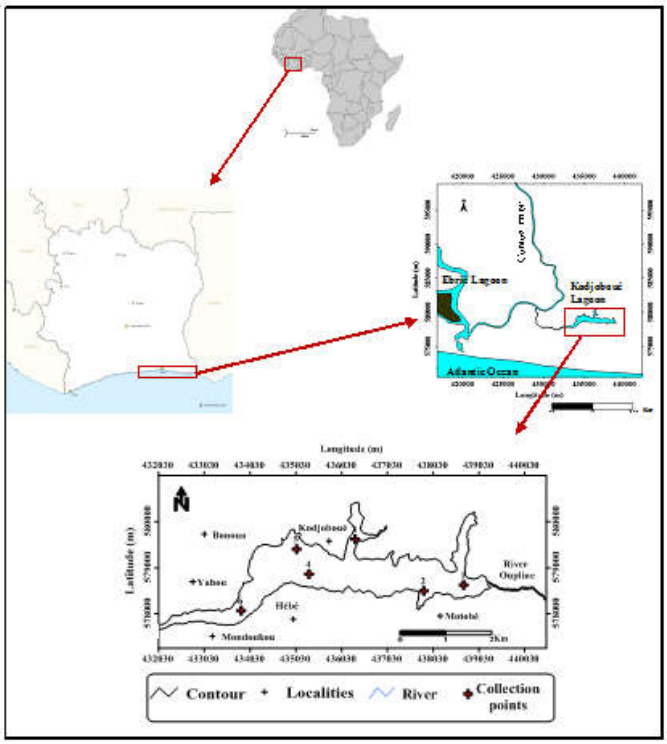

Figure 1. Geographic location of the study area and sampling stations

Material : The study was carried out on water samples taken from the Kodjoboué lagoon. The technical equipment used is composed of glassware and equipment. Sterilized 500 mL bottles were used to collect the surface water samples.

Method

Sampling: Sampling was done at the surface (approximately 0.5 m) of the water body during the three lagoon seasons (low (April), rainy (August) and flood (November)) in 2017. During each campaign, water was taken from six (6) stations. That is to say, six (6) water samples per campaign. A total of eighteen (18) water samples were taken during the three campaigns. The collected samples were transported in a cooler containing ice for bacteriological analyses in the laboratory. The bacteria analyzed are Total Coliforms, Fecal Coliforms, *Escherichia coli,* Enterococci and *Clostridium perfringens.*

Experimental protocol

Bacteriological analysis: The method used to test for Total Coliforms, Fecal Coliforms, *Escherichia Coli* and Enterococci is membrane filtration. The culture medium used during this analysis is Rapid'E. Coli 2 agar while for Enterococci, BEA (Bile Esculin Azide) agar was used .On the other hand, the search for *Clostridium perfringens* was done by the method of incorporation in agar medium. The culture medium used is TSN (Tryptone Sulfite Neomycin) agar. For enumeration, after sowing, *Escherichia Coli* appears pink to purple while other Coliforms such as Total Coliforms, Fecal Coliforms appear blue on the culture medium. Enterococci appear black. *Clostridium perfringens* appears as large black colonies in depth.

Statistical analysis: The statistical software version 7.1 allowed to highlight the correlation matrix, the cumulative percentages, the eigenvalues, and the percentages of variances expressed by the factors, the projection of the variables and individuals in the factorial plans 1 and 2 of the different bacteria studied.These analyses highlighted the similarities and graphical positions that two or more variables would represent as they evolved.

Determination of the Origin of Faecal Contamination: According to Borrego and Romero (1982) in Wognin (2014), this criteria is based on the ratio of fecal coliforms to fecal streptococci (Enterococci) (Enterococci) (CF/SF) (table 2).

Table 2. Criteria for determining the origin of faecal contamination

Ratio FC/F S (R)	Source of contamination
R<0,7	strictly of animal origin
0,7<R<1	predominantly animal-dominated mixed
1<R<2	uncertain origin
2<R<4	predominantly human-predominant mixed
R>4	strictly of human origin

RESULTS

Spatial and temporal variation of indicators of bacteriological contamination of the waters of the Kodjoboué lagoon

Total Coliform loads (TC): The highest loads of Total Coliforms were recorded during the low-water season. These loads ranged from 400 CFU/100 mL to 5200 CFU/100 mL. Stations 1, 2, 3 recorded the highest loads. Next came the rainy season. Loads ranged from 200 CFU/100 mL to 2800 CFU/100 mL. Low levels were observed during the flood season. Values ranged from 150 CFU/100 mL to 1500 CFU/100 mL (Figure 2).

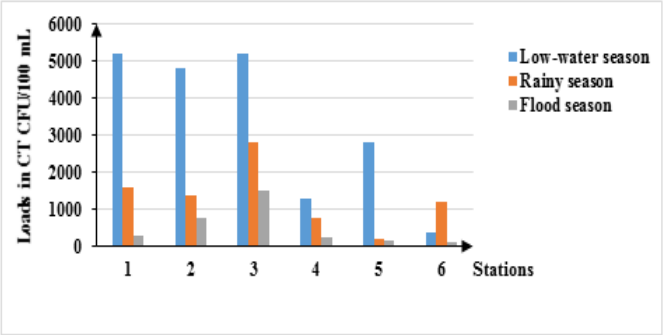

Figure 2. CT loading (CFU/100 mL) in Kodjoboué Lagoon by station and season

Fecal Coliform (FC) loads: In terms of fecal coliforms, the low-water season recorded the greatest loads. High loads were measured again at stations 1 and 2. These loads ranged from 50 CFU/100 mL to 1130 CFU/100 mL. As for the rainy season, the peak was reached at station 3. Levels ranged from 50 CFU/100 mL to 1300 CFU/100 mL. The lowest loads were recorded during the flood season. Loads ranged from 40 CFU/100 mL to 180 CFU/100 mL (Figure 3).

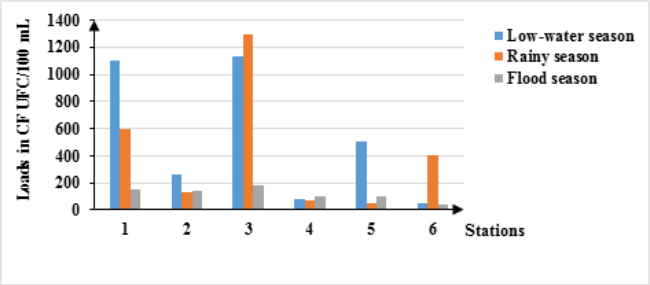

Figure 3. CF loading (CFU/100 mL) in Kodjoboué Lagoon by station and season

Loads in *Escherichia Coli* (*E. coli*): The highest loads were recorded at Station 3 during the low and rainy seasons. These loads ranged from 20 CFU/100 mL to 890 CFU/100 mL and 20 CFU/100 mL to 900 CFU/100 mL respectively.The lowest loads were recorded during the flood season with loads ranging from 12 CFU/100 mL to 60 CFU/100 mL (Figure 4).

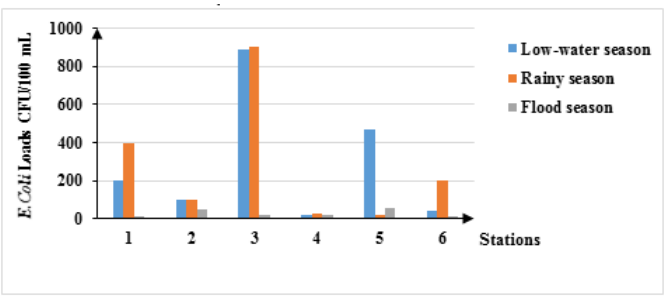

Figure 4. *E.coli* loads (CFU/100 mL) in Kodjoboué Lagoon by station and season

Enterococci loads: The low-water season had the highest concentration of enterococci. The highest loads was recorded at Station 2. Loads ranged from 10 CFU/100 mL to 80 CFU/100 mL. This was followed by the rainy season when loads ranged from 10 CFU/100 mL to 55 CFU/100 mL.The highest loading was recorded at Station 1, with loads ranging from 0 CFU/100 mL and 20 CFU/100 mL (Figure 5).

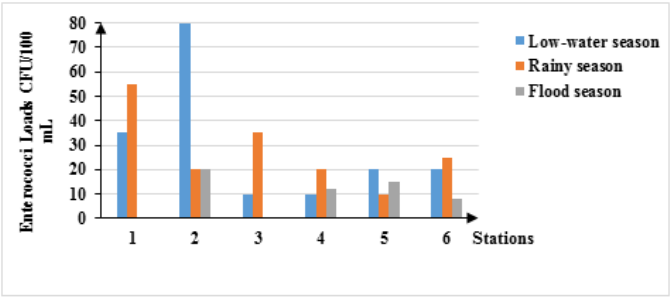

Figure 5. Enterococciloads (CFU/100 mL) in Kodjoboué Lagoon by station and season

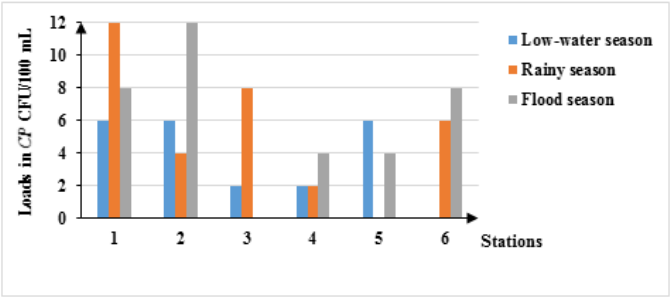

Figure 6. *CP* loading (CFU/100 mL) in Kodjobouélagoon by station and season

Clostridium perfringens loads: During the low-water season, the recorded *Clostridium perfringens* loads ranged from 0 to 6 CFU/100 mL. The highest loads were recorded at Stations 1, 2, 5, and in the wet and flood seasons the highest loads were recorded at Stations 1 and 2.These loads ranged from 0 to 12 CFU/100 mL. *Clostridium perfringens* was less observed in the low-flow season than in the wet and high-flow season (Figure 6).

Average loads of contamination indicators: The average annual loadings of each bacterium studied at the station level are presented in Table 3**.** The average total coliform loadings ranged from 583.33 CFU/100 mL ± 548.48 to 3166.67 CFU/100 mL ± 1877.05. The highest loading was recorded at Station 3.Fecal coliform was also recorded at Station 3. Loads ranged from 163.33 CFU/100 mL ± 205.02 to 870 CFU/100 mL ± 603.57. *Escherichia coli* loads ranged from 23.33 CFU/100 mL ± 5.77 to 604.33 CFU/100 mL ± 503.47.The highest load was also recorded at station 3. On the other hand, the highest load of Enterococci was recorded at station 2 and the highest load of *Clostridium perfringens* was recorded at station 1. Loads ranged from 14 CFU/100 mL ± 5.29 to 40 CFU/100 mL ± 34.64 and 2.66 CFU/100 mL ± 1.15 to 8.66 CFU/100 mL ± 3.05, respectively.

Table 3. Average loadings of contamination indicators in the Kodjoboué Lagoon

		Bacterial loads (CFU/100 mL)				
SP	Season	TC	FC	*E. coli*	Enterococci	*CP*
1	LWS	5200	1100	200	35	6
	RS	1600	600	400	55	12
	FS	300	150	12	00	8
	A	**2366,67 ± 2538,37**	**616,67±475,22**	**204±194,03**	**30±27,83**	**8,66±3,05**
2	LWS	4800	280	100	80	6
	RS	1400	130	100	20	4
	FS	800	139	50	20	12
	A	**2333,33±2157,16**	**176,33±72,59**	**83,33±28,86**	**40±34,64**	**7,33±4,16**
3	LWS	5200	1130	890	10	2
	RS	2800	1300	900	35	8
	FS	1500	180	23	00	0
	A	**3166,67±1877,05**	**870±603,57**	**604,33±503,47**	**15±18,02**	**3,33±4,16**
4	LWS	1300	80	20	10	2
	RS	800	70	30	20	2
	FS	280	105	20	12	4
	A	**793,33±510,03**	**85±18,03**	**23,33±5,77**	**14±5,29**	**2,66±1,15**
5	LWS	2800	510	470	20	6
	RS	200	50	20	10	0
	FS	194	100	60	15	4
	A	**1064,67±1502,84**	**220±252,38**	**183,33±249,06**	**15±5,00**	**3,33±3,05**
6	LWS	400	50	40	20	0
	RS	1200	400	200	25	6
	FS	150	40	13	8	8
	A	**583,33±548,48**	**163,33±205,02**	**84,33±101,07**	**17,66±8,73**	**4,66±4,16**

SP: sampling points, **LWS:** Low-water season, **RS:** rainy season, **FS:** Flood season, **A:** Average.

Principal Component Analysis of Bacteriological Loadings in Kodjoboué Lagoon

Correlation Matrix: Table 4 shows the different correlations between bacteriological loads. There is a very good correlation between *E. Coli* and Fecal Coliforms (R = 0.88). Fecal Coliforms and Total Coliforms are well correlated (R = 0.76*). E. Coli* and Fecal Coliforms are fairly well correlated (R = 0.60). Enterococci and Fecal Coliforms are moderately correlated (R = 0.52).

Table 4. Correlation matrix of bacteriological loads of the Kodjoboué lagoon

Germs	TC	FC	*E. Coli*	Enterococci	*CP*
TC	1,00				
FC	**0,76**	1,00			
E. coli	**0,60**	**0,88**	1,00		
Enterococci	**0,52**	0,30	0,21	1,00	
CP	0,06	0,24	0,19	0,40	1,00

Eigenvalues of the bacteriological loads of the Kodjoboué lagoon: Table 5 shows that the first two factors (fact.1 and fact.2) account for 55.89% and 22.81% of the variance expressed, respectively. This gives 78.70% of the cumulative variance. Factors 1 and 2 therefore give more than 70% of the information. This analysis will be limited to these two factors.

Table 5. Eigenvalues and percentages of variances expressed by factors

	F1	F2	F3	F4
Own value	2,79	1,14	0,76	0,23
% variance expressed	55,89	22,81	15,17	4,60
% cumulative variance	55,89	78,70	93,87	98,47

Projection of variables in the factorial design (fact.1-fact.2) : Projection of the variables in the factorial design (fact 1 and fact 2) shows that factor 1 gives 55.89% of the statistical information. It is determined in its positive part by Total Coliforms, Fecal Coliforms, Enterococci and *E. Coli.* Factor 2, which gives 22.81% of the information, is marked in its positive part by *Clostridium perfringens* (Figure 7).

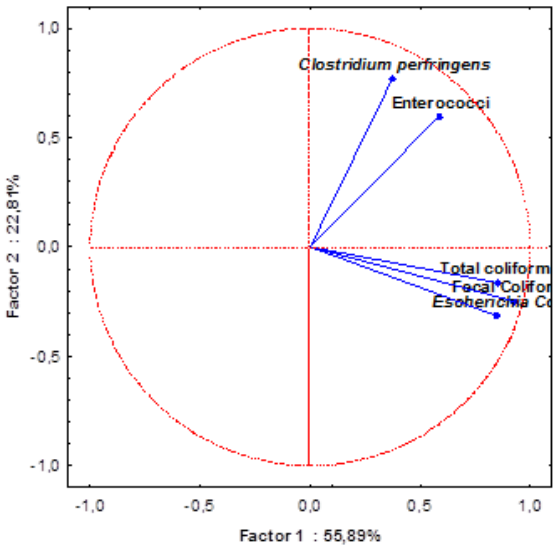

Figure 7. Variable spacing in the factorial design (fact.1 and fact.2)

Projection of individuals in factorial design (fact.1-fact.2): From the factorial design analysis, two (2) families of statistical units are distinguished (Figure 8).

- **Family I (F1)** is characterized by low loads of Enterococci and *Clostridium perfingens.*
- **Family II (F2)** is determined by high loads of Total Coliforms, Fecal Coliforms and *E. coli.*

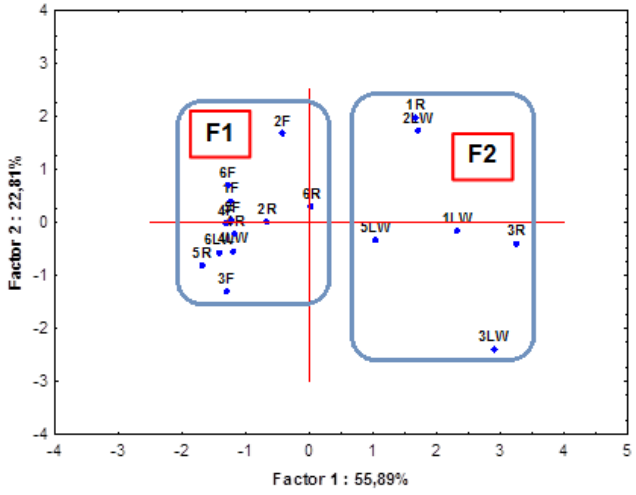

Figure 8. Space for statistical units in the factorial design 1 and 2

Origin of Faecal Contamination

Table 6 gives the ratios of Fecal Coliforms/Fecal Streptococci (Enterococci) (CF/FS) determining the origins of fecal contamination in the Kodjobouélagoon. The value of the ratio obtained is 16.188 CFU/100 mL. With regard to this value, the origin of the fecal contamination of the lagoon is strictly human (CF/SF 4).

Table 6. Origin of fecal contamination of samples from the Kodjoboué lagoon

Germs \ Lagoon	Kodjoboué
Fecal Coliforms (FC) in CFU/100mL	355,22
Fecal Streptococcus (SF) in CFU/100mL	21,94
Ratio FC/SF (R)	16,19
Origin of the contamination	Strictly of human origin

DISCUSSION

Contamination indicators counted in the Kodjoboué lagoon showed variable loads at the level of seasons and stations. The high loadings of Total Coliforms, Fecal Coliforms and *E. coli* recorded are believed to be due to anthropogenic actions. The presence of these indicators would be due to animal and human feces. According to Traoré *et al* (2012), runoff and winds carry animal droppings directly into the lagoon or the streams that feed it. The fecal coliform loads recorded at Stations 1 (1100 CFU/100 mL), 3 (1130 CFU/100 mL) in the low water season and Station 3 (1300 CFU/100 mL) in the rainy season would be due to their proximity to the Oupline River, Motobé Village and Kodjoboué Village.The presence of these villages influences the fecal coliform load through direct or indirect discharges into this body of water. Also, the presence of a few fish farms affects the quality of this water. In addition, the high loads of Enterococci and *Clostridium perfringens* recorded during the rainy season could also be due to the heavy rainfall recorded during this period which drained the watershed into this lagoon. The excreta of animals such as reptiles, migratory birds, domestic animals (dogs...) are transported through runoff during the rainy season to the lagoon.Also, it should be noted that *Clostridium perfringens* are used as indicators of long-term faecal contamination (Alvaro *et al*., 2009). In low-water seasons, the relatively lower concentrations are due to low runoff due to the scarcity of rainfall during this period. The average fecal coliform loads obtained are below the Canadian Health standard. This means that these waters are of acceptable quality for recreational and sports activities. The results of the Principal Component Analysis highlighted the proximity of the variables (contamination indicators) in the different factorial plans.The strong positive correlations between Fecal Coliforms and Total Coliforms and between *E. coli* and Fecal Coliforms showed the high presence of these bacteria in the lagoon. This strong correlation would indicate a common source of contamination. Enterococci loads were lower than those of fecal coliforms in the water. These results are consistent with those of Kuitcha *et al.* 2010. The latter are abundant in faeces and represent the predominant environmental indicators (Leclerc, 1981 in Kambiré, 2014).Fecal coliforms are generally more abundant in human feces than enterococci, which are more numerous than fecal coliforms in animals (Koffi-Nevry *et al.*, 2008).The value of the ratio of "Fecal Coliforms/Fecal Streptococci (Enterococci)" (CF/SF) recorded is greater than four (4) (CF/SF> 4), indicating contamination of strictly human origin. This high ratio could be explained by a strong human influence on this watercourse.

CONCLUSION

At the end of this study, it appears that the Kodjoboué lagoon contains loads of indicators of faecal contamination. This shows that

the waters are subject to anthropogenic influence.Fecal Coliforms/Fecal Streptococci (Enterococci) ratio values greater than four (4) showed that human influence was high in this lagoon and indicated contamination of strictly human origin.In general, the fecal coliform loads recorded were below the Canadian Health standard, indicating that the waters of the Kodjoboué lagoon were of acceptable quality for recreational and sports activities.

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