ISSN: 2320-5407 Int. J. Adv. Res. 9(11), 422-430

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/13759
DOI URL: http://dx.doi.org/10.21474/IJAR01/13759

ISSN NO. 2320-5407

*RESEARCH ARTICLE*

# ESTIMATION OF PHOSPHORUS AND NITROGEN RELEASED BY THE BREEDING OF OREOCHROMIS NILOTICUS IN CAGES IN THE TOHO AND TODOUGBA LAGOONS(SOUTHER BENIN) BETWEEN 2017 AND 2020

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## Manuscript Info

*Manuscript History*
Received: 19 September 2021
Final Accepted: 24 October 2021
Published: November 2021

***Key words:-***
Aquaculture, Nutrients, Discharges, Aquatic Ecosystems, South Benin

## Abstract

The present study aim to estimate the ratio of aquaculture in the phosphorus and nitrogen concentrations determined in the Toho - Todougba lagoons. For this purpose, the two lagoons were subdivided into 7 stations for the determination of phosphorus and nitrogen concentrations in the water column. Production data from 2017 to 2019 were collected from the Direction of the Ficheries Production and from the literature. Data for 2020 were collected directly from fish farmers. Annual tilapia production was estimated by year and the amounts of phosphorus and nitrogen released from aquaculture are deduced based on the ratio of Montanhini Neto & Ostrensky (2013). The concentration of each of these nutrients was estimated by station and compared to the concentration determined by laboratory analysis of the water. This methodology shows that the amount of phosphorus and nitrogen released to the environment varies from 0.49 mg/L to 0.18 mg/L for phosphorus and from 1.53 mg/L to 0.58 mg/L for nitrogen. The lowest values are obtained in 2020 and differ significantly from the other years ($p < 0.05$). The quantity of phosphorus discharged is higher at the high production stations (Tonon 0.20 mg/L and Lokohoué 0.11 mg/L). Some of this is stored in the sediment. The nitrogen generated by aquaculture is significantly lower than the average determined in water ($p < 0.05$). However, the concentration determined is still related to the amount of organic matter released due to aquaculture. Although aquaculture is not the only source of nutrient release to water, strategies for aquaculture with less nutrient release should be determined.



## Introduction:-

Food security has become a global concern, and all of the United Nations institutions are focusing on it, especially with the current influence of the effects of climate change (Béné et al., 2015; Costello et al., 2020; FAO, 2020). As a result, all political and socio-economic strategies that can enable the availability of food resources for especially

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vulnerable populations are encouraged throughout the world. The Republic of Benin is part of this same dynamic through its agricultural policies, funding and subsidies for agricultural projects and the development of agri-entrepreneurship. In this dynamic towards agricultural development, the promotion of aquaculture is a fundamental pillar to facilitate access to quality fish products on the one hand and on the other hand to promote the development of youth entrepreneurship in this sector to face unemployment (PNDF_Aquaculture, 2019). The fish farming systems that has been expanding in Benin for nearly 10 years is cage fish farming. To this end, the Toho and Todougba lagoons are home to the large number of cages installed for aquaculture in Benin (DPH/MAEP, 2018)with a prospect of intensification over the years.

Unfortunately, the cage aquaculture system is a source of enrichment of water bodies in organic matter, phosphorus and nitrogen (Abery et al., 2005; Guo et al., 2009; MPO, 2015)which are factors leading to eutrophication when in excess (Carpenter, 2005; El-Sheekh et al., 2021). Eutrophication is a permanent stress to aquatic living resources (Vodougnon et al., 2018)with the corollary of biodiversity loss. Research results on the assessment of the ecological status of Toho and Todougba lagoons through trophic status indices revealed that the lagoons are in an advanced pollution trend and will be further affected if the trend continues (Achoh et al., 2021). It should be noted that the concentration of phosphorus (0.02 mg/L to 0.42 mg/L) and nitrogen (1.91 mg/L to 4.03 mg/L) (Achoh et al., 2021)determined in the lagoons is not solely due to fish farming since there are several other activities that interact with the environments. So, what is really the share of fish farming in the concentration of phosphorus and nitrogen in Toho and Todougba lagoons? The answer to this question is the subject of this study.

## Materialsand Method:-

### Study area

The Toho and Todougba lagoons are located between 6° 23' and 6° 27' N and 2° 07' and 2° 13' E. They have an area of 914.259346 hectares or 9142593.46 square meters and an average depth of 3.2 meters with an estimated volume of 29256299.072 cubic meters or 29256299072 liters. They form a lagoon complex with other lagoons in the basin, notably Ahouangan, Dathi and Djonou lagoons. The Toho and Todougba lagoons have become entrenched ecosystems fed mainly by rainwater and runoff. Despite the variation of the physico-chemical quality of the water during the year, the Toho and Todougba lagoons are increasingly attractive for the development of cage fish farming and this since the first trials in 2013. The number of cages installed on these lagoons is growing every year.

In addition to cage aquaculture, market gardening, the hotel and restaurant industry and tourism are among the activities that interact with these environments and that are likely to influence their functioning. There is also fishing which is practiced there with the use of non-regulatory gear by the majority of anglers as a way of resilience in the face of declining catches.

To conduct this study, seven (07) stations were selected taking into account the presence or absence of cages, the distribution of cages on the complex and accessibility. The characteristics of each of these stations are presented in Table 1 and the stations are represented in figure 1.

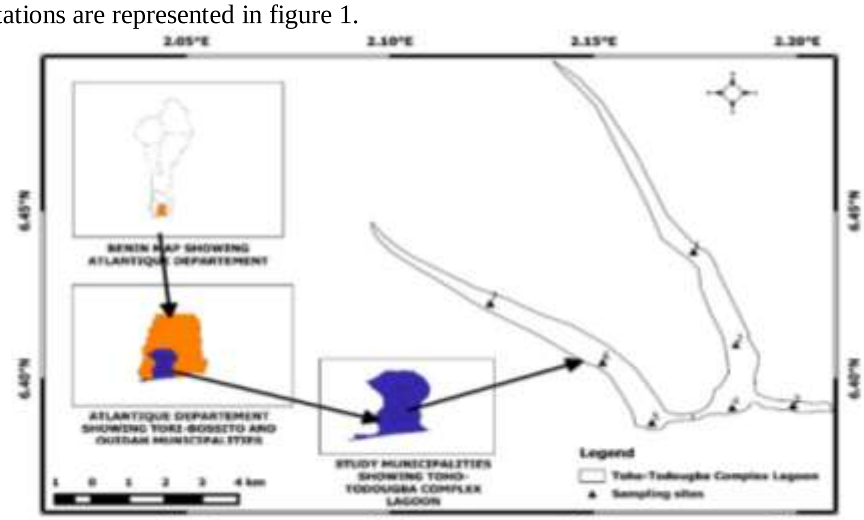


**Figure 1:-** Map of the study area.

**Table 1:-** Characteristics of the study stations.

| Stations | Characteristics | Number of cages used for tilapia farming | |
|---|---|---|---|
| | | 2019 | 2020 |
| Adjadji | Extreme zone of the right arm of the complex, in contact with the full flood with a low aquaculture production and receiving the waters having washed the plantations of palm groves and residual waters of hotels and restaurants. | 13 | 10 |
| Lokohoué | An area of high aquaculture production that receives a moderate amount of runoff directly and is adjacent to a floating restaurant on the water. | 138 | 96 |
| Pont | Area of exit of the water circulation receiving any type of waste coming from the locality of Pahou. It is located about 100 meters from the new market of Pahou under construction. It also houses cages for aquaculture. | 78 | 60 |
| Tonon | Area housing the farm with more cages in operation on the water, an area of high aquaculture production and not directly receiving runoff. | 240 | 180 |
| Tchiakpè | As the intersection zone between the right and left arms, there is no aquaculture production. However, it is a transit zone for people and goods coming from or going to the center of Pahou towards the village Tchiakpècodji. | 0 | 0 |
| Savi I | Medium aquaculture production area receiving water that has washed out the palm plantations. There is a weak aquaculture production at this level. There is a private school and a hotel on the edge of this resort. | 20 | 16 |
| Savi II | Extreme zone of the left arm in contact with the full flood, receiving the waters having washed the plantations of palm plantations, no aquaculture production. | 0 | 0 |

**Data collection and production estimation**

The estimation of the share of phosphorus and nitrogen contributed by the cage aquaculture of the species *Oreochromis niloticus* to the concentration of these nutrients in the Toho and Todougba lagoons was possible based on the annual biomass produced. Indeed, the data on production, the total number of cages, the number of operational cages, the annual number of production cycle for the species were collectedfrom the Direction of the Ficheries Production of the Ministry of Agriculture, Livestock and Fisheries and from the literature. Thus, the 2017 report on the state of fish farming in Benin from the Project of Extension of Continental Aquaculture phase 2 (PROVAC-2, 2017), the 2018 annual activity report of the Direction of the Ficheries Production(DPH/MAEP, 2018), the results of the work of Aïzonou et al.(2019); Pèlèbè et al.(2020), and the data collected in 2020 were used (Table 1). The number of operational cages that were only used for the production of *Oreochromis niloticus* species are not available in the 2017 and 2018 reports. It was determined for these years using the percentage of operational cage for tilapia production determined by Aïzonou et al.(2019) which represents 90% of the total number of operational cage. The same was true for the annual biomass of tilapia produced which was estimated by considering the average biomass per cycle and per cage for tilapia which is 1033.89 kg (Aïzonou et al., 2019).Data from 2017 to 2020 were considered for this study because prior to 2017, no data are officially available on cage production statistics for Toho and Todougba Lagoons although it started in the years 2013. The work ofKpenavoun Chogou et al. (2015) was only a census of operational fish farmers. From the collected data, the estimated total annual biomass for tilapia production of *Oreochromis niloticus* was determined by multiplying the yield per cage by the number of production cycle and by the number of operational cage for tilapia production. For the calculation of concentrations by station, only 2019 and 2020 production data were considered because data by station do not exist for other years.

After determining the annual biomass produced per year, the amount of phosphorus and nitrogen were then estimated considering the ratio established by Montanhini Neto & Ostrensky, (2013)according to which 1000 kg of tilapia *Oreochromis niloticus* produced in cages release 14.26 kg of phosphorus and 44.95 kg of nitrogen into the environment. The amount of phosphorus and nitrogen released from 2017 to 2020 were thus estimated from the biomass calculated for each year.

In addition, at each study station, water samples are collected and brought back to the laboratory for determination of phosphorus and nitrogen concentrations in the water column by spectrophotometry. At these stations, the number of operational cages for tilapia rearing was counted in 2019 (Aïzonou et al., 2019)and in 2020. This allowed the estimation of the biomass produced per study station and the deduction of the amount of phosphorus and nitrogen released at each station.

Next, an estimate was made of the amount of phosphorus and nitrogen that would be produced by a set of 100 cages. This estimate was necessary because of the upcoming installation of an aquaculture village by the Territorial Agency for Agricultural Development Pole 7 (ATDA 7) of the Ministry of Agriculture, Livestock and Fisheries.

**Statistical analysis of the data**

The data obtained were inserted into the Excel spreadsheet and the calculated average values of the quantity of phosphorus and nitrogen discharged were compared between years by the Mann Withney test (α = 0.05). After estimating the concentration of phosphorus and nitrogen discharged per study station, the resulting averages were compared between years. These estimated concentrations were compared to the concentration means determined in the laboratory for each station. The Mann-Whitney test was used for this purpose with (p-value = 0.05). The means per station were represented as a histogram.

**Table 2:-** Estimated production of tilapia in cages in Toho and Todougba Lagoonsper year.

| Years | Tilapia yield per cycle in kg | Total number of cages counted per year | Total number of operational cages per year | Total number of operational cages per year to produce tilapia | Average number of production runs per year for tilapia | Total production of tilapia in Toho -Todougba cageper year (kg) |
|---|---|---|---|---|---|---|
| 2017 | 1033.89 | 475 (PROVAC-2, 2017) | 475 | 428 | 2 (PROVAC-2, 2017) | 883975.95 |
| 2018 | 1033.89 | 536 (DPH-SADA, 2019) | 536 | 482 | 2 (DPH-SADA, 2019) | 997497.072 |
| 2019 | 1033.89 | 604 (Aïzonou et al., 2019) | 544 | 489 | 1.65 (Aïzonou et al., 2019) | 834603.5669 |
| 2020 | 1036.16 | 631 (data collected from 2020) | 403 | 362 | 1 (data collected from 2020) | 375421.6984 |

The tilapia yield per production cycle was revealed in 2019 (1033.89 Kg) by the work of Aïzonou et al., (2019). In this study, this same yield was maintained for the years 2017 and 2018 given the non-existence of these data from the Direction of Fisheries Production. The yield used for 2020 was determined following data collection from producers in 2020.

## Results:-

**Estimated amount of phosphorus and nitrogen released per year**

Table 3 shows the estimated amount (kg/year) of phosphorus and nitrogen released from cage aquaculture in 2017, 2018, 2019, and 2020 and the resulting concentrations in mg per liter of water. Over the last four years, the highest amount of phosphorus was released into the water in the year of 2018 that amounts to 14224.31 kg/year while the year 2020 recorded the lowest phosphorus release (5341.79 kg/year). The trend is the same for nitrogen discharged which is 39734.72 kg/yr, 44837.49 kg/yr, 37515.43kg/yr and 16838.24 kg/yr for 2017, 2018, 2019 and 2020 respectively. The estimated concentrations in mg/L for phosphorus and nitrogen by year have the same trend as the amount discharged except that the concentrations for 2017, 2018, and 2019 are not significantly different from each other but are different from 2020 ($p$-value< 0.05).

**Table 3:-** Amount of phosphorus (P) and nitrogen (N) discharged by production year between 2017 and 2020.

| Years | Total production of tilapia per year(kg) | [P] kg/an | [N] Kg/an | Volume of water in lagoons (Litre) | [P] (mg/L) | [N] (mg/L) |
|---|---|---|---|---|---|---|
| 2017 | 883975.95 | 12605.50 | 39734.72 | 29256299072 | 0.43[a] | 1.36[a] |
| 2018 | 997497.07 | 14224.31 | 44837.49 | 29256299072 | 0.49[a] | 1.53[a] |
| 2019 | 834603.57 | 11901.45 | 37515.43 | 29256299072 | 0.41[a] | 1.28[a] |
| 2020 | 374599.23 | 5341.79 | 16838.24 | 29256299072 | 0.18[b] | 0.58[b] |
| p-value | | | | | <0.05 | <0.05 |

**Estimation of phosphorus and nitrogen discharge per study station**

The amount of phosphorus and nitrogen discharged per study station and the concentration in mg/L were estimated and compared with the concentrations determined for the same nutrients from the laboratory analyses. Table 4 shows that during the years 2019 and 2020, the amount of phosphorus and nitrogen discharged into the water by tilapia farming recorded high values at the Tonon, Lokohoué and Le Pont stations. During 2019, the values obtained are respectively 5838.34 kg/year, 3357.04 kg/year and 1897.46 kg/year for phosphorus and 18403.45 kg/year, 3357.04 kg/year and 5981.12 kg/year for nitrogen. The same trend was recorded in 2020 for the same study stations that recorded the highest values for the two nutrients. The Tchiakpè and Savi II stations did not directly receive phosphorus and nitrogen inputs from aquaculture.

Figure 2 shows the histograms of the average concentrations of phosphorus and nitrogen determined in the laboratory and the concentrations estimated from the production data by station. It can be seen that for phosphorus (Figure 2A), with the exception of the Tonon and Lokohoué stations, the concentrations determined in the water for the other stations are significantly higher than those estimated from the production data ($p < 0.05$). For these stations, the estimated concentrations for 2019 (Tonon: 0.20 mg/L and Lokohoué: 0.11 mg/L) are significantly higher than those for 2020 (Tonon: 0.09 mg/L and Lokohoué: 0.05 mg/L). The estimated average in 2019 (0.20 mg/L) for the Tonon station is significantly higher than that determined (0.09 mg/L) in 2020 ($p < 0.05$). The concentrations of this nutrient determined directly in the water recorded the highest value at the Adjadji station followed by the Savi II station for respective values of 0.25 mg/L and 0.22 mg/L. For these same stations, the values estimated from the production data are 0.01 mg/L and 0 mg/L for 2019 and 2020, respectively.

In contrast to phosphorus, nitrogen concentrations determined in water at all stations are significantly higher than estimated values in 2019 and 2020 (p-value< 0.05) (Figure 2B). For the estimated 2019 and 2020 averages, only the Tonon station had a significant difference between the values which are 0.63 mg/L in 2019 and 0.287 mg/L in 2020, respectively. The average concentrations determined for this nutrient are 3.01 mg/L, 2.10 mg/L, 3.70 mg/L, 2.47 mg/L, 2.80 mg/L, 1.91 mg/L and 3.79 mg/L for the Adjadji, Lokohoué, Pont, Tonon, Tchiakpè, Savi I and Savi II stations respectively.

**Table 4:-** Estimated phosphorus and nitrogen concentration released from the tilapia farm in 2019 and 2020 by study station.

| Years | Parameters | Station of Study | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Adjadji** | **Lokohoué** | **Pont** | **Tonon** | **Tchiakpè** | **Savi 1** | **Savi II** |
| **2019** | Biomass produced (kg) | 22176.94 | 235416.75 | 133061.64 | 409420.44 | 0.00 | 34118.37 | 0.00 |
| | P rejeted (kg) | 316.24 | 3357.04 | 1897.46 | 5838.34 | 0.00 | 486.53 | 0.00 |
| | N rejeted (kg) | 996.85 | 10581.98 | 5981.12 | 18403.45 | 0.00 | 1533.62 | 0.00 |
| | [P] (mg/L) | 0.01 | 0.11 | 0.06 | 0.20 | 0.00 | 0.02 | 0.00 |
| | [N] (mg/L) | 0.03 | 0.36 | 0.20 | 0.63 | 0.00 | 0.05 | 0.00 |
| **2020** | Biomass produced (kg) | 10338.90 | 99253.44 | 62033.40 | 186100.20 | 0.00 | 16542.24 | 0.00 |
| | P rejeted (kg) | 147.43 | 1415.35 | 884.60 | 2653.79 | 0.00 | 235.89 | 0.00 |
| | N rejeted (kg) | 464.73 | 4461.44 | 2788.40 | 8365.20 | 0.00 | 743.57 | 0.00 |
| | [P] (mg/L) | 0.01 | 0.05 | 0.03 | 0.09 | 0.00 | 0.01 | 0.00 |
| | [N] (mg/L) | 0.016 | 0.152 | 0.095 | 0.286 | 0.000 | 0.025 | 0 |

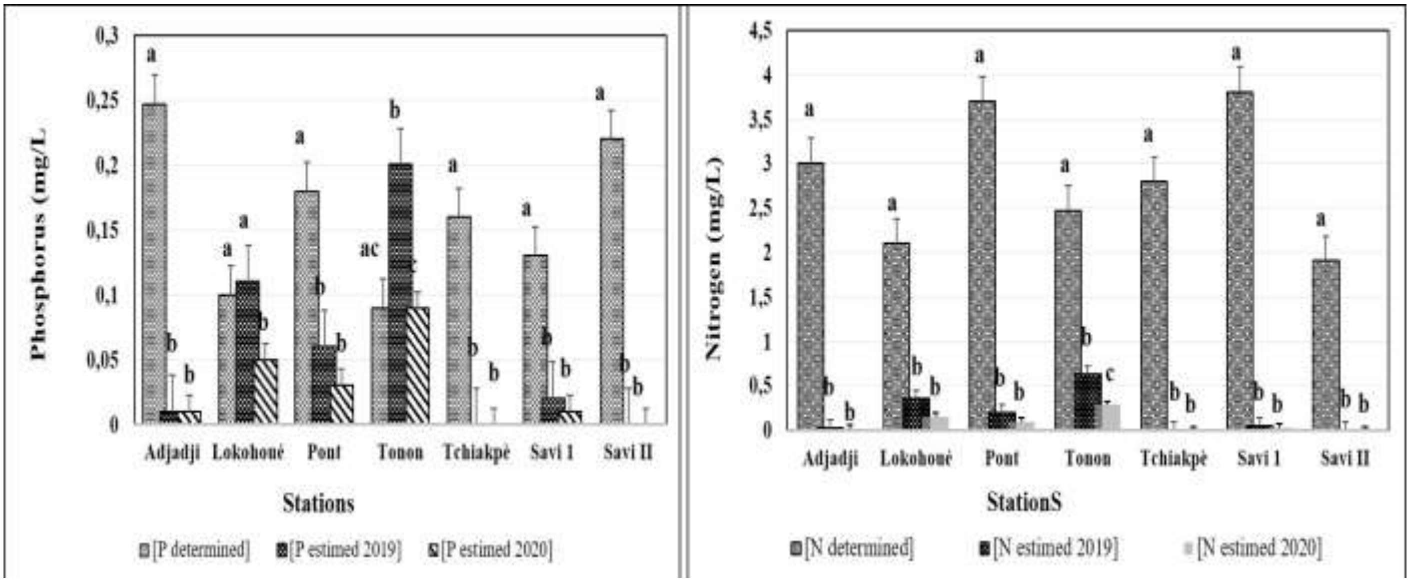


**Figure 2:-** Histograms of determined water concentrations and estimated aquaculture inputs for phosphorus (A) and nitrogen (B).

**Estimation of the concentration of phosphorus and nitrogen to be generated by the aquaculture village**

The estimation of the amount of phosphorus and nitrogen that will be discharged and their concentration in relation to the ecosystem water for the aquaculture village consisting of 100 cages was done based on the current production data (Table 5). The result is that 2325.14 kg of phosphorus and 7329.23 kg of nitrogen will be discharged from the aquaculture village per year for an estimated annual tilapia production of over 163 tons. In terms of concentration, the 100 cages will produce 0.25 mg of nitrogen per liter and 0.08 mg of phosphorus per liter of water.

**Table 5:-** Phosphorus concentration to be emitted by the aquaculture village.

| | |
|---|---|
| Number of cages to install | 100 |
| Estimated rate of operational cages (90%) | 90 |
| Number of cages used to produce tilapia (90% of operational cages) | 81 |
| Quantity of fish expected per year in kg | 163053 |
| P rejeted kg | 2325.14 |
| N rejeted kg | 7329.23 |
| [P] mg/L | 0.08 |
| [N] mg/L | 0.25 |

## Discussion:-

Aquaculture production from cages in Benin constitutes an important part of the aquaculture production statistics according to the Directorate of Agricultural Statistics of the Ministry of Agriculture, Livestock and Fisheries. On the Toho and Todougba lagoons in the south of Benin, the number of cages installed represents about 94% of the total number of cages installed on Beninese waters. This shows the importance of these ecosystems for national fish farming production.

As cage fish farming is a source of nutrient release to ecosystems (Abery et al., 2005; Guo et al., 2009), estimation of the amount of phosphorus and nitrogen released to Toho and Todougba lagoons by tilapia aquaculture found more or less significant variation between the years 2017 and 2020. The amounts of discharge are intimately related to the amount of biomass produced (Montanhini Neto & Ostrensky, 2013). To this end, since annual production is higher in 2018, it stands to reason that the amounts of phosphorus and nitrogen discharged are also higher. It is then the high production that explains the high amount released in 2018. The low amount released in 2020 compared to other years is related to the advent of the Coronavirus pandemic which impacted the aquaculture sector by increasing input prices resulting in low annual production (Erinle et al., 2021; Hasan et al., 2021; Houessou et al., 2021; Senten et al., 2020; Tougan & Théwis, 2020).

Comparing the estimated concentrations of phosphorus and nitrogen due to aquaculture with the concentrations determined after sampling the lagoon water by station, it appears that for some stations, the estimated quantities are significantly higher than those determined (Tonon and Lokohoué station for phosphorus). This is due to the fact that these stations have the highest number of cages installed and do not receive runoff directly compared to other stations. Therefore, the low amount determined compared to the estimated amount released by aquaculture at these stations is related to the sedimentation gradient which results in the estimated amount not being that found in the water column. Much of it is accumulated in the sediment (Holtan et al., 1988; Jin et al., 2006).

At the bridge station, where aquaculture is not as negligible, the estimated amount of phosphorus released into the environment is below that determined in the water column. This means that apart from aquaculture, there are other important sources of phosphorus input into the environment. It should be noted that this station is located in a sort of depression with respect to the surrounding locality and therefore receives all the runoff water with all its nutrient load. As a result, although there is a sedimentation gradient, the quantity determined in the water column is higher and reflects the importance of the quantity of phosphorus that this station receives through runoff. The Adjadji and Savi II stations, where the amount of aquaculture input is very low or even zero compared to the determined amount, should be noted that they are in contact with a vast palm grove and receive the leaching water. The quantities determined at these stations are higher than those of all other stations (concentrations determined and estimated together). This reflects the magnitude of the loading that these two extreme lagoon stations receive.

Concerning nitrogen, it is observed that the estimated quantities are significantly lower than the determined quantities for all the study stations. Even at the stations where the number of cages is important, the same trend was observed. This can be explained by the fact that around the two lagoons, market gardening sites are developed and use fertilizers that end up in the water after rainfall (Canga et al., 2016; Carignan & Kalff, 1980; Maranger et al., 2008).

Also, microbial activity tends to increase the amount of nitrogen in the water as a result of high organic matter discharge. This may also condition the elevated water N level relative to the estimated amount contributed by aquaculture. However, the input of organic matter from aquaculture is significant and thus contributes to this high concentration for what is determined. For stations where aquaculture does not exist, the nitrogen level is due to the organic load of the leachate received.

The present study considers tilapia cage culture, which represents about 90% of the total production. The remaining production (10%) covered by catfish farming Clarias gariepinus was not considered although it also has its share of phosphorus and nitrogen that it releases into the environment. This means that the estimated contribution from aquaculture should be higher if the contribution from catfish farming is considered.

## Conclusion:-

The estimation of the amount of phosphorus and nitrogen released by aquaculture was done to critically look at the share of this activity in the current water load of Toho and Todougba lagoons. The estimated amount of phosphorus and nitrogen released by aquaculture into the environment from 2017 to 2020 is 0.43 mg/L, 0.49 mg/L, 0.41 mg/L and 0.18 mg/L for phosphorus and 1.36 mg/L, 1.53 mg/L, 1.28 mg/L and 0.58 mg/L for nitrogen respectively. Comparing the estimated concentration contributed by tilapia aquaculture to the determined concentration in the water column, it appears that for some stations, the determined averages are below the estimated ones (Tonon and Lokohoué stations) for phosphorus. At the same time, for all the extreme stations of the two lagoons (Adjadji, Pont, Savi II), the determined concentration is higher than the estimated one because of the importance of the runoff water they receive.As for nitrogen, the concentrations determined are higher than those estimated for all stations. Therefore, although the input of phosphorus and nitrogen to the environment exists outside of any aquaculture activities, it should be noted that aquaculture contributes an important part of the nutrient load of these lagoons. Thus, the higher the intensity of aquaculture, the greater the amount of phosphorus and nitrogen it releases. Under these conditions, what are the technical strategies for aquaculture production in cages that can significantly reduce the amount of phosphorus and nitrogen discharged without negatively affecting the production yield?

## Acknowledgements:-

The authors would like to thank the Direction Fisheries Production, the fish farmers and the readers for their contribution to the collection of production data and the writing of this manuscript.

**Conflict of interest**
The authors declare that there are no conflicts of interest.

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