Calibration of physicochemical parameters in aquaculture. A case study of tilapia breeding in Mozambique

S A Mulema¹, R Prada-Núñez², and S M Mendoza-Lizcano²
¹ Universidade Licungo, Quelimane, Moçambique
² Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: sergiomulema@gmail.com

Abstract. This paper discusses the adequacy of methods used in monitoring the aquatic environment in aquaculture. It is assumed that the strategy of controlling each of the environmental parameters by observing their compliance with the technical limits established in aquaculture is not sufficient to highlight all the aspects that may compromise the quality of the process. Therefore, the univariate methods that are usually used in water monitoring in aquaculture cannot show aspects of the process derived from the joint variability between the parameters. Thus, a multivariate method for monitoring the aquatic environment in aquaculture based on Hotelling's T² chart was proposed in this paper. Data on four physicochemical parameters (oxygen, temperature, pH and transparency) were collected from four aquatic species breeding ponds at the company Aquapesca in Mozambique, located in southeastern Africa. The correlation structure evidenced in the four physicochemical parameters analyzed showed a strong and positive relationship between temperature and pH, oxygen and transparency are inversely correlated. This correlation structure indicates that a possible reduction in water temperature also reduces the pH and vice versa, while a reduction in transparency implies an increase in dissolved oxygen. The multivariate method used shows the relationship between the parameters and the strategies to manage them, as well as the control strategy of the multivariate structure through Hotelling's T² chart, pointing out and correcting all the aspects that may compromise the quality of the breeding of the species in aquaculture.

1. Introduction
The success of aquatic species cultivation in aquaculture depends, in large part, on the habitat to which the hatchlings are exposed. The quality of this aquatic habitat is guaranteed by keeping under control the physicochemical parameters, such as: oxygen, pH, temperature, salinity, alkalinity, ammonia, nitrate, nitrite, phosphorus, turbidity or transparency, silicon, among others, regularly controlled. Therefore, it is generally assumed that the aquatic environment in aquaculture is of quality if the physicochemical parameters that define it are kept within the established optimal levels and over time do not present significant variability. To achieve good production, it is necessary to keep the physicochemical conditions of the water within tolerance limits for breeding. The quality of the water is determined by its physicochemical properties and the temperature, oxygen, pH and transparency are the most important parameters since they act directly on the influence of the productivity and reproduction of the fish, so these must be kept under control [1].

The physicochemical properties of water are an indicator of water quality in the process of breeding marine species in aquaculture, since they define the aquatic habitat which, in turn, condition the development of captive breeding [2]. The control of the aquatic environment in aquaculture is
usually carried out by observing if the values of the parameters are within the tolerance limits defined for each one of them [3]. This methodology allows for evidence of parameter mismatches in terms of their recorded level (high or low), rather than the significant variability of each of the parameters, so little correlation between them. The aquatic environment can present all its physicochemical properties with levels within the established limits, however, record significant variability in some of the parameters. A small variation in one of the physicochemical parameters affects the aquatic environment causing crises that can lead to death [3]. Sudden changes in water temperature in the order of 5°C cause stress in the fish, and in more critical cases, death [2].

The physicochemical parameters presented above are interdependent, so that the mismatch of one can interfere with the levels of the other, affecting the quality of the aquatic environment. However, these parameters are usually monitored independently in aquaculture production firms, so that the multivariate correlation structure between them is usually not exploited [3-5]. In this work, the level, variability and correlation structure between the physicochemical parameters are analysed using statistical methods. The correlation structure between the physicochemical parameters has already been studied by [6] using the principal component analysis (PCA) method, and [7] using the correspondence analysis. The studies carried out by [8-10] propose new working methods in aquaculture based on multivariate statistical models that exploit, in addition to the main effect of each parameter, the joint effect between them. This is the main purpose of this work, to analyze not only the level and variability of each of the physicochemical parameters, but also the relevant information in the correlation structure between them that can improve decision making in the monitoring of the aquatic environment in aquaculture.

2. Methodology
The data used in this paper was recorded at Aquapesca, Ltda. in Mozambique - one of the largest aquaculture companies in the southern region of Africa. The data collection process consisted of the periodic measurement of four physicochemical parameters (temperature, oxygen, pH and transparency).

Data for all four parameters were measured on four tilapias (Oreochromis mossambicus) breeding racks in Mozambique at three times (6h, 12h, and 18h) over 29 days, based on an experimental pattern where the pond factors and measurement period were controlled for. The database has a matrix structure $X_{340 \times 6}$ where 340 is the number of rows (85 data from each of the 4 ponds) and 6 variables (4 variables that identify the four physicochemical parameters and two factors that discriminate the ponds and measurement periods). The technical procedure used to measure these parameters was based on the line presented by [3].

Throughout the data collection process, the parameters were measured at the same time in each pond and in each measurement period, ensuring correspondence and balance in the data. The physicochemical parameters were measured using the appropriate measuring instruments. The temperature was recorded based on the thermometer. The pH, oxygen and transparency were measured through the oximeter, pH-Meter and Secchi disk, respectively.

3. Results
This section presents the main results of the monitoring of the aquatic environment, characterized by the four physicochemical parameters, using the proposed statistical method. The hypothesis is that univariate methods are not efficient enough to exploit all relevant aspects in the decision making in a multivariate process. The usual strategy of measuring each parameter independently and observing if their values are in accordance with the technical limits established in aquaculture only allows controlling the instantaneous levels of each of the parameters, however, nor the variability, so little the co-variability between them is controlled, so if the process is affected by such characteristics there would be no way to detect it. Therefore, it is necessary that the following aspects be considered in the monitoring of the aquatic environment in aquaculture: i) the conformity and stability of each of the physicochemical parameters - to identify the cause of the mismatch of the aquatic environment; ii) the
correlation structure of the physicochemical parameters - to understand how the levels of one parameter can change with the change of the other; and iii) the conformity and multivariate stability of the physicochemical parameters - to point out changes in the process caused by the correlation of the parameters.

In controlling the conformity of the parameters, the tolerance limits for each of them were considered. Based on the literature used, the vector of the lower (25.0, 4.5, 7.0, 25.0) and upper (32, 9, 9, 40) compliance limits were defined, and the coordinates correspond to the following order: temperature, oxygen, pH and transparency, respectively. The control of the univariate variability of the physicochemical parameters was performed based on the Shewhart process control chart [11], with variability of 3σ, that is, the upper and lower stability limit of each parameter is \( \bar{p} \pm 3\sigma \), where \( \bar{p} \) is the mean of the physicochemical parameter and \( \sigma \) its respective standard deviation, that is, we consider that a parameter did not have a significant variability if the observed value is within the band \( \bar{p} \pm 3\sigma \).

Figure 1 presents the control charts of the four physicochemical parameters considered in this work. The conformity control limits are represented in the four charts by interrupted horizontal lines, and the stability limits by continuous horizontal lines. Each chart is divided into four parts (vertical lines), each part representing the data of each of the four tanks considered in the experiment.

![Figure 1](image_url)

**Figure 1.** Compliance and stability control charts for physicochemical (a) temperature vs time; (b) oxygen vs time; (c) pH vs time; (d) transparency vs time.
With regard to the compliance of the aquatic environment, the charts show that, at certain points, the values of the physicochemical parameters were outside the established compliance limits. The pH values were the most compliant with the requirements for this parameter, with only 3 observations outside the compliance limits (one in pond 1 and two in pond 4, see Figure 1(c)). Oxygen registered very mismatched values in pond 1 and pond 3, with most of its values being below the lower limit in these two ponds. Transparency shows more mismatched values in pond 2 and pond 4, with most observations below the lower limit. In all these cases where the physicochemical parameters are outside the limits, they indicate that the aquatic environment was out of control due to lack of conformity of the parameters (Figure 1(b)).

Regarding the variability of the aquatic environment, the charts in Figure 1 show that only the temperature and pH had significant variations in order of 3σ. The temperature has two observations (one in pond 3 and one in pond 4, see Figure 1(a)) outside the stability limits. The pH has two observations out of control in pond 4 (Figure 1(c)). Oxygen and transparency do not have observations out of stability control limits, however, the autoregressive time series structure presented by the observations and the changes highlighted between observations from different ponds show that there is considerable variability in the data (see Figure 1(b) and Figure 1(d), respectively).

The univariate control charts presented in Figure 1 do not exploit the correlation between the physicochemical parameters considered. If the joint variability of each parameter pair has relevant process information these graphs cannot model it. Consider below a principal component analysis in order to exploit the correlation structure between the physicochemical parameters. Based on Kaiser's criteria, two main components were determined, with a total variability of 66.8%.

Table 1 shows the weights of the parameters in each particular component. Whereas a variable has a significant weight in the component if it is greater than 0.5, then, component 1 is dominated by low values of oxygen and high values of transparency and the second component is dominated by high values of temperature and pH.

Figure 2 shows how the physicochemical parameters are related in the two determined components. The temperature and pH coordinates are almost stuck together indicating that these two parameters are strongly correlated, with both contributing positively to component 1 and negatively to component 2. On the other hand, oxygen and transparency are inversely correlated in both components.

This information, evidenced by the correlation between the parameters, is relevant when managing the physicochemical parameters to keep the aquatic environment under control. In cases where there are records of very high values of one of the parameters it is important to know to what extent its level should be lowered without compromising the other parameters to which it is correlated.

Such information evidenced by the correlation between parameters was not modeled in the univariate charts presented in Figure 1 and may change an important decision in monitoring the aquatic environment by including it in the model. Therefore, the Hotelling $T^2$ chart was adjusted to include not only the main effect of each parameter, but also its correlation structure.

The Hotelling $T^2$ chart is defined by: $T_i^2 = n(p_i - \bar{m})\Sigma^{-1}(p_i - \bar{m})$. Where $p_i$ is the vector that collects the value of each parameter at the instant $i$, $\bar{m}$ is the average vector of the process under control and $\Sigma^{-1}$ is the inverse of the variance-covariance matrix of the four physicochemical parameters. When the process is under control there is a probability $\alpha$ that the statistic $T_i^2$ exceeds the control limit $CL = \chi^2_{p,\alpha}$ [12]. Thus, the graph $T_i^2$ has only one stability limit ($CL$: the upper limit).

---

**Table 1. Main components.**

| Parameters | PC1    | PC2    |
|------------|--------|--------|
| Temperature| 0.2857 | -0.6482|
| Oxygen     | -0.6165| -0.4191|
| pH         | 0.2561 | -0.6232|
| Transparency| 0.6875 | 0.1257 |
In addition to stability control based on the CL limit, $T^2$ chart was developed to control the multivariate compliance of the parameters considered. For this purpose, the vectors of the lower (25.0, 4.5, 7.0, 30.0) and upper (32, 9, 9, 40) limits of the physicochemical parameters were transformed to the environment $T^2$, where the values 2.57 and 37.5 were obtained respectively.

**Figure 2.** Relationship between physicochemical parameters in PCA loadings.

The determined Hotelling $T^2$ chart is presented in Figure 3, where the interrupted horizontal lines indicate the compliance control limits and the continuous horizontal line is the stability limit. The vertical lines separate the data of the four ponds considered in this work.

**Figure 3.** Multivariate monitoring of the aquatic environment.
4. Discussion
The correlation structure between the parameters showed in Figure 2 indicates that a possible reduction of the temperature in the water also reduces the pH and vice versa. Likewise, a reduction in transparency implies an increase in dissolved oxygen. Therefore, this structure of correlation between the parameters shows that the univariate charts presented in Figure 1 are not adequate to control all the relevant aspects of the process. In this case, Hotelling's $T^2$ chart was applied to overcome this drawback. With respect to compliance, $T^2$ chart shows many observations below the lower limit, for all ponds. Thus, in all these cases the aquatic environment is said to have been out-of-control due to insufficient physicochemical composition in the water.

Compared to the univariate charts, this result can be attributed to the main effect of each of the physicochemical parameters, and it can be said that the aquatic environment was mainly out-of-compliance due to low oxygen levels in pond 1 and pond 3, and low levels of transparency in pond 2 and pond 4. Temperature and pH contributed moderately to this mismatch. As for the stability of the aquatic environment, $T^2$ chart shows five observations outside the stability limit (one in pond 2, one in pond 3 and three in pond 4). Therefore, in these cases the aquatic environment was out-of-control due to lack of stability.

The observations in pond 3 and pond 4 shown by $T^2$ chart in Figure 3 coincide with those shown in the temperature and pH control charts in Figure 1(a) and Figure 1(c), respectively, with the only mismatch of the aquatic environment in pond 3 being caused by significant temperature variability, and the mismatches shown at three points in pond 4, one being caused by the temperature mismatch and two by the pH mismatch. However, the observation outside the stability limit indicated by the $T^2$ chart in pond 2 does not coincide in any of the univariate charts presented in Figure 1, i.e., the $T^2$ chart indicates that the aquatic environment was out of control due to lack of stability, but none of the parameters individually are shown in this condition. In this case, the mismatch of the aquatic environment evidenced by $T^2$ chart is attributed to the joint variability of the physicochemical parameters demonstrated by their correlation structure and not to the individual effect of each of them. Therefore, in the pond 150 (observation 65 of the monitoring process) the process was really out-of-control due to the mismatch of the stability of the aquatic environment and there was no capacity to detect it by the univariate charts, incurring the type 2 error that consists in considering that the process was under control, when in fact, it was changed.

5. Conclusions
In this work was analyzed the influence of the correlation structure of physicochemical parameters in decision making in the process of monitoring the aquatic environment in aquaculture. It was defended the hypothesis that a multivariate process should be monitored based on multivariate methods to overcome the limitation of univariate methods of not being able to model the correlation structure between variables. On the other hand, the physicochemical properties of water were analyzed in terms of its level and variability in the culture of aquatic species in aquaculture. The results showed that in addition to the conformity of the physicochemical parameters which is usually given the highest priority, the control of variability is very necessary and relevant to detect sudden changes in each parameter and the relationship between them.

The correlation structure evidenced in the four physicochemical parameters analyzed shows a strong and positive relationship between temperature and pH, oxygen and transparency are inversely correlated. This correlation structure between the parameters indicates that a possible reduction in water temperature also reduces the pH and vice versa, while a reduction in transparency implies an increase in dissolved oxygen. The univariate charts adjusted for each physicochemical parameter were only able to point out process changes caused by the main effect of each parameter. However, Hotelling's $T^2$ indicated, in addition to all of these, the changes caused by the effect of the correlation structure between the parameters. Therefore, the strategy of controlling a multivariate process based on the individual control of each variable makes the process very vulnerable to type 2 error (considering that a process is under control when in fact it is not).
References

[1] Saavedra M A 2006 Manejo del Cultivo de Tilapia (Nicaragua: University of Hawai’i)
[2] Bautista Covarrubias J C, Ruiz Velazco A J, De Jesus M 2011 Calidad de agua para el cultivo de Tilapia en tanques de geomembrana Revista Fuente 3(8) 10
[3] Alves C S, Mello G L 2007 Manual para Monitoramento Hidrobiologico em Fazendas de cultivo de Camarão (Recife: Universidad Federal de Pernambuco)
[4] Aznar A 2000 Determinacion de los parámetros fisicoquímicos de calidad del agua Revista Interdisciplinar de Gestión Ambiental 2(23) 12
[5] Sotolu A, Faturoti E 2009 Growth performance and haematology of clarias gariepinus (Burchell, 1822) fed varying inclusions of Leucaena leucocephala seed meal based-diets Revista Científica UDO Agrícola 9(4) 979
[6] López Martinez L, Paredes Jimenez A N, Alcazar Oliver J G 2010 Analisis de parametros fisicoquimicos y biologicos en las aguas costeras de la regon de Murcia III Jornadas de Introducción a la Investigación de la Universidad Politecnica de Cartagena (III JIIUPCT) (Murcia: Universidad Politecnica de Cartagena)
[7] Zhou R, Quin X, Peng S, Shi H, Deng S 2014 Macroinvertebrate investigation and their relation to environmental factors in Bohai Bay Acta Ecologica Sinica 64(1) 50
[8] Mulema S A, Carrión A 2018 Quality and productivity in aquaculture: Prediction of oreochromis mossambicus growth using a transfer function ARIMA model International Journal for Quality Research 12(4) 823
[9] Mulema S A, Carrión A, Ernesto V 2018 Analysis of fertilizer effect in the Tilapia growth of Mozambique (Oreochromis mossambicus) International Journal of Agricultural and Biosystems Engineering 12(2) 59
[10] Mulema S A, Carrión A 2019 Monitoring of an aquatic environment in aquaculture using a MEWMA chart Aquaculture 504 275
[11] Shewhart W 1931 Economic Control of Quality of Manufactured Product (London: Macmillan and Co Ltd.)
[12] Aparisi F, Haro C 2003 A comparison of T² control charts with variables sampling schemes as opposed to MEWMA chart International Journal of Production Research 41(10) 2169