

**EFFICIENCY AND RELIABILITY ANALYSIS OF 9  
WASTEWATER TREATMENT TECHNOLOGIES FROM  
FORTALEZA – BRAZIL FOR WASTEWATER REUSE IN  
AQUACULTURE AND IRRIGATION**

By: Michael Alderson

Submitted in partial fulfilment of the requirements for the degree of Master of Science in Degree Programme in the Faculty of Science Agriculture and Engineering

School of Civil Engineering and Geosciences  
School Office: Cassie Building  
Newcastle University  
Newcastle upon Tyne  
NE1 7RU  
UK

Submission date: 16<sup>th</sup> October 2009

I hereby certify that this work is my own, except where otherwise acknowledged, and that it has not been submitted previously for a degree at this, or any other university.

Michael Alderson

## ACKNOWLEDGMENTS

I am very grateful for the chance given to me by Newcastle University and my supervisor Dr. Cesar Mota to undertake this project. I would also like to thank Dr. Mota for his guidance in the selection of my project, the aid provided for the planning stages of my trip, for his availability to help and especially for the links and new people which I was able to meet through him.

I would like to make a especial mention to Dr. André Bezerra dos Santos and Marcio Botto - my two mentors during my stay in Brazil. Thanks to them I felt at home in an unknown country from the moment I met them, and was able to experience a time which I will never forget. Furthermore, their knowledge of the subject, dedicated supervision and guidance in ensuring my project went ahead, made me realise that I had with me the best supervisors anyone could ask for.

I would also like to thank CAGECE for providing the required data and the Federal University of Ceará, for providing all the facilities required for me to carryout my project. Thanks to all the staff at the university and the students who made my days at the university as pleasant as they could be.

Much gratitude goes as well to Engineers without Borders UK and Newcastle's University Tulip fund for providing financial assistance in the development of the project.

Finally, but not least, thanks to my family and friends for making everything easier and encouraging me with their support. Thank you all.

## ABSTRACT

The study analyses the removal efficiency and reliability (at an 80% reliability level) of 57 WWTP belonging to 9 wastewater treatment technologies for wastewater reuse in aquaculture and agriculture in Fortaleza – Brazil, using their performance and effluent quality as the basis for their suitability. The technologies include septic tanks (ST); septic tanks + anaerobic filters (ST+AF); septic tanks + anaerobic filters + chlorination (ST+AF+Cl); facultative ponds (FP); facultative + maturation ponds (FP+MP); anaerobic + facultative + maturation ponds (AP+FP+MP); facultative aerated ponds + facultative + maturation ponds (FAP+FP+MP); upflow anaerobic sludge blanket reactors (UASB); upflow anaerobic sludge blanket reactors + chlorination (UASB+Cl). The parameters used for the analysis were determined by the WWTPs measurements available compiled by CAGECE, which was in some cases very limited. These included; COD, TSS, turbidity, conductivity, ammoniacal nitrogen, *E. Coli*, TTC and BOD. The parameter limits selected were hypothetically set up following Brazilian legislation values and values suggested by research. The results showed discrepancies with expected performances of some technologies, influenced by lack of data. In some cases great variability between individual WWTPs was seen suggesting management and maintenance complications. The most appropriate technology proved to be the AP+FP+MP systems (WSPs), followed by ST+AF+Cl and FAP+FP+MP. UASB and UASB+Cl performed similarly to ST+AF systems whilst the worst performances were provided by ST, FP+MP and FP. The study concludes that further research into the individual WWTPs of the treatment technologies should be carried out.

**Key words:** wastewater, treatment plant, treatment technology, aquaculture, irrigation, parameters, efficiency, reliability, analysis, effluent quality

## TABLE OF CONTENTS

<b>1.</b>	<b>LITERATURE REVIEW.....</b>	<b>7</b>
<b>1.1</b>	<b>Treated wastewater reuse.....</b>	<b>9</b>
<b>1.1.1</b>	<b>Treated wastewater reuse in irrigation.....</b>	<b>10</b>
<b>1.1.2</b>	<b>Case study: Treated wastewater reuse for irrigation of food crops in Fortaleza - Brazil.....</b>	<b>13</b>
<b>1.1.3</b>	<b>Wastewater reuse in aquaculture.....</b>	<b>14</b>
<b>1.1.4</b>	<b>Case study: Wastewater reuse for Aquaculture in Fortaleza - Brazil.....</b>	<b>15</b>
<b>1.2</b>	<b>Treated wastewater parameter limits.....</b>	<b>16</b>
<b>1.2.1</b>	<b>Differences in parameter limits.....</b>	<b>17</b>
<b>1.2.2</b>	<b>Important parameters for wastewater reuse in irrigation.....</b>	<b>19</b>
<b>1.2.3</b>	<b>Important parameters for wastewater reuse in aquaculture.....</b>	<b>21</b>
<b>1.3</b>	<b>Wastewater treatment methods and technologies.....</b>	<b>24</b>
<b>1.3.1</b>	<b>Septic tanks.....</b>	<b>25</b>
<b>1.3.2</b>	<b>Septic tanks with anaerobic filters.....</b>	<b>26</b>
<b>1.3.3</b>	<b>Anaerobic ponds.....</b>	<b>26</b>
<b>1.3.4</b>	<b>Facultative ponds.....</b>	<b>27</b>
<b>1.3.5</b>	<b>Aerated facultative ponds.....</b>	<b>28</b>
<b>1.3.6</b>	<b>Maturation ponds.....</b>	<b>29</b>
<b>1.3.8</b>	<b>Waste Stabilization Ponds (WSPs).....</b>	<b>30</b>
<b>1.3.9</b>	<b>Chlorination.....</b>	<b>31</b>
<b>1.4</b>	<b>Technologies general overall efficiency, reliability and compliance with effluent quality.....</b>	<b>31</b>
<b>2.</b>	<b>INTRODUCTION.....</b>	<b>33</b>
<b>3.</b>	<b>METHODS.....</b>	<b>38</b>
<b>3.6</b>	<b>Parameter limits.....</b>	<b>39</b>
<b>3.7</b>	<b>Removal efficiency levels.....</b>	<b>40</b>
<b>3.2.1</b>	<b>Percentage verification of actual effluent levels falling within set limits (required levels).....</b>	<b>41</b>
<b>3.8</b>	<b>Reliability Analysis.....</b>	<b>42</b>
<b>3.8.1</b>	<b>Coefficient of reliability (COR).....</b>	<b>42</b>

3.8.2	Required design/operational values necessary to achieve the discharge standards/limits .....	45
3.8.3	Expected percentage compliance with the discharge Standards .....	45
4.	<b>RESULTS AND DISCUSSION</b> .....	47
4.1	Parameter removal efficiencies.....	53
4.1.1	COD removal.....	53
4.1.2	EC removal.....	54
4.1.3	Turbidity removal.....	55
4.1.4	TSS removal .....	56
4.1.5	<i>E. coli</i> removal.....	57
4.1.6	TTC removal .....	59
4.1.7	BOD removal.....	61
4.1.8	N-NH <sub>3</sub> removal.....	62
4.2	Percentage of parameter values complying with parameter standards .....	67
4.3	Interpretation of the coefficient of reliability.....	78
4.4	CV and COR values obtained.....	81
4.5	Effluent values required to reach the parameter limits .....	94
4.6	Percentage of compliance with the parameter limits at an 80% reliability level .....	108
5.	<b>CONCLUSION</b> .....	121
6.	<b>FUTURE WORK</b> .....	123
7.	<b>SUMMARY</b> .....	125

## **1. LITERATURE REVIEW**

Prevailing current increases of populations and expansion of urban areas in both the developing and developed world have led to an increase in pressure towards the rural sector into producing higher amounts of food, but simultaneously requiring it to lower its consumption of natural water resources. This is creating and leading to great complications, which could lead to a crisis of unprecedented magnitudes in many parts of the world, especially in countries facing increasing water shortages as a result of climate change and to those characterised by their dryness- arid semi/arid regions. This affects both population sectors: urban and rural, as demand required is not met, consequently bearing the strain of water shortages on both population sectors (IWMI, 2000a).

The fact that wastewater levels are growing, adds on to the strain being imposed to the environment. This thought can be mitigated efficiently with existing technologies and effective management schemes. By introducing a 'recycling' scheme of treated wastewaters which would result in their implementation for irrigation and aquaculture practices, potentially creating a sustainable cycle of water re-use; this would help relieve the strain partially, providing farmers with an increased water resource to work with, hence alleviating poverty levels and providing an increase in food security (Mara, 2003; UN, 20009).

The complication in expanding the development of wastewater treatment facilities in most developing countries lays in the governmental priorities of development set by each country. This refers in most cases, to economic growth through industrialisation,

which consequently leads to higher levels of urbanisation expansion and eventual increases in demand of wastewater treatment facilities. The implementation of these wastewater treatment facilities is in some occasions unaffordable for some countries, or perceived erroneously by others as unnecessary, as they might be regarded as a loss of capital when invested in due to lack of immediate economic gain from them. This thus leads to a lack of investment in the appropriate technologies, hence failing to meet the demand required and subsequently worsening ecological conditions; terrestrial and marine.

The erroneous view of capital loss caused by investment in these technologies has already been proved as a misconception. It has been demonstrated that quality of life and economic growth in the long run are intrinsically linked to the quality of the environment (Parr & Horan, 1996; Ludwig, 1998; Feenstra *et al.*, 2000; IWMI, 2000a; Mara 1989; Shuval *et al.*, 1986; WHO, 2006). It is impossible to detach economic development issues with that of the environment, as many forms of economical development erode the environmental resources on which they depend on, thus leading to environmental degradation and subsequently undermining economic development, eventually worsening the livelihoods of many, mainly the poor (WCED, 1987).

Currently, the effects of climate change and global warming are constantly making the development of water services a requirement of a higher priority and urge in many parts of the world where dry conditions and drought are threatening millions of lives. These developments have been currently stumped as a result of the current economic crisis, which has negatively stricken aid agencies and charities which aim to improve these kind of services (UN, 2009). Furthermore, to add unto the problem, it has



been predicted that over 50% of the world's population will suffer water shortage in the next 30 years (Postel, 1997; UN Environment Programme, 2000; Hunt, 2003) and the areas which will be worst affected will be those found in the developing world.

As the UN World Water Assessment Programme (2009) states, the world cannot afford to stop investing in water technologies and water service developments. New techniques and sustainable management schemes need to be prepared and implemented in the areas which will be worst affected in order to face the imminent water shortages yet to come. The pressure of agriculture which consumes around ~70% of the global available water, in conjunction with many other industries whilst there is still a huge unfulfilled domestic demand of water; calls for a more sustainable approach to the consumption of the global water abstraction. This sustainable implementation involves the direct reuse of treated wastewaters for agriculture and aquaculture, as well as its use in industry and for domestic supply (Mara, 2003).

### **1.1 Treated wastewater reuse**

As wastewaters from urban areas may carry biological and chemical pollutants from industrial developments, their direct use pose detrimental health effects for those who deal with them directly without appropriate equipment, as well as those who consume raw infected crops which have been irrigated with these waters, as well as fish that have been bred in them. Furthermore, they could inflict serious contamination of water bodies such as rivers, canals, lakes and/or oceans; jeopardizing use of these water resources for future generations (WHO, 2006; UNEP, 2004).

Health risks for communities, farmers and the consumers of products (crops and fish) cultivated with untreated wastewaters arise from the presence of viruses, bacteria and parasites which could also develop in the water bodies exposed to the discharge. It is of vital importance that these health risks are addressed for the re-use cycle of wastewater to be sustainable. Hence the importance in wastewater treatment technology and its crucially required investment by developing countries governments, which should always implement appropriate realistic legislation and policies referring to the required standards and guidelines for their safe reuse (WHO, 2006).

### **1.1.1 Treated wastewater reuse in irrigation**

Utilization of treated wastewaters for irrigation greatly eases the huge demand of water consumption required by irrigation which presently accounts for 70 - 80% of the annual water demand in many countries (Feigin *et al.*, 1991). This effluent though will vary significantly in composition when compared with the regular water supply used for irrigation. According to the type of treatment it undergoes and its intensity, as well as its chemical and biological features, the effluent will present differences influencing the following parameters:

- COD and BOD indices are expected to be larger in treated wastewaters as treatment processes can affect differently the levels of reduction of organic matter content.
- Pesticide residues may be common in wastewater effluents which in many circumstances will prevail in the effluent after treatment as these organic toxic substances are not removed during treatment.

- Due to the persistence of inorganic salts, such as sodium and chloride in the treated wastewater effluent there is an increase in the salinity of the treated wastewater effluent. During the treatment only bicarbonates are able to precipitate.
- Macronutrient levels such as nitrogen and phosphorous also vary and should always be considered as useful additions to the treated wastewater effluent, but should be always kept to appropriate levels. Otherwise, this could inflict groundwater contamination if quantities which exceed the required values for irrigation of the chosen crops.
- Trace element content will be found in higher levels for treated wastewater, especially when dealing with industrial effluents (B, Cu, Mn, Mo and Zn). This could increase toxicity levels, in particular with the addition of trace elements such as Cd, Pb and Hg.
- Although most wastewater treatments aim to eliminate pathogenic organisms such as bacteria and viruses, these might be found in treated effluents especially in treatment plants which are not working effectively. Parasites such as protozoa and helminths can be also found in certain occasions.

Irrigation management with treated wastewaters should always consider the points mentioned above in conjunction with general irrigation guidelines such as evapotranspiration rates (consumptive use), choice of irrigation method, fertilization, drainage and other management practices. If these points are followed, then the advantages provided by wastewater reuse in irrigation can be numerous:

- water would be conserved and would consequently relieve the stress of water shortages;

- reduction of pollution of water sources (rivers, canals, lakes, oceans) by the implementation of untreated effluents used for irrigation;
- can provide in certain cases enough nutrients for effective plant growth thus discarding the need of fertilizer application (economical gain for poor farmers) and cancelling the negative effects caused by their implementation;
- increases in yields when compared with fresh water application; and
- provides a constant, cheap and reliable water source for farmers to use.

Simultaneously, there are also negative effects which can arise from the implementation of treated wastewaters for irrigation when efficiency of treatment plants is limited thus affecting effluent quality. The effects listed below should not go ignored:

- Detrimental health effects might affect farmers exposed to the effluent used for irrigation when the water treatment processes are not working appropriately and acceptable levels of water quality are not met;
- then contamination of ground waters from an excess of nitrates might also result;
- an accumulation of heavy metals and other chemical pollutants;
- the formation of environments ideal for disease vectors to thrive in; and
- the development of eutrophication, blocking wastewater passages for irrigation and other water sources.

Considering the points mentioned above, careful planning of the irrigation systems should be carried out; following accepted effluent quality standards; with constant monitoring of the effluent and maintenance of the WWTPs, in order to ensure their efficiency and reliability (Dos Santos, 2006; Mara, 2003; Mota et al., 2007).

### **1.1.2 Case study: Treated wastewater reuse for irrigation of food crops in Fortaleza - Brazil**

Studies at the Federal University of Ceará in Fortaleza, Brazil (2006) showed that the implementation of treated wastewater from 1 waste stabilization pond system in series (anaerobic pond, facultative and 2 maturation ponds) provided high yields and productivity of food crops; watermelon and papaya in this case. The irrigation of these crops was carried out with different water compounds and irrigation practices which were then compared; fresh water + NPKS, treated wastewater, treated wastewater +  $\frac{1}{2}$  NPKS and treated wastewater + NPKS. It was concluded that the type of water compound which presented better yields, higher productivity and fruit quality depended on the irrigation method used and the particular crops nutrient demands.

Irrigation of papaya was carried out by micro-sprinklers, which when using treated wastewater + NPKS provided the best results for yields and Brix degree (highest dissolved solids contents), representing best fruit quality and taste.

The highest yields and the best fruit quality for watermelon resulted from the appliance of treated wastewater +  $\frac{1}{2}$  NPKS via sewage dripping, over furrow. In this case, amounts of NPKS appliance can be lowered as well as the consumption of freshwater for irrigation and thus managing its use more efficiently.

The experiments showed that it is not only feasible, but reasonable as well to apply treated wastewater for the irrigation of crops. The treated wastewaters used for irrigation presented levels within the WHO (2006) accepted guidelines for irrigation,

and its outcomes produced fruits with the ideal microbial quality ready for human consumption under Brazilian legislation (Agência de Vigilância Sanitária, 2001).

### **1.1.3 Wastewater reuse in aquaculture**

Aquaculture is known as the practice in which fish, crustaceans or aquatic vegetables are ‘cultivated’ in artificial or natural “fish farms”, where they are found in enclosed spaces and once fully grown, are then gathered and sold ready for consumption – also known as water farming (Mara, 2003; Mota *et al.*, 2007).

Research has shown that aquaculture carried out with treated wastewaters makes economical sense and provides considerable profits over those sustained with non-treated wastewater. By reusing wastewater in this manner, fish can be cultivated without the need to feed them, as the wastewater ‘fertilizes’ the fishes’ habitat ideally for them to prosper and grow. Furthermore, this option presents a viable option for the provision of protein in the diet of many people in developing countries, and for a reasonable price, making the product accessible to everyone (Mara, 2003; Mota *et al.*, 2007).

It is worth mentioning that wastewater fed-aquaculture follows fundamental Chinese philosophical principles of ‘holism, harmony, self-resiliency, regeneration and circulation’, as it aims to reuse wastes for the production of food, whilst protecting the environment and subsequently creating a sustainable development (Mara, 2003). Additionally, aquaculture effluents can be also applied for irrigation practices, thus offering the advantages provided by this kind of reuse as mentioned in section 1.1.1.

Just as for irrigation, wastewater quality for aquaculture should comply with minimum microbiological standards in order to guarantee that the health of workers carrying out this practice is not affected negatively, and to ensure the products are safe for human consumption (Dos Santos, 2006; Mara, 2003; Mota *et al.*, 2007).

#### **1.1.4 Case study: Wastewater reuse for Aquaculture in Fortaleza - Brazil**

An additional study conducted by the Federal University of Ceará in 2009 focused in the potential and feasibility of aquaculture, using treated wastewater from the same waste stabilization pond system used for the study mentioned in section 1.1.2 (comprising of 4 ponds). The results demonstrated that Nile tilapia, *Oreochromis niloticus* was able to thrive and grow ideally for aquaculture purposes in tanks supplied by treated wastewaters presenting WHO (2006) accepted guidelines. The fish did not require feeding, as the treated wastewater provided the ideal environment for the fish to grow, providing positive individual growth rates. The produced fish possessed the acceptable microbial values for human consumption under Brazilian legislation (Agência de Vigilância Sanitária, 2001).

This comes to show that ideal management of treated wastewaters can provide not only a sustainable effluent for the production of fruits and crops, but it can also serve as an ideal environment for aquaculture. Furthermore, the selection of wastewater treatment technologies to provide suitable water for reuse practices, in this case for irrigation and aquaculture, should be carried out according to the economical, social, geographic and climatic conditions of an area. This comes as a result of technologies operation variations when it comes to warmer and colder climates, size (according to

population requirements) and price of construction and maintenance. Fundamentally, some technologies are more viable in certain areas than others even if their actual efficiency, reliability and final effluent levels are not as good when compared against each other (UNEP, 2004).

## **1.2 Treated wastewater parameter limits**

It is of vital importance to provide treated wastewater effluents which comprise the required characteristics for successful sustainable production of crops in irrigation reuse and for fish populations in aquaculture. In order to achieve this, targets need to be set as a way of locating an acceptable standard; these are known as parameter limits which will ultimately define the suitability of the treated wastewaters for their respective reuse.

There is a variety of parameter limits set in different countries which present varying values of acceptable criteria for wastewater irrigation and aquaculture. The United States, for example, uses the US Environmental Protection Agency guidelines (1992), whilst others use the WHO (2006a & 2006b) values, as they are recognised as the world standards and are less stringent, making them more realistic for the developing world (Mara, 2003).

It is imperative for developing countries to set realistic and pertinent wastewater parameter limits as these have to be put in a frame which will enable them to be categorized as real achievable targets. This will depend on a particular areas affluent



characteristics/composition and subsequent effluents purpose, either for reuse or discharges of other kinds (IWMI, 2000a; Mota *et al.*, 2007; Shuval *et al.*, 1986).

Developed countries have already achieved positive results on this matter, setting high standards and achieving them with their advanced wastewater technologies, although they are presently fine-tuning the control of micro-pollutants or the impacts of pollutant in fragile areas (Von Sperling & Lemos Chernichero, 2000). However, developing countries are still struggling in developing proper discharge standards as many are currently trying to follow the example of developed countries by lowering the parameter limits, whilst at the same time having to deal with an increase in environmental pollution of the water sources (Jhonstone & Horan, 1994; 1996; Nascimento & Von Sperling, 1999; Nascimento & Von Sperling, 1998; Von Sperling, 1998).

Although the values of these guidelines differ, their aim is the same; to provide wastewaters which by being used, will not harm the environment, will not cause excess disease in the people who handle them in irrigation fields and in aquaculture tanks/ponds, as well as the people who consume the end product of both reuse practices (Feigin, 1999; IWMI, 2000a; Mara, 2004; Mota *et al.*, 2007; WHO, 2006a, 2000b).

### **1.2.1 Differences in parameter limits**

Some of the levels perceived as acceptable in developed countries present values which are too stringent for developing countries standards, especially those presented by the USEPA (1992). These guidelines for example, suggest BOD levels of  $\leq 10$  mg/L,

turbidity levels of  $\leq 2$  NTU and *E. coli* levels of 0 per 100ml for wastewater reuse in agriculture, which for developing countries presents a nearly impossible and irresponsible standard to achieve (Mara, 2003).

Many developing countries find themselves with little background research on their own untreated wastewaters characteristics, and so, without knowing their constituents and hence lacking the knowledge of the ideal treatment requirements, tend to adopt those stringent parameter limits employed in the developed world. This in many occasions induces 'overkill' (Mara, 2003). This concept refers to the setting of parameter limits to excessively high standards, unnecessary for most places and unrealistic in terms of them being achieved with the available technologies. This then results consequently in economic and social complications, in situations where wastewater treatment technologies implemented to reach these stringent limits are too costly to maintain by the population, and eventually breakdown with no chance of repair. This in some cases leads to eventual health problems of individuals as the WWTPs stop operating, subsequently failing to treat the wastewaters properly and exposing people to the effects that this conveys. This issue has led to deaths of people in the long run, as has been the case in developing world (Mara, 2003).

In Brazil this 'overkill' concept is being avoided and realistic/pertinent to the area parameter limit guidelines are being developed and applied such as those suggested by CONAMA (Nascimento & Von Sperling, 1999), SEMACE – acting as an environmental quality regulator as part of a local branch of the state of Ceará and by the 'Programa de Pesquisas em Saneamento Básico' (research programme of basic sanitation), also known as PROSAB (Dos Santos, 2006; Mota *et al.*, 2007).

### **1.2.2 Important parameters for wastewater reuse in irrigation**

Factors such as pH, organic matter, total suspended solids, pathogens, nutrients (nitrogen and phosphorous), ammonia and conductivity all affect crop development and growth and should always be analysed when using treated wastewaters.

Factors such as the pH and alkalinity, are important factors as they will influence photosynthesis of plants and respiration. Values considered as acceptable fall within 6.5 – 8.4, although values suggested by CONAMA for unrestricted irrigation range from 6 – 9 (Dos Santos, 2006).

Presence of organic matter, measurable by COD and BOD, is usually seen as a positive factor, although its levels should be controlled. Too much of it could result in denitrification, which would be negative for plant growth (Bastos, 2003). BOD values recommended reach 60 mg/L (Mota *et al.*, 2007) and COD values 200 mg/L (Semace, 2002).

Total suspended solids on high levels can cause the destabilization of organic matter, as a result of gas production and soil pore obstruction, causing eventual impermeability of the soils (Paganini, 1997). The highest risk posed by high TSS values is that of obstructing irrigation systems. Values above 50 mg/L can cause severe irrigational problems (Dos Santos, 2006).

Pathogens levels such as *E. coli* values and helminth eggs require to be controlled in order to avoid contamination of the crops and subsequent contamination of people who deal with them and consume them. Levels suggested by the WHO (2006a) for unrestricted irrigation levels of *E. coli* are expected to be  $\geq 10^3$  per 100 mL (geometric mean) and for restricted irrigation  $\geq 10^5$  per 100 mL (geometric mean). The levels for restricted irrigation adapted by PROSAB ( $\geq 10^4$  per 100 mL) (Dos Santos, 2006) (which is more localized to Brazil), suggest that the WHO values apply for restricted irrigational practices in which the workers do not come in direct contact with the water, due to mechanization of agriculture or safety equipment availability. For both types of irrigation, if children under 15 years are exposed then  $\leq 0.1$  helminth eggs levels are required, as opposed to  $\leq 1$  helminth egg (WHO, 2006a).

Ammonia levels for irrigation are usually found between 0-5 mg/L but wastewater effluents in developing countries, such as those found in Brazil tend to surpass this level slightly. This should not pose big problems for irrigation. In many cases, ammoniacal nitrogen does not present specific limits as it will be in many cases preserved within the effluent as part of intended nutrient conservation, aimed to conserve nitrogen and phosphorous levels, in order to aid fertilization of crops when applied (Mota *et al.*, 2007). These important mentioned macro-nutrients are both beneficial for the growth of the plants but in excess could overdose them, their ideal values will depend on the requirements of the plants being grown (Mota *et al.*, 2007).

Conductivity is one of the most important parameters for irrigation, as its high levels will present salinization levels which will greatly affect plant growth and

development negatively, if found in excess- salts will accumulate in plant roots and limit their availability of water.

Salinity levels and risk will be low when conductivity is found below 750  $\mu\text{S}/\text{cm}$  and intermediate when found between 750 – 1500  $\mu\text{S}/\text{cm}$  at 25°C. Maximum levels for irrigation have been set to up to <3000  $\mu\text{S}/\text{cm}$  (Semace, 2002), levels above this value would present severe salinity and the failure of crops. Furthermore, much of the literature would suggest this level as being too high (Mara, 2003; Mota *et al.*, 2007).

### **1.2.3 Important parameters for wastewater reuse in aquaculture**

The main parameters affecting the well being and growth of fish are: oxygen demand (OD); pH; alkalinity; nutrients (nitrogen and phosphorous); chlorophyll and ammonia (Bastos *et al.*, 2003b).

Toxic compound presence of toxic compounds such as ammonia and/or heavy metals, which could kill off an entire fish crop, will influence pH values, thus serving as an indicator. The ideal pH for the cultivation of fish ranges from 6.5 – 9.5 (Bastos *et al.*, 2003b).

When referring to OD, each fish species is resistant to different limit concentrations, which influence their growth, development and could determine their survival. Lack of OD can be related to high fish density, large organic compounds presence and the formation of a large algal community in the tanks surface (Kellner & Pires, 1998). Studies by Kellner & Pires (1998) sustain that Nile tilapia is able to

survive in precarious OD conditions of only 0.5 mg/L, whilst Bastos *et al.* (2003b) states that tilapias exposure of 20 minutes up to 1 hour, to levels lower than 1 mg/L can be lethal.

Electrical conductivity levels, if exceeded can cause malformation of fish, retardation in growth and death. As electrical conductivity is directly related to the ions presence in the water and thus, the salinity levels, ideal levels are found within 200 – 1000  $\mu\text{S}/\text{cm}$  (Bastos *et al.*, 2003b).

Temperature suitability also depends on the fish species being cultivated, although on a general basis, it is known to influence fish metabolism, negatively when temperatures are low. The ideal temperatures for tropical species such as tilapia is found within 20°C – 30°C (Bastos *et al.*, 2003b). Ideal temperatures will benefit and allow all of the physiological characteristics of fish to function properly (Silva *et al.*, 2001).

Phosphorous is an essential nutrient for the food chain of fish, but it is usually found on low quantities as a result of nutrient removal in the wastewater treatment plants. It can be found in fish tanks in the form of orthophosphate which is assimilated by phytoplankton and thus benefiting the fishes diet (Bastos *et al.*, 2003b).

Chlorophyll levels are representative of primary productivity and the trophic state of the aquatic environment. Within this, phytoplankton and zooplankton are seen as important factors as they compose the fish's diet, especially at their initial growth stages (Bastos *et al.*, 2003b).

Fish pathogen transmission is directly related to the quality of the water in which they are bred, maximum levels for *E. coli* are  $10^4$  per 100 mL (WHO, 2006b). Factors such as time of exposure, cultivated species and the stress caused by the fishes habitat on their population will also determine the level of fish contamination (Araujo, 2000).

The presence of ammonia is of crucial importance, as it is very common to find high levels of it in domestic and industrial wastewaters. Ammonical nitrogen (N-NH<sub>3</sub>) is one of the forms in which ammonia can present itself, especially from domestic wastewater as a result of human urine and faeces which can be highly toxic to fish (Alabaster & Lloyd, 1982). It is also thought that toxicity of this kind might be attributed to algae, zooplankton and the fish themselves (Mara & Pearson, 1986). Ammoniacal nitrogen toxicity will depend on parameters such as pH, OD, temperature and salinity of the water (measurable by conductivity) (Bastos *et al.*, 2003b). The literature suggests that levels of ammoniacal nitrogen for fish should range from 2 – 5 mg/L (Dos Santos, 2006) in aquaculture tanks, although results from experiments (such as that mentioned in section 1.1.5) have shown that mean levels of up to 7.7 mg/L have been able to sustain Nile tilapia populations (Mota *et al.*, 2009).

In reality the requirements set for aquaculture with treated wastewaters do not differ from those for conventional aquaculture. They always need to take into consideration the amount of water required in conjunction with its quality, as mentioned, as well as the technique applied for the cultivation of the fish and the fish species chosen (Bastos *et al.*, 2003b).

### 1.3 Wastewater treatment methods and technologies

Wastewater treatment processes can be classified in three different forms; physical, chemical and biological. Due to the fact that these processes don't function solely, their final operation classification reflects a determined unitary process. The removal of diverse pollutants can be associated with different treatment levels, classified as preliminary, primary, secondary, tertiary and advanced (Mota *et al.*, 2007).

The first two steps rely on physical mechanisms of pollution removal; preliminary treatment refers to the initial process of large solid removal, followed by the primary treatment which removes sediment solids and a significant amount of organic matter. Organic matter is removed more efficiently in secondary treatment, eventually also removing nutrients such as nitrogen and phosphorous. Tertiary treatments, which are not usually applied in Brazil, specialize in removing specific pollutants such as other nutrients, metals and non biodegradable material. These treatment processes can be also added to other treatment units in order to complete the removal of pollutants. Finally, advanced treatments seek to remove suspended and dissolved material, process which is also not applied regularly in Brazil (Mota *et al.*, 2007).

Over the years various studies carried out have focused in determining the performance of the diverse wastewater treatment methods and technologies available, focusing on their operational efficiency, according to the parameter limits set and objective use (Arceivala 1981; Qasim, 1985; Mara, 2003; Metcalf & Eddy, 2003; Von Sperling & Chernicharo, 2005; Von Sperling & Oliveira, 2009; WEF & ASCE, 1992). Although there is a general consensus on the abilities of each wastewater treatment



technology, these studies have suggested in certain cases, great differences between the performances of some of the wastewater treatments, and consequently provided a diversified amount of performance levels for each, suggesting that the facts on these technologies are yet not fully agreed on.

Some of the typical wastewater treatment technologies used in Brazil, and those found predominantly in the city of Fortaleza (location of study) have been provided below with a brief description and summary of their operation efficiency, using the values accepted as the general consensus for each.

### **1.3.1 Septic tanks**

Considered as being one of the most basic and simplest forms of wastewater treatment, they are applied on-site and composed of a watertight tank which collects wastewater from toilets, showers and sinks. This technology specializes in removing suspended solids (50%), but it may also remove BOD (30 – 40%) and is also capable of reducing *E. coli* values by 0.5-1.8 log units (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf & Eddy, 2003; Von Sperling & Chernichero, 2005; Von Sperling & Oliveira, 2009). If designed with a connection (via overflow) to a drainage field where it would undergo natural purification, leftover suspended solids and viruses could potentially be removed. This is not its speciality though, and its overall removal of pathogens is low; its efficiency compared to the other treatment technologies is limited. Problems may arise with this technology if desludging is not carried on a regular basis, or if only the liquid effluent is being removed. This could cause overflowing due to the accumulated presence of the solids potentially causing blockages of drains and sewers.

The restrictions of this technology limit their suitability for their implementation in city wastewater treatment, hence their focused implementation in households and small communities/neighbourhoods usually in rural areas (UNEP, 2004).

### **1.3.2 Septic tanks with anaerobic filters**

The addition of anaerobic filters in septic tanks increases their capacity to remove particles and degrade biomass. They are added as an addition to the septic tanks, either in the form of one or more filter chambers. The filter material is composed of rocks, gravel, cinder or other filter materials with sizes ranging from 12 – 55 mm in diameter, which have been attached with biomass. By providing a large surface area, the organic matter is degraded effectively by its prolonged exposure to the active biomass found within the filter. At ideal retention times (0.5 – 1.5 days) and a maximum flow rate of 2.8 m/d, suspended solid and BOD removal can reach levels of up 80 – 85%, COD efficiency removal levels can reach 70 - 80 %, SS removal efficiency levels are very high reaching 80 - 90 %, Ammonia-N removal efficiency will not surpass 45 %; Phosphorous removal efficiency is found below 35 %; and Nitrogen removal is limited, levels do not exceed 60 %. Although anaerobic filters provide a considerable improvement on septic tanks, they are still considered apt only for neighbourhoods and households (Tilley *et al.*, 2008).

### **1.3.3 Anaerobic ponds**

Anaerobic ponds are the first type found in a series system of WSP and are sometimes implemented on their own; their main purpose is to remove suspended solids

and BOD (reaching levels of up to 40 – 60% BOD<sub>5</sub> removal at 20° C – with increasing removal levels related to higher temperatures) (Mara, 2004; Mota *et al.*, 2007). They act as an open septic tank and have virtually the same function. Retention times are usually short ranging from 1-2 days, time which allows them to efficiently remove the mentioned constituents. The removal of the BOD is achieved when sedimentation of settleable solids and their subsequent anaerobic digestion occurs, which results in a sludge layer. The bacterial action occurring within the anaerobic pond is representative of that which occurs in anaerobic reactors. In addition, these ponds can retain toxic compounds resulting from industrial wastewaters. Desludging of digested solids accumulation should be done every once a year as regular desludging schemes will be more efficient in the long run. Scum will accumulate on the surface of the pond, but it does need require removing, unless fly breeding starts becoming an issue (Mara, 2003). This kind of system when operated by itself will present low levels of pathogenic removal (Mota *et al.*, 2007).

#### **1.3.4 Facultative ponds**

As according to Mara (2003), two types of facultative ponds can be found. One type deals with raw wastewater, prior any treatment, and the other deals with partially treated wastewater usually from anaerobic ponds. Their main purpose is to remove BOD from low BOD loadings (75 - 85% removal efficiency rates) and faecal coliforms (1 – 2 log units removal efficiency), they can additionally remove COD (60 – 85% removal efficiency rates), SS (70 – 80 %), Ammonia-N (< 50%), Nitrogen (< 60%) and Phosphorous (< 35%) (Mota *et al.*, 2007). This is carried out through the development of a healthy algae population, which will depend of the loadings, temperature and sun

exposure (factors favourable in Fortaleza) at which the ponds are exposed. Changes in thermal stratification result in algal banding and consequently, with the help of light attenuation they cause physiochemical stratifications. This alters pH levels greatly, reaching levels of 9 - 10 which cause the rapid die off of faecal coliforms. Furthermore, the stratification caused will lead to an even higher reduction in BOD and suspended solids (Mara, 2004).

### **1.3.5 Aerated facultative ponds**

The treatment mechanisms for aerated facultative ponds differ from that of conventional facultative ponds, as oxygen is pumped into the pond by mechanical means, either by surface aerators or compressed air, instead of relying in the oxygen produced by photosynthetic action of algae. The energy levels produced by the aerators is aimed exclusively to the aeration of the water mass and thus, does not influence suspended solids, which tend to undergo sedimentation forming a sludge bed which will then be decomposed anaerobically. Only soluble BOD and finely particulate remains are found in the liquid mass after undergoing the aerobic decomposition, thus presenting the same function as a conventional facultative pond (Mota *et al.*, 2007). As shown by Mota *et al.* (2007), removal efficiency levels for BOD are high, ranging from 75 – 85%; COD presents 65 – 80 % removal efficiency; SS undergoes a 70 – 80% removal efficiency; Ammonia – N removal efficiency levels are below 30%; Nitrogen removal efficiency levels are below 30%; whilst Phosphorous removal efficiency levels fall below 35% and removal efficiency levels for faecal coliforms of 1 - 2 log units can be reached.

### **1.3.6 Maturation ponds**

These types of ponds are usually found at the end of a Waste Stabilization Pond system (WSP), as the last stage of the treatment. Their main aim is to reduce viruses, excreted pathogens and faecal bacteria which are leftover from the treatment of facultative ponds. As suggested by Mara (2003), treatment of wastewaters, once completed in maturation ponds and after having been treated in facultative and anaerobic ponds, are then suitable for implementation in aquaculture and irrigation. BOD, suspended solids and nutrients, such as nitrogen and phosphorous are removed only slightly. However, extremely high removals of *E. coli* in well maintained WSP systems with 2 maturation ponds, have reached 99.99% removal rates (Mara, 2004). This kind of removal is effective on shallow ponds, where light penetration through the small algae population present, acts as a crucial factor in the removal process (Mara, 2004).

### **1.3.7 Upflow anaerobic sludge blanket reactors (UASBs)**

This type of technology has been applied successfully in tropical and sub-tropical regions, particularly in Brazil, Colombia and India (van Haandel & Lettinga, 1994; Foresti, 2002). Their specialization lays in the treatment of domestic wastewaters but they have also successfully treated biodegradable industrial and agro-industrial wastewaters. In this system, wastewaters undergo screening and grit removal processes to remove suspended solids, the affluent is then distributed as evenly as possible across the base of this high rate anaerobic reactor. At that time, the effluent flows upwards through a sludge blanket resulting in anaerobic biochemical reactions through the

contact between the wastewater and the anaerobic bacteria found in the sludge and thus removing efficiently BOD by 60 – 75 %; COD by 55 – 70%; SS by 65 – 80 %; Ammonia – N by less than 50%, Nitrogen by less than 60% and Phosphorous by less than 35%. As the process continues and the affluent continues rising more BOD and COD is removed. The final effluent produced has extremely low suspended solid levels as a phase separator keeps high levels of sludge in the lower part of the reactor and levels of *E. coli* removal of 99% (a reduction from around  $10^7$  per 100 ml to  $10^5$  per 100 ml) (Mara, 2003). Due to their performance and low retention times, UASBs are regarded as suitable treatment technologies for this kind of wastewaters and are, consequently, implemented for large communities and cities (UNEP, 2004).

### **1.3.8 Waste Stabilization Ponds (WSPs)**

This technology comprises Anaerobic ponds + Facultative ponds + Maturation ponds, and thus provides of all their environmental services combined. They are the most cost-effective wastewater treatment technology for the removal of pathogenic micro-organisms according to IRC (2004) - when efficiency is analyzed in relation to their operation and maintenance costs - which are 16 – 38% less than those of the UASBs respectively (Peña *et al.*, 2000). Although retention times are longer than that of UASBs; in certain occasions after 1-2 days they have achieved BOD removal levels of up to 70-80% at temperatures of around 25°C (Peña *et al.*, 2000) thus complying with the necessary requirements for effluent discharges. Furthermore tests with APs showed better performance for TSS, settleable solids and COD removal than UASB's when treating strong domestic wastewaters in Ginebra – Colombia, and these only represent the initial stage of WSPs (Peña *et al.*, 2000). As a result they have been considered to be

the most suitable system for the treatment of wastewaters in tropical, arid and semi-arid areas presenting a developing economy (Peña *et al.*, 2000; IRC, 2004; Curtis, 1994; Mara & Pearson, 1998). On a general basis their constituents will achieve the following efficiency removal levels; BOD (75 – 85%), COD (70 - 83 %), SS (70 - 83 %), Ammonia – N (50 -65 %), Nitrogen (50 – 65%) and Phosphorous (> 50%). As a result of their efficiency, they are used for large communities and in some cities (such as Fortaleza), although they are limited due to their large land requirements (Mota *et al.*, 2007).

### **1.3.9 Chlorination**

The addition of chlorine if applied into wastewater treatment plant correctly enables an extremely effective disinfection process, which seeks to eliminate almost all bacteria and viruses, reducing the risk of waterborne diseases. It is regarded as a very effective technique to eliminate *E. coli* levels by erradicating it completely in less than 1 minute of exposure. It will also eliminate the *Hepatitis A virus* in around 16 minutes, the *Giardia parasite* in about 45 minutes and *Cryptosporidium* in about 6-7 days (Lenntech, 2008).

## **1.4 Technologies general overall efficiency, reliability and compliance with effluent quality**

A lack of research concerning the analisis of wastewater treatment technologies in reference to their efficiency and reliability in providing suitable effluents for reuse in irrigation and aquaculture (especially in developing countries), means that a

comparisson between the technologies mentioned is limited to undirectly related studies.

Investigations carried out by Oliveira & Von Sperling (2007), Von Sperling & Lemos Chernicharo (2000), Von Sperling & Oliveira (2009) and Von Sperling (2005) have provided constituent removal efficiency levels, categorization of technologies complying with effluent quality standards and reliability analysis of wastewater treatment plants (representing different technologies) in producing surface water effluents in southern Brazil.

Results from Sperling & Lemos Chernicharo (2000) showed that most technologies are capable of reaching reasonable and realistic values of effluents for parameters (compatible with existing parameter limits) such as BOD (100 mg/L), COD (200 mg/L) and SS (90 mg/L). Opposingly, for other parameters, these weren't as effective, as was the case for Ammonia levels (15 mg/L), Nitrogen (20 mg/L), faecal coliforms ( $1 \times 10^4$ ) helminth eggs ( $\leq 1$  egg/L) and especially Phosphorous (4 mg/L), only a few proved succesful, in which waste stabilization ponds were the most effective from the mentioned technologies.

A comparative perfomance evaluation of full-scale anaerobic and aerobic wastewater treatment process in southern Brazil (Von Sperling & Oliveira, 2009) showed that on a general basis, removal efficiencies were negative in some events for almost all of parameters. This, according to the study, was attributed to problems in operational functions of the WWTPs and on their maintenance, probably associated with solids loss in the final effluent. Furthermore, it stated that performance of FPs were



similar to those of UASB with no post treatment and UASB+ AF regarding organic matter. Its mean effluent values as well as efficiency values were compared with those considered typical by the technical literature, composed by Areceivala (1981), Qasim (1985), WEF & ASCE (1992), Mara (2003), Metcalf & Eddy (2003) and Von Sperling & Chernicharo (2005), and in most occasions they failed to match. Higher mean effluent levels were reported for this study, as well as mean lower removal efficiency levels especially for FPs (Von Sperling & Oliveira, 2009).

A reliability analysis of wastewater treatment plants carried out by Oliveira & Von Sperling (2007) using a 95% reliability level for effluent discharge to surface waters showed that most WWTPs, belonging to 6 wastewater treatment technologies (Septic tanks + anaerobic filters, facultative ponds, anaerobic + facultative ponds, activated sludge, upflow anaerobic sludge blanket and upflow anaerobic sludge blanket reactors followed by post-treatment) failed to comply with the required effluent standards. The best performances were obtained from AS and UASBs with post treatment, whilst higher effluent concentrations and worst performances were provided by ST+AF and AP+FP.

## **2. INTRODUCTION**

The semi-arid city of Fortaleza (mean annual temperature of 28 °C), situated in the North East of the Brazilian coast and state capital of the state of Ceará, is a city with a large increasing urban population (3.4 million) and with a dispersed significant rural population on its outskirts, which makes up a fraction of Ceará's 35% total rural population (CEARA, 1999). Already, this rural population has experienced the effects of frequent and extended droughts, which have inflicted much suffering and determined the vulnerability of this population – considered as the poorest in the region - to this type of crisis (Mayorga *et al.*, 2001). The relationship between climate patterns and the effects of droughts has confirmed this susceptibility and is representative of even larger complications which lay ahead as droughts are expected to increase in frequency and intensity as a result of climate change and global warming (Hunt 2003; Mara, 2003; Postel, 1997; UN 2000). This indicates that the potential implementation of treated wastewater reuse in this area is a logical option which would aid mitigate the suffering caused by future more unpredictable droughts. The weakness of this region to this kind of problems is not unique, but on the contrary, Fortaleza and its surroundings is one which shares its fragile socio-economic and climatic conditions with many in the developing world and sister cities in the South American continent, hence its potential representation as an example of what could be done in similar locations.

The city possesses a number of diverse wastewater treatment technologies (anaerobic and aerobic) situated within the city and around its outskirts. They are maintained by 'CAGECE', the local water company for the state of Ceará, generally known for its high quality standards and supported by the local community. Nevertheless, in order to consider the use of treated wastewaters to help satisfy the needs of rural populations as well as urban, the potential of treated wastewater

technologies has to be first analysed in order to determine the best option, and the acceptable effluents for reuse practices, in this case for aquaculture and irrigation. This can be done by determining their removal efficiency levels and most importantly, their reliability, against a realistic set of parameter targets (Crites & Tchobanoglous, 2000; Metcalf & Eddy, 2003; Oliveira & Von Sperling, 2007, 2009; Von Sperling & Chernicharo, 2005).

Removal efficiency levels – as the name implies - seeks to determine the capabilities of wastewater treatment plants (WWTPs), in removing certain wastewater constituents categorized as measurable parameters, which would otherwise limit the effluents suitability for this kind of reuse practices. A reliability analysis of the WWTPs adds onto this differentiation in more detail and provides a more insightful projection of the wastewater treatment technologies behaviour, thus aiding in the determination of their suitability (Crites & Tchobanoglous, 2000; Metcalf & Eddy, 2003; Oliveira & Von Sperling, 2007).

In addition, reliability refers to the probability of obtaining an acceptable performance for a definite amount of time under specific conditions. More specifically to WWTPs, it can represent a percentage of time at which the expected effluent values meet the parameter limits (Dean & Forsythe, 1976a; Niku *et al.*, 1979, 1981; Crites & Tchobanoglous, 2000; Metcalf & Eddy, 2003; Oliveira & Von Sperling, 2007). In other words, a WWTP will be completely reliable if the effluent it produces does not exceed the parameter limits set, in this case for aquaculture and irrigation reuse practices. On the contrary, if the effluent does exceed these set values, then the WWTP would not be

regarded as suitable for this appliance as it would have failed to provide the required effluent, and would therefore compromise the success of both practices.

Due to variations in wastewater effluents and in actual WWTPs, their probability of failure to meet the standards should be always considered when being designed, and bearing this in mind, they should be always built to produce an effluent below the standard limits set. For this, a mean value should be applied which would ensure this failure is avoided with a certain reliability level. This can be calculated by means of the coefficient of reliability (also known as COR) which relates the mean effluent values of individual parameters to the standards that must be achieved so as to avoid the failure of the treatment, or the surpassing of the parameter set limits on a probability basis, as explained by Niku *et al.*, (1979).

The concept of the coefficient of variation (CV) and COR can be applied in 3 different ways. For existing parameter limits set by legislation, a WWTP could be designed in order to accommodate the expected variability (CV) which it is bound to produce – determined by other WWTPs of the same sort – in order to still comply with the required standards. For WWTPs already in operation, the concept can serve to determine whether the operational practices are suitable or not in producing the effluent values, considering its expected variability (CV), which should fall within the required percentage of compliance with the parameter limits. Thirdly, if actual CV values are known for WWTPs, as well as different processes, a regulator could specify reasonable and pertinent effluent standards/limits within the grasp of the WWTPs operating capabilities (Oliveira & Von Sperling, 2007).

This concept has been carried out to analyse the effluent of 57 WWTPs belonging to 9 wastewater treatment technologies, with the aim to determine their suitability for reuse in aquaculture and irrigation. The WWTPs removal efficiency levels have been calculated, as well as their COR values from their CV values produced by the measurements of COD, BOD, electrical conductivity, turbidity, *E. coli* and thermotolerant coliforms, on the basis of acceptable parameter limits for the effluents reuse practice in aquaculture and irrigation. The 9 wastewater treatment technologies include; septic tanks (ST), septic tanks + anaerobic filters (ST+AF), septic tanks + anaerobic filters + chlorination (ST+AF+Cl), facultative ponds (FP), facultative + maturation ponds (FP+MP), waste stabilization pond systems comprised of anaerobic ponds + facultative ponds + maturation ponds (WSP or AP+FP+MP), facultative aerated ponds + facultative ponds + maturation ponds (FAP+FP+MP), upflow anaerobic sludge blanket systems (UASB) and upflow anaerobic sludge blanket systems + chlorination (UASB+Cl). Their suitability for these reuse practices will be based on their treatment capabilities and effluent quality. Other influential factors affecting their suitability, such as their socio-economic characteristics, maintenance and additional requirements, have not been analysed as they go beyond the scope of this study.

The importance of this study is magnified by the fact that there is no research of the type which has gathered these technologies and compared their removal efficiencies in producing effluents suitable for aquaculture and irrigation (both restricted and unrestricted). Although studies carried out by Olivera & Von Sperling (2007, 2009) in Brazil have specialized in the evaluation of performances of certain wastewater treatment technologies, these do not cover all of the mentioned technologies and do not analyse their performance for this kind of reuse practices. Furthermore, the idea that

these practices present a realistic alternative in mitigating the expected water scarcity related issues in the years to come (especially in arid and semi arid regions of the developing world), should serve as an incentive to expand research on this topic.

### **3. METHODS**

The data gathered for the analysis of reliability and efficiency of the wastewater treatment technologies was obtained directly from ‘CAGECE’ – the state owned water company, known for their high-quality service (in the context of developing countries) in the region and supported by the local population, operating for the state of Ceará in Northeast Brazil.

The raw data was firstly evaluated in order to remove the presence of outliers. For this, lower and upper limits were calculated for each parameter and each wastewater treatment technology, by using their respective upper and lower quartiles range. These were multiplied by 1.5 (focusing in removing even mild outliers as there was great variability between values) and their value was added to the upper quartile (to obtain the upper limit) or subtracted from the lower quartile (to obtain the lower limit). If values obtained for the lower limit were negative, then a value of 0 was used (Dos Santos, 2009).

The final dataset comprised of 12275 values recorded from 57 WWTPs situated around the city of Fortaleza, representative of 9 different wastewater treatment technologies parameter readings. Values have been obtained from late 2005 up until early 2009, time span in which some months’ data has been absent for certain

parameters in different treatment plants as measurements haven't been carried out consistently. The technologies include:

- i. septic tanks (ST);
- ii. septic tanks + anaerobic filters (ST + AF);
- iii. septic tanks + anaerobic filters + chlorination (ST + AF + Cl);
- iv. facultative ponds (FP);
- v. facultative ponds + maturation ponds (FP + MP);
- vi. anaerobic ponds + facultative ponds + maturation ponds (AP + FP + MP);
- vii. aerated facultative ponds + facultative ponds + maturation ponds (AFP + FP + MP);
- viii. Upflow anaerobic sludge blanket (UASB) no post treatment;
- ix. Upflow anaerobic sludge blanket + Chlorination (UASB + Cl).

### **3.6 Parameter limits**

The ideal discharge limits/standards were obtained from a compilation of international and local studies/sources (Dos Santos, 2006; WHO 2006a, 2006b; Semace 2002; Mota *et al.*, 2007; Silva *et al.*, 2001) in order to ensure that they provided a pertinent and relevant set of values required for this area, aiming to avoid the concept of 'overkill' as described by Mara (2003). When research showed different values for the different parameters, the less stringent values were applied.

The parameter limits determined as suitable for this study and appropriate for developing countries are shown below:

- Chemical oxygen demand (COD): 200 mg/L (Semace, 2002)
- Biochemical oxygen demand (BOD): 60 mg/L (Mota *et al.*, 2007)
- Conductivity for unrestricted and restricted irrigation: 3000  $\mu\text{S}/\text{cm}$  (Semace, 2002)
- Conductivity for aquaculture: 1000  $\mu\text{S}/\text{cm}$  (Semace, 2002; Dos Santos, 2006)
- *E. coli* for unrestricted irrigation:  $10^3$  for every 100 ml (Dos Santos, 2006; WHO, 2006a)
- *E. coli* for restricted irrigation & aquaculture:  $10^4$  for every 100 ml (Dos Santos, 2006; WHO, 2006a, 2006b)
- Total suspended solids (TSS): 50 mg/L (Semace, 2002)
- Ammoniacal nitrogen ( $\text{N-NH}_3$ ) for aquaculture: 5 mg/L (Dos Santos, 2006; Mota *et al.*, 2007)
- Turbidity: 5 NTU (Mota *et al.*, 2007)
- Thermotolerant coliforms (TTC) for unrestricted irrigation:  $10^3$  for every 100 ml (Mota *et al.*, 2007; WHO, 2006a)
- Thermotolerant coliforms (TTC) for restricted irrigation & aquaculture:  $10^4$  for every 100 ml (Mota *et al.*, 2007; WHO, 2006a, 2006b)

### **3.7 Removal efficiency levels**



Calculations for the removal efficiency levels of the tested parameters were carried out using both, affluent and effluent actual WWTPs readings for each of the technologies. This was carried out by applying Eq. 1 as shown below:

$$\text{Removal efficiency \%} = 100 \times \frac{l'_x - m'_x}{l'_x}$$

**Equation 1**

were  $l'_x$  is the actual affluent measurement for the selected parameter being tested going into the WWTPs, and were  $m'_x$  is the actual effluent exiting the WWTPs of the same parameter.

For the parameters *E. coli* and TTC, the removal efficiencies were calculated in log units due to their orders of magnitude. This was carried out using Eq. 2 as followed:

$$\text{Log units removal efficiency} = -\text{LOG } 10 \left( 1 - \frac{\text{Removal efficiency \%}}{100} \right)$$

**Equation 2**

were removal efficiency % represents the result calculated from Eq. 1.

### **3.2.1 Percentage verification of actual effluent levels falling within set limits (required levels)**

Once the efficiency had been determined, a calculation to establish what percentage of the effluents being produced from each technology complied with the limits/standards set for each parameter was carried out. This facilitated the comparison between technologies regarding their suitability in providing acceptable levels. For this, Eq. 3 was applied as shown below:

$$\% \text{ of effluent compliance} = 100 \times \frac{\text{Frequency } (N)}{n}$$

**Equation 3**

where  $N$  represents the effluent values and  $n$  represents the number of effluent values analysed.

### **3.8 Reliability Analysis**

#### **3.8.1 Coefficient of reliability (COR)**

By using a developed coefficient of reliability ( $COR$ ) as developed by Niku *et al.*, (1979) based on assumed lognormality of the data, the reliability of WWTPs can be calculated. Referring to a certain period of time in which the effluents provided by WWTPs do not surpass the required levels for a certain parameter being analysed.

Assumed lognormality has been used as it is the most representative overall fit to effluent constituents values as shown by Dean and Forsythe (1976a, 1976b), Niku *et al.* (1979, 1981, 1982), Niku and Schroeder (1981), Berthouex and Hunter (1981) and

Charles *et al.* (2005). This was then confirmed and tested by Oliveira (2006) who undertook this assumption through a categorization of the parameter or constituent distributions based on 35 WWTPs in Brazil. The study concluded that lognormal distribution is the most accurate method to describe the behaviour of constituents such as BOD, COD, TSS and FC present in WWTPs effluents. This could additionally be applied to other parameter/constituents as has been done in this study.

Thus, coefficients of variation (*CV* s) of the WWTP technologies analysed in this study were calculated for the parameter measurements available. Hence for example, if a certain parameter standard is 200 mg/L and it is to achieve this level 80% of the time during its operation (80% reliability), then the WWTP treatment must be made or operated in a way to obtain a specific mean effluent concentration which falls within this limit.

The *COR* relates mean design or operation concentrations of each parameter being analysed to the standards required, based on probability:

$$m_x = (COR)X_s$$

**Equation 4**

where  $m_x$  is the mean design or operation effluent concentration (units according to parameter type),  $X_s$  the effluent concentrations parameter standard or limit (its units according to the parameter type) and *COR* represents the coefficient of reliability.

The coefficient of reliability *COR* can be calculated from the following formula:

$$COR = \sqrt{CV^2 + 1} \times \exp \left\{ -Z_{1-\alpha} \sqrt{\ln(CV^2 + 1)} \right\}$$

**Equation 5**

where *CV* is the coefficient of variation (standard deviation divided by the mean design or operation actual effluent value),  $\alpha$  represents the probability of meeting the parameter standards or limits and  $Z_{1-\alpha}$  represents the standardized normal variate as represented in the values of standardized normal distributions table (Table 3.1).

An example of the values selected for probability of failure ( $\alpha$ ) and the standardized normal variate percentiles ( $Z_{1-\alpha}$ ) can be seen in Table 3.1.

It should be noted that *COR* values have been obtained based on the values provided by the original data and not from the logarithm of the data. Furthermore, the analysis of the data has been carried out according to wastewater treatment technologies by compiling the data of their respective WWTPs, meaning WWTPs haven't been analysed individually against each other but put into a group to represent their respective wastewater treatment technology.

Once the *COR* values were obtained, these enabled the determination of the required design operational effluent values to reach the required parameter discharge standards/ limits to be made.

**Table 3.1. Values of standardized normal distributions**

Cumulative probability (1 - $\alpha$ ) = reliability	$Z_{1-\alpha}$
50	0.000

60	0.253
70	0.525
80	0.842
90	1.282
95	1.645
98	2.054
99	2.326

### **3.8.2 Required design/operational values necessary to achieve the discharge standards/limits**

By using the *COR* values obtained, the design/operational values that would result in an optimum performance by reaching the required discharge standards/limits were calculated by means of Eq. 4 for all of the WWTPs.

### **3.8.3 Expected percentage compliance with the discharge Standards**

Once the *CV* values were obtained, an expected percentage of compliance with the set limits could be calculated using the actual effluent values for each WWTP technology and their parameters. This aims to demonstrate the performance levels of the WWTP technologies in reference to their maintenance and functioning levels.

By applying a formula developed by Niku *et al.*, (1979) (Eq. 6), which takes into consideration the relationship between normal and lognormal distributions, and some algebraic manipulations that take into account the *CV* values, the expected compliance percentage can be calculated.

$$Z_{1-\alpha} = \frac{\ln X_s - \left[ \ln m'_x - \frac{1}{2} \ln(CV^2 + 1) \right]}{\sqrt{\ln(CV^2 + 1)}}$$

**Equation 6**

were  $m'_x$  is the actual mean effluent value for the analysed parameter.

Once the  $(1 - \alpha)$  values had been calculated, a value belonging to the cumulative probability of the standardized normal distribution (distribution  $Z$ ) had to be obtained. This was carried out applying the means of the NORMSDIST function in Microsoft Excel (Oliveira, 2007), which can be found also in other statistical sources as shown by Snedecor & Cochran (1989) and Montgomery & Runger (1999).

An example of how Eq. 6 has been applied is shown below for one WWTP technology according to a selected parameter. In this case, a mean effluent concentration of 137 mg/L is being produced, the  $CV$  value is 0.47 and using a set limit of 200 mg/L of COD, then  $Z_{1-\alpha}$  is:

$$Z_{1-\alpha} = \frac{\ln(200) - \left[ 137 - \frac{1}{2} \ln(0.47^2 + 1) \right]}{\sqrt{\ln(0.47^2 + 1)}} = 1.061$$

**Equation 7**

By using Table 1, the relationship between the two categories shows that value for  $Z_{1-\alpha} = 1.061$  corresponds to  $(1 - \alpha) = 0.856$ . Thus, the expected value of compliance with this specific effluent set limit is nearly 85.6%, if the WWTPs of this technology were to maintain the same functioning conditions.

#### 4. RESULTS AND DISCUSSION

The selection of parameters for each evaluation depended on the available records present and the relevancy of the parameters needed for each of the effluent reuse purposes (aquaculture, restricted and unrestricted irrigation). This refers to the lack of data regarding affluent concentration for some of the parameters, showing only their effluent values and consequently, not allowing efficiency levels to be calculated (affluent values required). Thus for efficiency and reliability calculations, the representative parameter effluent concentrations used to test the technologies included:

- i. Chemical oxygen demand (COD);
- ii. electrical conductivity (EC);
- iii. turbidity;
- iv. *E. coli*;
- v. total suspended solids (TSS) and
- vi. thermotolerant coliforms (TTC).

Due to the lack of affluent records, efficiency was not calculated for the following parameters:

- vii. Biochemical oxygen demand (BOD) and
- viii. ammoniacal nitrogen (N-NH<sub>3</sub>).

Table 4.1 shows the number of WWTPs included in the analysis belonging to their respective technology, and the parameters used for the evaluations. As some of the

WWTPs did not monitor all of the mentioned parameters, there is a differentiation between the numbers as shown in the Table 4.2 – here, the mean affluent and effluent concentrations per parameter and the respective removal efficiencies (where applicable) of the 9 WWTP technologies has been quantified.



**Table 4.1 Number of WWTPs per technology and their respective parameters evaluated**

Parameters	Technologies									Total WWTP
	ST	ST + AF	ST + AF + Cl	FP	FP + MP	AP + FP + MP	AFP + FP + MP	UASB (no post treatment)	UASB + Cl	
COD (mg/L)	5	17	3	8	2	6	1	3	11	56
EC ( $\mu$ S/cm)	5	17	3	8	2	5	1	3	11	55
Turbidity (NTU)	5	17	3	8	2	5	1	3	11	55
<i>E. coli</i> (NMP/100 ml)	5	17	3	7	2	1	1	2	8	46
TSS (mg/L)	5	17	3	8	2	6	1	3	11	56
TTC (NMP/100 ml)	1	10	3	7	1	4	1	2	10	39
BOD (mg/L)	0	0	0	3	0	2	0	0	0	5
N-NH <sub>3</sub> (mg/L)	5	17	3	8	2	6	1	3	11	56

**Table 4.2. Mean parameter concentrations of 9 WWTP technologies with their removal efficiency (where applicable)**

Evaluation	Parameters	Technologies									
		ST	ST + AF	ST + AF + CI	FP	FP + MP	AP + FP + MP	FAP + FP + MP	UASB	UASB + CI	
Efficiency & Reliability	COD	Raw influent (mg/L)	974	996	538	709	701	803	571	721	803
		Treated effluent (mg/L)	646	656	299	284	209	137	188	266	364
		Removal efficiency (%)	43	23	54	56	69	80	64	55	49
	EC (µS/cm )	Raw influent (µS/cm )	1499	1401	1198	1465	1355	1507	1148	1664	1290
		Treated effluent (µS/cm )	1850	1612	1309	1255	1246	1300	1033	1891	1703
		Removal efficiency (%)	-20	-69	-11	15	8	10	10	-14	-32
	Turbidity (NTU)	Raw influent (NTU)	376	426	205	310	299	357	213	371	328
		Treated effluent (NTU)	400	306	104	331	190	96	177	197	202
		Removal efficiency (%)	42	-6	41	-77	17	-140	13	42	29
	<i>E. coli</i> (NMP/100 ml)*	Raw influent (MPN/100 ml)	2.E+07	5.E+07	4.E+07	5.E+07	7.E+07	2.E+07	3.E+07	9.E+07	4.E+07
		Treated effluent (MPN/100 ml)	8.E+02	3.E+02	4.E+02	8.E+04	4.E+03	9.E+01	5.E+02	7.E+02	4.E+02
		Removal efficiency (log units)	4	2	3	1	4	5	4	2	4
	TSS (mg/L)	Raw influent (mg/L)	372	717	191	280	268	354	178	391	316
		Treated effluent (mg/L)	295	323	66	149	93	61	94	131	148
		Removal efficiency (%)	18	-8	37	37	58	80	43	51	40
	TTC (NMP/100 ml)*	Raw influent (MPN/100 ml)	1.14E+08	1.89E+08	2.26E+08	4.73E+07	1.90E+07	3.26E+07	1.85E+07	1.84E+07	3.60E+07
		Treated effluent (MPN/100 ml)	4.38E+02	3.88E+02	1.17E+03	5.28E+04	6.20E+05	1.39E+03	2.57E+03	7.09E+02	1.15E+03
		Removal efficiency (log units)	6	2	3	1	1	2	4	2	3
Reliability**	BOD (mg/L)										
	Treated effluent (mg/L)	-	-	-	109	-	50	-	-	-	
	N-NH3 (mg/L)										
	Treated effluent (mg/l)	84	75	43	45	32	25	27	49	93	

\* Geometric mean for coliforms

\*\* Efficiency analysis not carried out for the represented parameters due to a lack of affluent data

Parameter values used to determine removal efficiency and reliability presented as being of great variability in reference to their sampling frequency in each wastewater treatment technology and on monitoring periods. In some instances, some of the parameters weren't measured at all for certain treatment technologies (such is the case for BOD), whilst others presented great frequency and monitoring of each parameter mentioned and more. It is important to point out, that due to this variability some parameters which would have been important for this study, had to be excluded as a result of their lack of availability and subsequent lack of consistency (such as free residual chlorine, total nitrogen and total phosphorous, to mention a few).

The data obtained is representative of great differences in raw affluent values, and in some instances, presents higher concentrations than those suggested by the literature in reference to domestic wastewater compositions (Arceivala, 1981; Mara, 2003; Quasim, 1985). Differing from this, the values presented did fall below those recorded in southern Brazil as presented by Von Sperling & Oliveira (2009). This alterations in affluent, consequently affect the treated effluent values for each parameter, which also differ greatly from individual WWTPs and from wastewater technology to wastewater technology.

This difference as mentioned can be attributed to the complexity and differences in affluent compositions which are dependent on their sources, whether it is rural or urban and due to the kind of treatment they undergo under the different wastewater treatment technologies mentioned. Differences can be attributed to environmental characteristics (such as pH and temperature) as well, and to mechanical factors which differ in each WWTP, in reference to their design, operational performance and

maintenance- or lack thereof in this case as shown by the data's variance in accordance to past literature (Areceivala, 1981; Qasim 1985; WEF & ASCE, 1992; Mara, 2003; Metcalf & Eddy, 2003; Von Sperling & Chernicharo, 2005). Higher buffering capacities of some wastewater treatment technologies affect effluent values resulting in more differences, when compared with more compact treatment units (more unstable due to effluent composition variations). In other instances, treatments which rely on natural systems, such as FPs, MPs and WSPs are dependent on their design and not entirely on their operational methods, as they have no means of controlling the process by regulations or operational changes – case in which efficiency and effluent values in most cases have agreed with past literature values (Metcalf & Eddy, 2003; Oliveira & Von Sperling, 2009; Oliveira & Von Sperling 2007). This suggests that its actually maintenance of those systems which is greatly affecting their efficiency, and not their overall capacity to provide suitable effluent for reuse in agriculture and aquaculture. This makes the issue more a matter of WWTPs management, organization and maintenance skills by the local water company, CAGECE – representative of a common problem within developing countries as suggested by Mara (2003) and more specifically in Brazil by Oliveira & Von Sperling (2009, 2007).

Comparisons between the wastewater treatment technologies removal efficiency levels have been provided in the form of box-and-whisker plots (Fig 4.1 – 4.5) and the percentage of WWTPs of each wastewater treatment, performing under the required limits, has been presented in the form of histograms (Fig 4.7 – 4.17).

## 4.1 Parameter removal efficiencies

### 4.1.1 COD removal

Mean COD removals (Fig 4.1) were overall positive for all technologies, referring to the fact that in most cases some WWTPs reached levels of efficiency above 90%. Oppositely, most technologies were also representative of WWTPs which presented levels of efficiency below 0%, reaching levels of up to -434 % removal efficiency (ST+AF) – this great discrepancy between WWTPs from the same treatment technologies is representative of mechanical failures, lack of maintenance and/or inadequate operational methods (Oliviera & Von Sperling, 2009, 2007).

For this parameter, the WSP system (AP+FP+MP) provided the highest efficiency removal, whilst ST+AF presented the lowest levels with 50% of its WWTPs achieving a mean efficiency level of 23%, disagreeing with the literature which suggests higher levels for this treatment technology when compared with SPs operating exclusively (Mota *et al.*, 2007).

Overall, mean COD effluent concentrations were higher in all cases than those suggested by Arceivala (1981), Qasim (1985), WEF & ASCE (1992), Mara (2003), Metcalf & Eddy (2003), Mota *et al.*, (2005) and Von Sperling & Chernicharo (2005). They did fall within the levels presented in the study conducted by Von Sperling & Oliveira (2009) in southern Brazil, which presents more familiar results. This tendency also applies to the mean efficiency levels but to a lower degree - the WSP systems and the UASBs were the only treatment technologies which agreed with expected removal

efficiencies provided by Arceivala (1981), Qasim (1985), WEF & ASCE (1992), Mara (2003), Metcalf & Eddy (2003), Mota *et al.*, (2005) and Von Sperling & Chernicharo (2005), whilst the rest of the treatment technologies complied with those provided by Von Sperling & Oliviera (2009).

#### **4.1.2 EC removal**

This parameter presented one of the highest variations between positive and negative removal efficiency percentages, as shown in Table 4.2 and Fig 4.2. Great differences were also found between WWTPs within treatment technologies, especially in the case of ST, ST+AF and UASB+CI which presented highly heterogeneous behaviours as expected (Oliviera & Von Sperling, 2007). Once again, ST+AF presented the lowest minimum removal efficiency percentage, reaching an extremely low value of -12642 %. On the contrary, both ST and ST+AF reached 100% removal efficiency levels. The pond systems (FP, FP+MP, AP+FP+MP and FAP+FP+MP) presented on average their upper and lower quartiles above 0% removal efficiency, whilst both UASB and UASB+CI systems presented their upper and lower quartile values below the 0% removal efficiency level. This suggests that compact treatment units are prone to increase conductivity levels rather than decrease it (ST data is the exception) and thus representing potentially higher salinity levels, posing a risk for both irrigation practices and aquaculture (Dos Santos, 2006; Mota *et al.*, 2007).

The highest mean removal efficiency percentage for EC was obtained by FP (15%) whilst the lowest mean removal efficiency percentage was obtained by ST+AF (-69%).

### 4.1.3 Turbidity removal

This was another parameter which did not present clear trends between the wastewater treatment technologies, and which also presented great differences between individual WWTPs. These differences were emphasized, as shown in Fig 4.3, by the fact that for the pond systems, all of them presented their upper and lower quartiles for removal efficiency levels above 0%, except for the WSP systems which provided both quartiles below 0% (lowest mean efficiency removal when compared with all treatment technologies, at -140%), but at the same time the maximum value of efficiency for WSP systems was the only one to reach 100% removal efficiency. Highest mean values were obtained by ST (42%) and UASB (42%) which would agree with their tendency to provide similar results as sustained by Von Sperling & Oliveira (2009), but in this case as the differences between the similar treatment technologies was significant; ST+AF provided a -6% removal efficiency, ST+AF+Cl provided 41% and the UASB+Cl provided 29%, their coinciding values might not be of real significance. It may be said that UASB and UASB+Cl provided a significant turbidity removal efficiency as both presented their upper and lower quartiles above 0% removal efficiency.

It can be concluded that turbidity is affected in very different ways by different wastewater treatment technologies and in this case by the performance of each WWTP operated within each of those mentioned.

#### 4.1.4 TSS removal

For this parameter, removal efficiency levels were high for most treatment technologies (Table 4.2 and Fig 4.4) – most of them presenting their lower and upper quartiles above 0% removal efficiency, with the exception of ST and ST+AF. The differences between individual WWTPs for each wastewater treatment technology are very wide nevertheless, with some maximum values above 95% and minimum values reaching -3819% (ST+AF).

Results for pond systems and UASB, UASB+Cl were more favourable compared to those from ST and ST+Cl. WSPs were the highest and complied with the expected values reaching a mean 80% removal efficiency (Mara, 2003; Mota *et al.*, 2007; Von Sperling, 2005). WSP maximum values reached 100% whilst its minimum was the highest of all wastewater treatment technologies, being the only non negative value (18%). It is worth mentioning that FP values did not fall within ‘traditional’ literature standards as already mentioned, but they did comply with the more pertinent values presented by Von Sperling & Oliveira (2009) - reaching a mean removal efficiency value of 37%. UASB and ST+AF values failed to comply even with those suggested by Von Sperling & Oliveira (2009), presenting mean removal efficiencies of 51% and -8% respectively, suggesting that operational standards and maintenance for these treatment technologies are below average, especially in the case of ST+AF as when compared with ST+AF+Cl, the differences are staggering (ST+AF+Cl presenting a 37% removal efficiency).



Mean effluent values for most treatment technologies were found to coincide with those suggested by Von Sperling & Oliviera (2009), with the exception of ST+AF, but greatly disagreeing with those suggested by Arceivala (1981), Qasim (1985), WEF & ASCE (1992), Mara (2003), Metcalf & Eddy (2003) and Von Sperling & Chernichero (2005), as values were significantly higher.

#### **4.1.5 *E. coli* removal**

Values for this parameter (Fig 4.5) and for TTC (Fig 4.6) were compared against those of faecal coliforms, as in much of the literature and studies conducted they are both used as applicable representatives of this parameter (Dos Santos, 2006; Mota *et al.*, 2007; Semace, 2002; WHO, 2006a, 2006b).

Removal efficiency levels fluctuated greatly between treatment technologies, but not as much between individual WWTPs when compared with the other parameters looked at (Fig 4.5). Values ranged from 1-5 log units mean removal efficiency and most wastewater treatment technologies provided higher values of removal (pool Table 4.2) than those suggested by the technical literature (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf & Eddy, 2003; Von Sperling & Chernichero, 2005) – referring to a 1 log unit removal, for those such as ST, ST+AF & UASBs, but agreeing with the high values suggested by Mara (2003) in the case of UASBs. In this case values obtained for these treatment technologies were surprisingly high causing doubts about the reliability of the data to arise, especially in the case of ST as it achieved mean removal efficiency levels of 4 log units, and presented higher values than that of ST+AF (2 mean log units removal) and ST+AF+Cl (3 mean log units removal). It is important

to point out that in certain WWTPs for ST+AF+Cl, measurements suggested that 100% removal efficiency of *E. coli* had been achieved, thus the discrepancy of the 75%, 90% and maximum log plot values for this wastewater treatment technology. This high level of efficiency although unlikely, could be attributed to the chlorination process. It should be noted that only 3 WWTPs are representative of this wastewater treatment technology and consequently, results might be biased.

Values for the WSP systems were very positive, proving their superiority in efficiency removal for this parameter over the other wastewater treatments, with a mean removal efficiency of 5 log units and a maximum value of 6.8 log units. The rest of the pond systems achieved their expected high values, with FP+MP and FAP+FP+MP reaching log removal units of 4 in conjunction with UASB+Cl, proving its added efficiency due to the chlorination process, over the UASB system with no post treatment. The FP system complied with the expected values of the technical literature by obtaining a 1 log removal unit (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf & Eddy, 2003; Von Sperling & Chernichero, 2005).

Mean effluent values (Table 4.2) were very positive and well below the standards suggested by much of the literature which ranges from  $10^2 - 10^7$  faecal coliforms (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf & Eddy, 2003; Von Sperling & Chernichero, 2005). Values ranged from the lowest 9.E+01 (WSPs system) to the highest being 08.E+04 (FP). Furthermore they were significantly lower, in all cases, than those obtained in southern Brazil as presented by Von Sperling & Oliveira (2009) by up to 3 log units.

This great difference, favouring the removal efficiency of these anaerobic technologies over their expected performance, can be related to the lack of measurements carried out for this parameter in relation to the WWTPs presenting measurements (Table 4.1), even though the data presented is still significant and valid. This factor could have also influenced the advantage of the compact systems such as ST, ST+AF and ST+AF+Cl over some of the ponds systems, such as FP, FP+MP and to a certain extent FAP+FP+MP values, which is unexpected.

#### **4.1.6 TTC removal**

It is of fundamental importance to refer to the influence of lack of data when it comes to analyzing this parameter (Table 4.1). The number of values obtained for each treatment technology in this case were in some cases very low. For ST only 3 values were obtained (Appendix CD – Reliability spreadsheet), whilst for FP+MP and FAP+FP+MP only 2 were analyzed for each (Appendix CD – Reliability spreadsheet). It is worth considering this when judging the significance of the results presented.

As in the case of *E. coli* removal (Fig 4.5), values between each WWTP in their respective wastewater treatment technology don't fluctuate as they do for other parameters (especially in the case of ST and FAP+FP+MP due to the lack of values), but the differences between the treatment technologies is significant. Mean log removal efficiency levels differentiated greatly from that of the suggested literature and presented by *E. coli*, by presenting ST as the best technology for the removal of TTC (6 mean log units removal), when this technology is known to carry out on average a 0.5-1.8 log unit removal (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf &

Eddy, 2003; Von Sperling & Chernichero, 2005; Von Sperling & Oliveira, 2009). This suggests that further on site measurements are required on this parameter and the veracity of its measurements being carried out, tested – relating to CAGECE's apparent management limitability.

Values which present more reliable data which relates to the expected removal efficiency levels and to those values presented by *E. coli* are provided by FP (1 mean log unit removal), ST+AF+Cl (3 mean log units removal), ST+AF (2 mean log units removal), UASB (2 mean log units removal) and UASB+Cl (3 mean log units removal). WSP's systems and FP+MP systems in disagreement with the values presented for *E. coli*, ranked low presenting 1 mean log units removal efficiency.

Mean effluent levels were slightly higher than those recorded for *E. coli* but they were still considerably lower than the expected values suggested by the mentioned literature (Arceivala 1981; Qasim, 1985; WEF & ASCE, 1992; Metcalf & Eddy, 2003; Von Sperling & Chernichero, 2005) and to those representative of southern Brazil (Von Sperling & Oliveira, 2009).

The pond systems presented the highest TTC levels which is unexpected, especially as FP+MP systems provided higher values than that of FP systems. This difference is greatly influenced by the lack of data available, but it simultaneously shows that maintenance of the single FP+MP system is not optimal (mean treated effluent  $6.20E+05$ ). Furthermore, compact systems such as ST and ST+AF systems provided the best results ( $4.38E+02$  and  $3.88E+02$  respectively), followed by UASB and UASB+Cl ( $7.09E+2$  and  $1.15E+2$  respectively). This is further proof that lack of

available data has influenced the outcome of the results, presenting the values for this parameter as an unreliable source.

#### **4.1.7 BOD removal**

As mentioned previously, BOD removal efficiency percentages could not be established due to the lack of affluent values (Table 4.2). Mean effluent values obtained for FP and for the WSP systems (Table 4.2) did provide on some information about these two systems. It should be noted that only 2 WWTP were representative of WSPs and 3 FPs.

Mean FP effluent value of 109 mg/L BOD (Table 4.2) could be categorized as being too high by Arceivala (1981), Qasim (1985), Metcalf & Eddy (2003), Mota *et al.*, (2007), WEF & ASCE (1992), and Von Sperling & Chernicharo (2005), but it does comply with the values of southern Brazil provided by Von Sperling & Oliveira (2009).

The WSP systems with a mean effluent value of 50% falls well within the expected results, suggesting proper maintenance of its WWTPs and its obvious superiority over FPs (Arceivala, 1981; Qasim, 1985; Metcalf & Eddy, 2003; Mota *et al.*, 2007; WEF & ASCE, 1992; Von Sperling & Chernichero, 2005; Von Sperling & Oliveira, 2009).

#### 4.1.8 N-NH<sub>3</sub> removal

As is the case for BOD, the lack of influent data for this parameter (Table 4.2) meant that removal efficiency percentages could not be calculated. However, the values representative of the mean treated effluent values can provide an idea of how each wastewater treatment affects the buffering of N-NH<sub>3</sub> – if at all.

The highest mean effluent values for ammonical nitrogen were obtained from UASB+Cl (93 mg/L), followed by ST (84 mg/L) and ST+AF (75 mg/L), whilst FP and ST+AF+Cl presented similar results as expected (45 mg/L and 43 mg/L respectively) (Von Sperling & Oliveira, 2009). The lowest values belonged to the 3 pond systems, with WSPs presenting the lowest value of all (25 mg/L) followed closely by AFP+FP+MP systems (27 mg/L) and the FP+MP systems (32 mg/L), thus proving to be the best technologies for removal of this kind when compared with other treatment types mentioned as suggested by Mota *et al.*, (2007), Von Sperling (2005) and Von Sperling & Olivera (2009).

Nevertheless, it is important to point out that none of the mentioned treatment technologies specialize in removing nutrients and ammonia completely for reuse in aquaculture, although the larger pond systems pose higher chances of achieving lower levels as a result of their higher retention times inducing volatilization (Dos Santos, 2006). WSP systems as shown provide the best results but their design is expected to provide higher levels than those ideal for this type of reuse -  $\geq 15$  N-NH<sub>3</sub> mg/L (Mota *et al.*, 2007),  $\geq 10$  N-NH<sub>3</sub> mg/L (Von Sperling, 2005), thus exceeding the maximum

permissible level of  $\leq 5$  N-NH<sub>3</sub> mg/L for aquaculture (Dos Santos, 2006; Mota *et al.*, 2007).

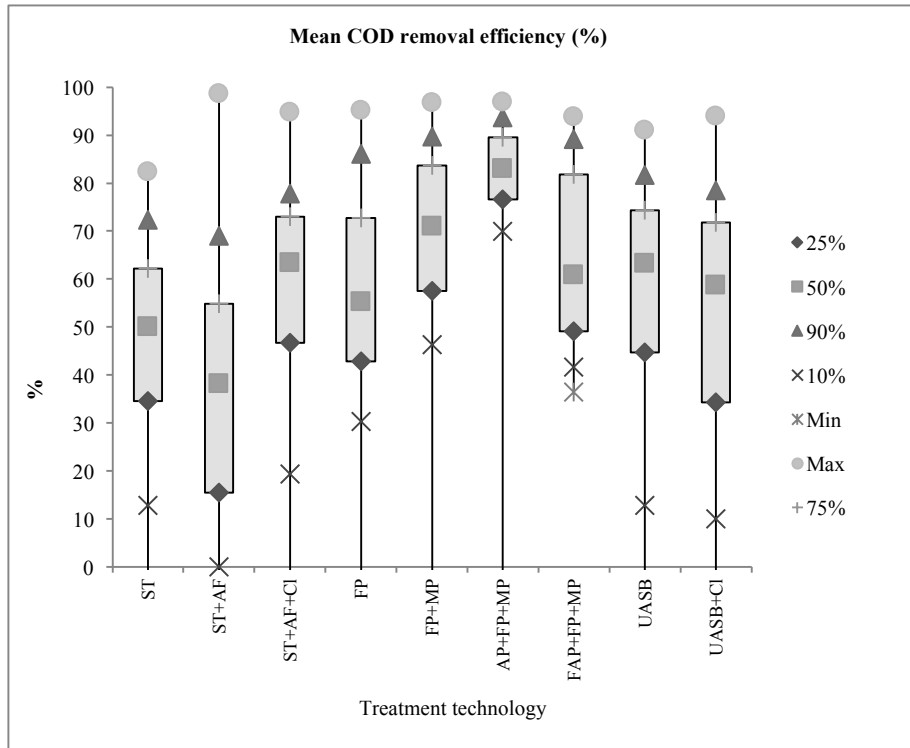


Figure 4.1 Mean COD removal efficiency percentages for each wastewater treatment technology

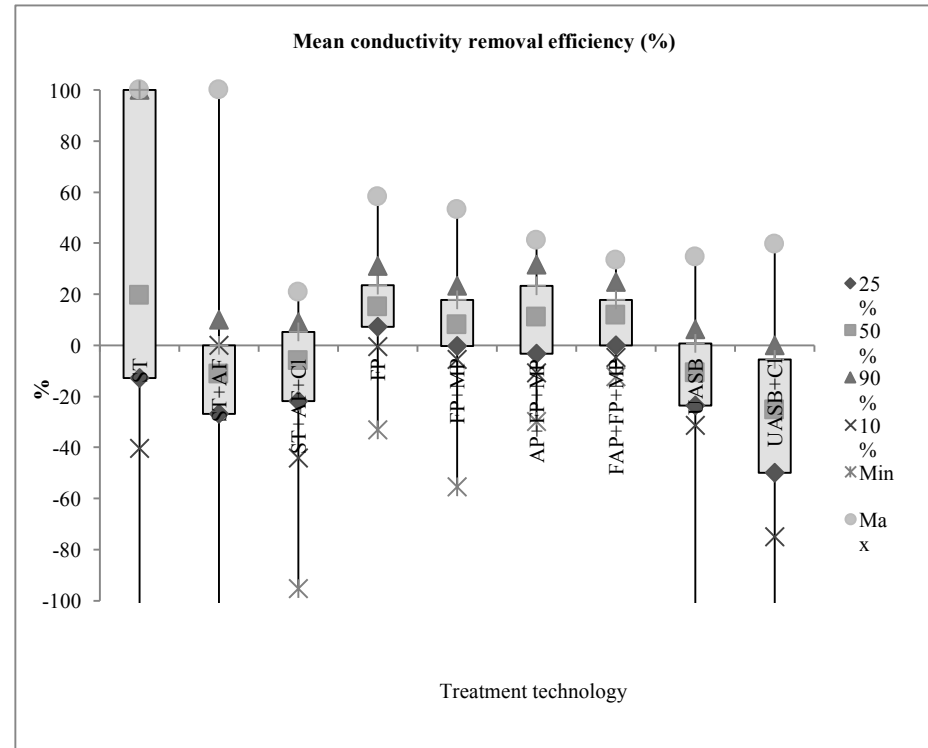
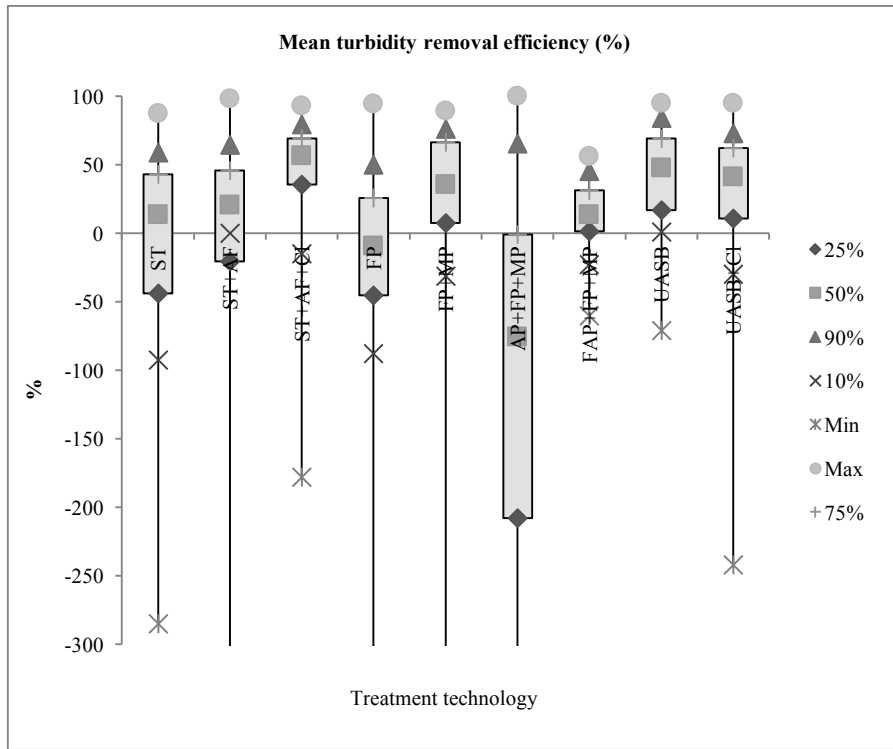
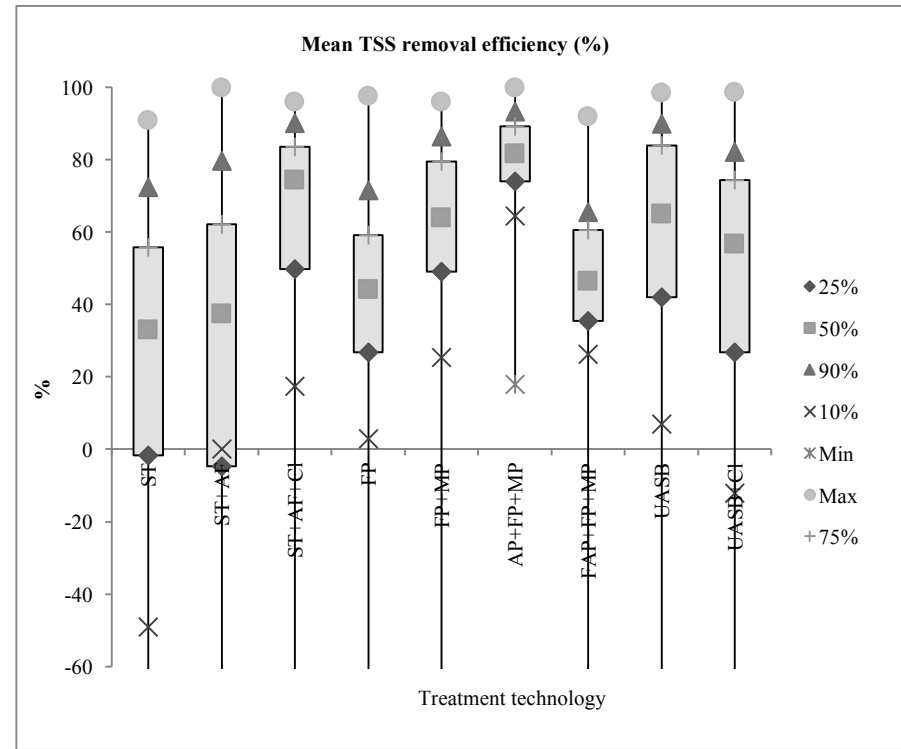


Figure 4.2 Mean conductivity removal efficiency percentages for each wastewater treatment technology





**Figure 4.3 Mean turbidity removal efficiency percentages for each wastewater treatment technology**



**Figure 4.4 Mean TSS removal efficiency percentages for each wastewater treatment technology**

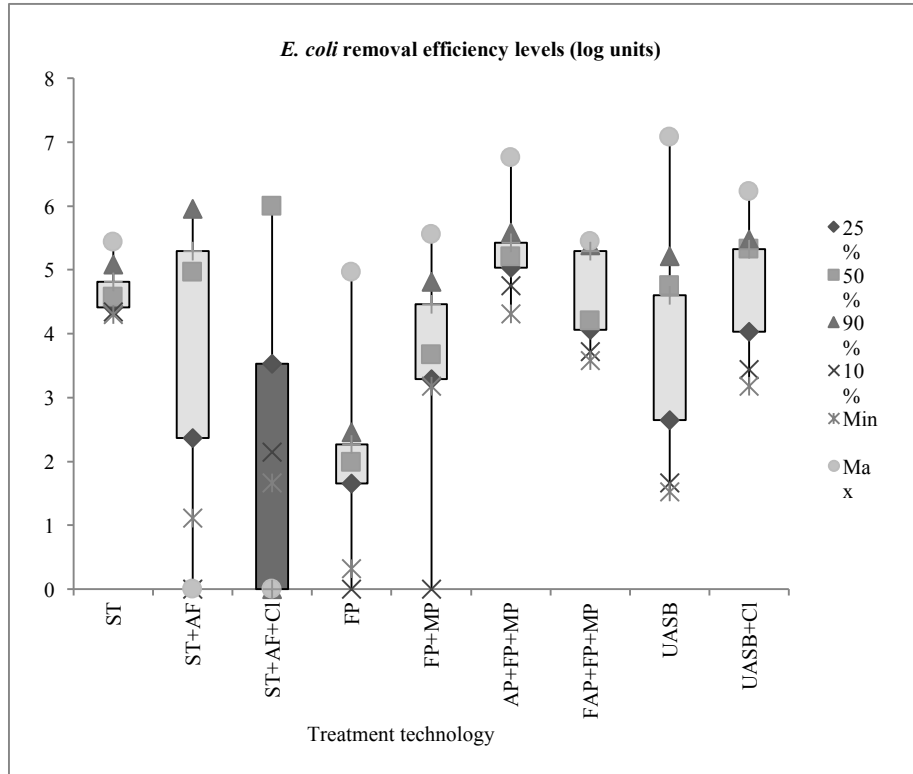


Figure 4.5 Mean *E. coli* removal efficiency (log units) for each wastewater treatment technology

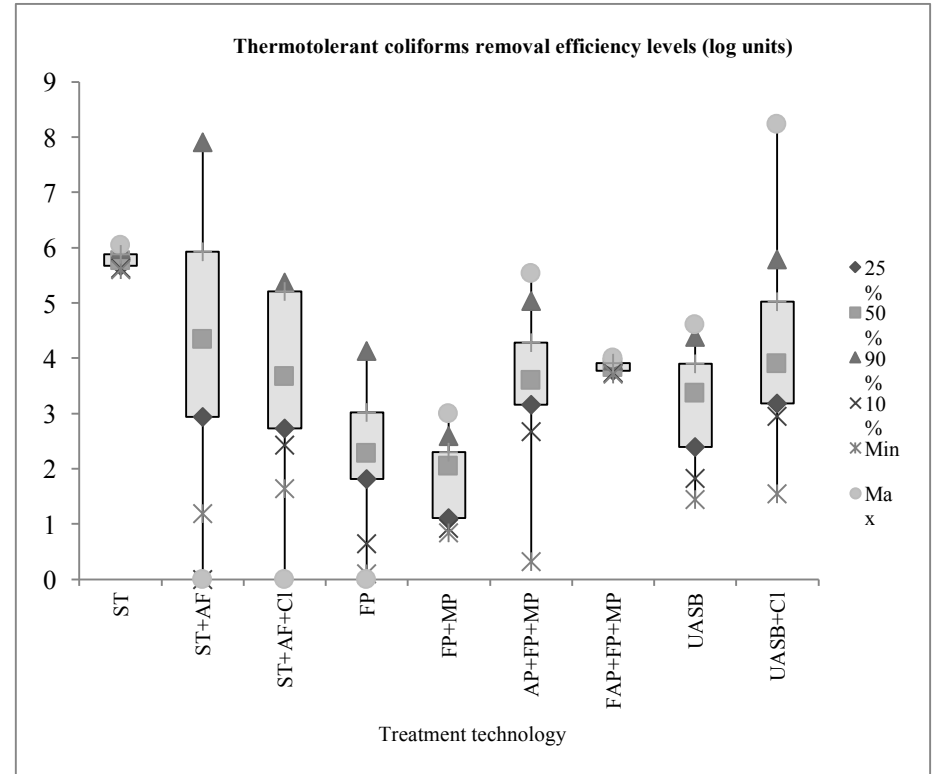


Figure 4.6 Mean TTC removal efficiency (log units) for each wastewater treatment technology

## 4.2 Percentage of parameter values complying with parameter standards

The relationship between the removal efficiency levels and percentage of compliance with the parameter limits is in most cases clear. The discrepancies created as a result of lack of data as mentioned already, has also influenced this analysis by producing unexpected values for some *E. coli* (Fig 4.11 & 4.12) and TTC values (Fig 4.13 & 4.14). In these cases, anaerobic treatment technologies lack of values has served to their advantage over aerobic systems such as FP and FP+MP, similarly lacking data, but which has presented significant lower values in their case to their disadvantage. Results by Mara (2003), Metcalf & Eddy (2003), Mota *et al.*, (2005) and Von Sperling & Chernicharo (2005) suggest that higher compliance with the discharge standards should be met by FP+MPs when compared to ST and ST+AF systems, and that values for FPs operating solely should present similar results with the mentioned anaerobic treatment technologies (Von Sperling & Oliveira, 2009). UASB and UASB+Cl values for these parameters did provide the expected results (Von Sperling, 2005; Von Sperling & Chernicharo, 2005; Von Sperling & Oliveira, 2009), which suggest their lack of ability in removing faecal coliforms (*E. coli* and TTC) for unrestricted irrigation when compared to the more complete aerobic processes. These low UASB values question the literature and disagree with some of Maras (2003) values – suggesting their great efficiency for this kind of removal - but who also recognizes the superiority of the aerobic systems. Both systems fail to provide at least a 50% of WWTPs to comply with both parameter limits. This difference might be attributed to the lack of maintenance of ideal operation levels for the mentioned technologies, which has been questioned already in this study (section 4.1), but not analysed as it does not fall within the scope of this project.

Overall values (Fig 4.6 – 4.16) imply that the aerobic system comprised by the AP+FP+MP (WSP) systems is the most suitable to provide effluents for agricultural reuse and aquaculture. It should be noted that although FAP+FP+MP presents positive values, lack of data (1 WWTP with 3 readings) for this treatment technology has influenced TTC values greatly and should therefore be ignored, as data for that parameter cannot be considered reliable due to its lack of consistency. This should be considered on a general basis regarding this wastewater treatment technology, although performance from it is expected to be high, as suggested by the literature (Mota *et al.*, 2007). Even so, both technologies provided compliance of 100% of their WWTPs to provide suitable quality effluent for irrigation and aquaculture in their respective *E. coli* values, TSS and the highest values for COD (Fig 4.6) (WSP's with 81% and FAP+FP+MP with 53%). Overall, the aerobic technologies also provided the highest levels of compliance for conductivity in aquaculture requirements (Fig 4.9), although all values fell below 50%, factor which should pose complications for this practice, although for irrigation (Fig 4.10) nearly all of the treatment technologies achieved 100% compliance. Furthermore, no WWTP of any treatment technology complied with the turbidity levels required (Fig 4.7), which might indicate that the parameter level chosen is too stringent, although even more stringent levels are applied in the developed world (> 2 NTU) by the USEPA (1992). Extremely low levels of compliance were also reported for N-NH<sub>3</sub> (Fig 4.15), where most treatment technologies present no percentage of compliance at all. Unusual high levels of compliance from ST+AF (11%) and ST+AF+Cl (20%) were obtained which relates to the lack of values presented for this parameter. For the same parameter, AP+FP+MP systems provided a 12 % of

compliance, determining that some of its WWTPs are capable of producing acceptable values.

These values, although showing that on a general basis the more complete aerobic technologies are more practical when it comes to providing suitable effluent for agriculture and aquaculture, also show that in certain parameters, number of WWTPs producing the required effluent is below half. This emphasizes the need to only allow WWTPs with the ideal design and maintenance to be used for these reuse practices. The success of the reuse practices will not be solely dependent on selecting a certain treatment technology, but selecting from them those WWTPs which are properly designed and maintained as variations between individual units of the same treatment technology are great. As mentioned, this is a common problem in Brazil and the rest of the developing world (Dos Santos, 2006; Mara, 2003; Mota *et al.*, 2007; Von Sperling, 2005; Von Sperling and Chernicharo, 2005; Oliveira & Von Sperling, 2007).

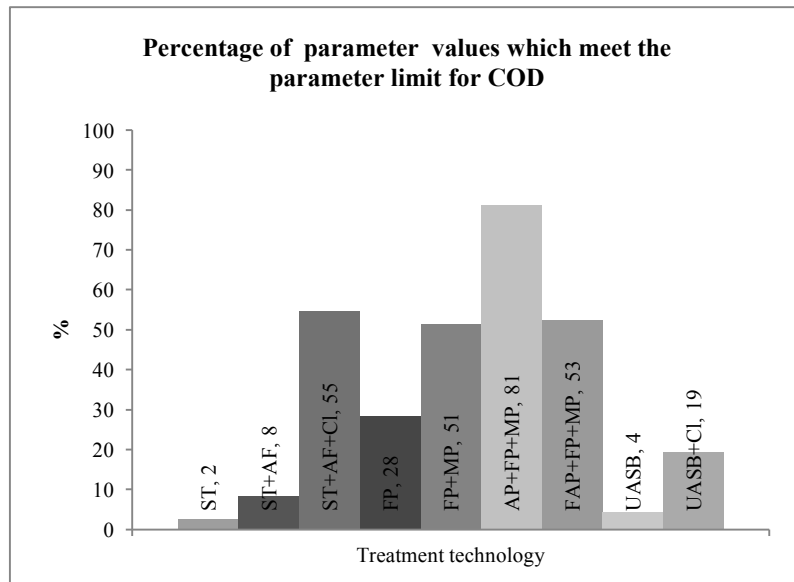
It is also of importance to address to the parameter limits and their reliability as appropriate representatives of effluent characteristics maximum allowable values. As removal efficiency results and percentage WWTPs compliance with the parameter limits have shown, some fall within the required values and others do not. This should not exclude completely WWTPs and treatment technologies which exceed these values (especially those which exceed them only slightly) from being potential sources of aquaculture and irrigation effluent wastewater providers. In practice, studies have demonstrated that even when some of the parameter limits are exceeded, both irrigation and aquaculture practices have been harnessed successfully (Mota *et al.*, 2009; Dos Santos, 2009).

Ammonia levels used for a Nile Tilapia aquaculture study in Fortaleza, Brazil, surpassed the required levels with an average concentration of 7.7 mg/L and a maximum value of 9.3 mg/L. Additionally, COD mean values were found below the required levels but with maximum values reaching 325 mg/L (above the suggested parameter limit); the same applied for BOD presenting maximum values of up to 74 mg/L (Mota *et al.*, 2009). During a similar study also held in the same location, concerning unrestricted irrigation of crops with treated wastewaters, ammonia levels were also high (5.3 mg/L) and COD values exceeded that set by the parameter limits, yet production of the crops were positive and complied with the legislations set for the Brazilian sanitary control agency (Dos Santos *et al.*, 2009).

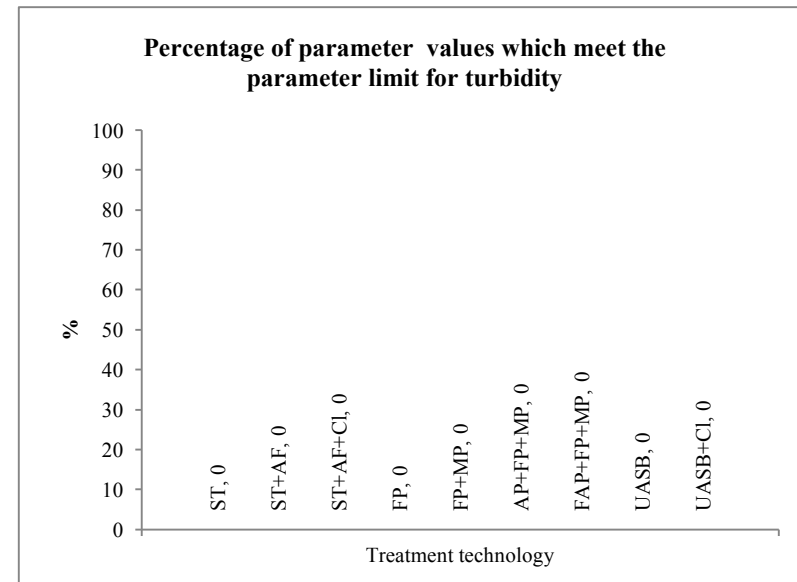
Studies such as these, in which parameter values exceed those proposed and which manage to provide acceptable products for human consumption ( $\leq 10^{-6}$  DALY ppa), suggest that parameters limit selected for this study might be still too strict or that parameter limits do not necessarily have to be met 100% of the time. For example values presented by the WHO (2006a), state that treated wastewater effluents containing up to  $10^5$  *E. Coli* per  $100 \text{ mL}^{-1}$  can be applied for unrestricted irrigation (when plants produced grow up to levels well above the surface) and for restricted irrigation when agriculture is carried out with highly mechanized machinery, avoiding human contact with the effluent. Moreover, a level of  $10^6$  *E. Coli* per  $100 \text{ mL}^{-1}$  can be applied (referring to treatment provided by septic tanks and UASBs) as restricted irrigation, when especial caution is applied in avoiding human contact with the effluents used (Dos Santos, 2006; WHO, 2006a). Higher values than those proposed for TTC, have been suggested by Mara (2003) and WHO (2006b) when it comes to aquaculture as well -

values of up to  $10^5$  TTC per  $100 \text{ mL}^{-1}$  are considered acceptable for wastewater effluents serving as aquaculture tank affluents (Mota *et al.*, 2007).

These are important factors to take into consideration, especially when it comes to developing countries and the complexity of their situations in adapting to high quality effluents. Less stringent levels would be useful to them in order to cope more effectively and allow reuse practices. This relates to the reliability analysis carried out in the following sections which aid in presenting a more realistic concept for their eventual appliance, but always aiming to maintain human health.

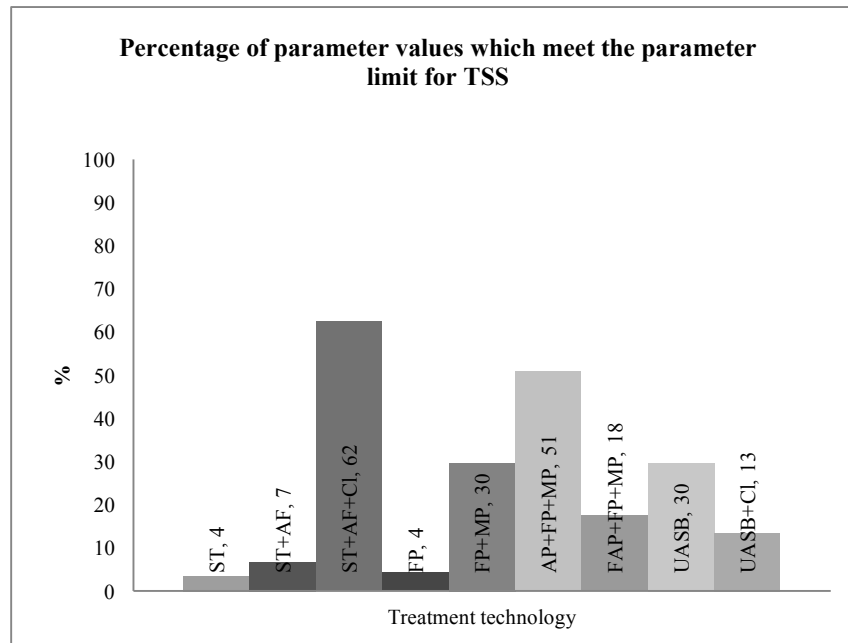


**Figure 4.7 Percentage of parameter values within each wastewater treatment technology meeting COD parameter limits**

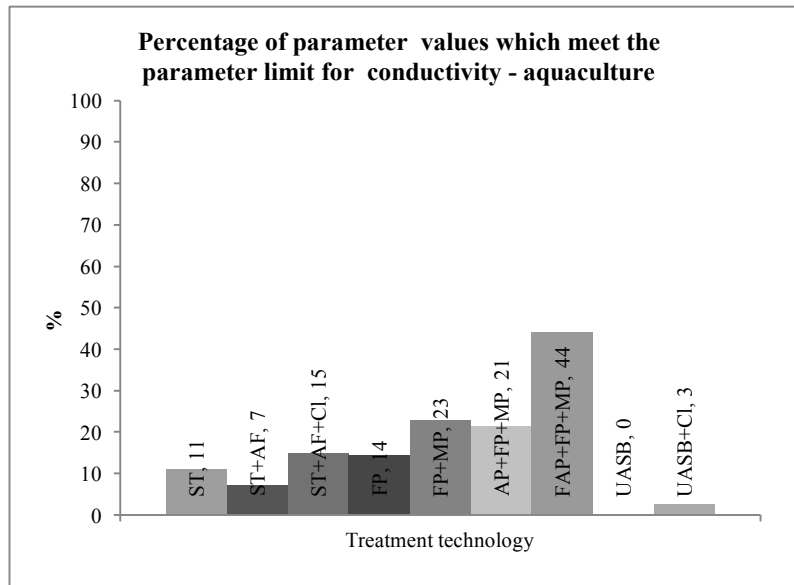


**Figure 4.8 Percentage of parameter values within each wastewater treatment technology meeting turbidity parameter limits**

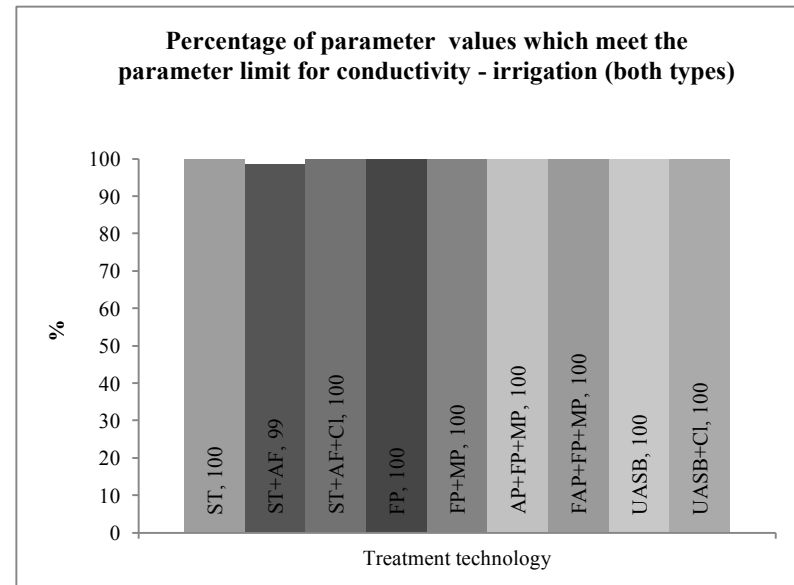




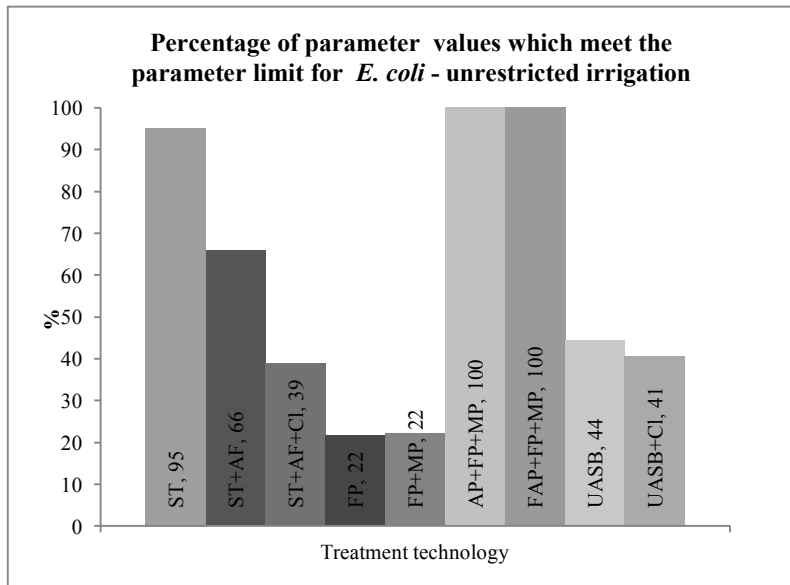
**Figure 4.9 Percentage of parameter values within each wastewater treatment technology meeting COD parameter limits**



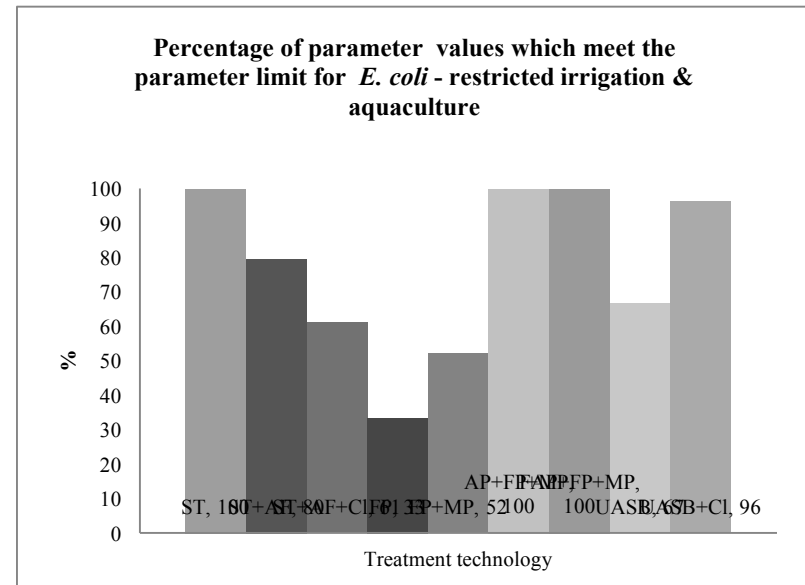
**Figure 4.10** Percentage of parameter values within each wastewater treatment technology meeting conductivity parameter limits for aquaculture



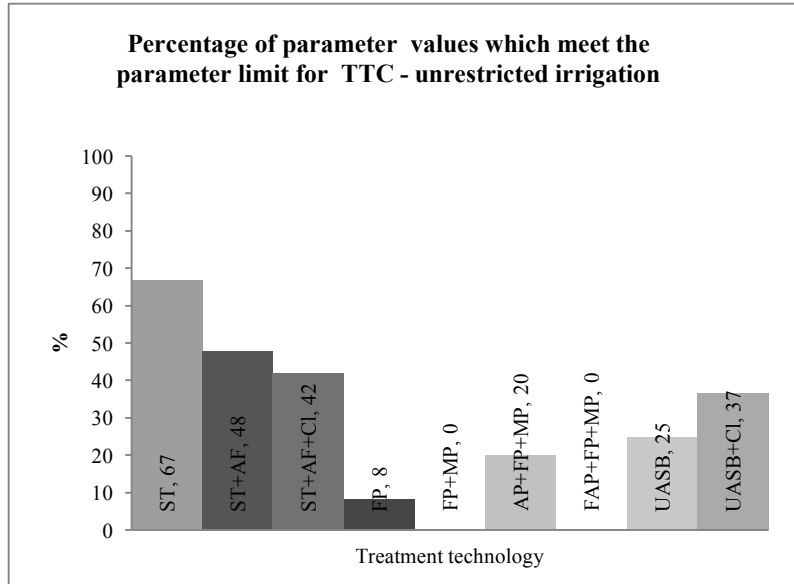
**Figure 4.11** Percentage of parameter values within each wastewater treatment technology meeting conductivity parameter limits for unrestricted and restricted irrigation



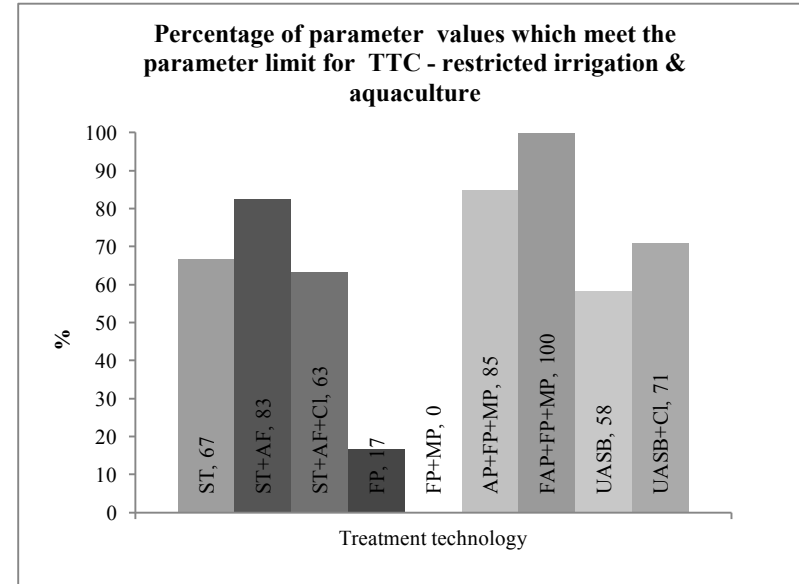
**Figure 4.12** Percentage of parameter values within each wastewater treatment technology meeting *E. coli* parameter limits for unrestricted irrigation



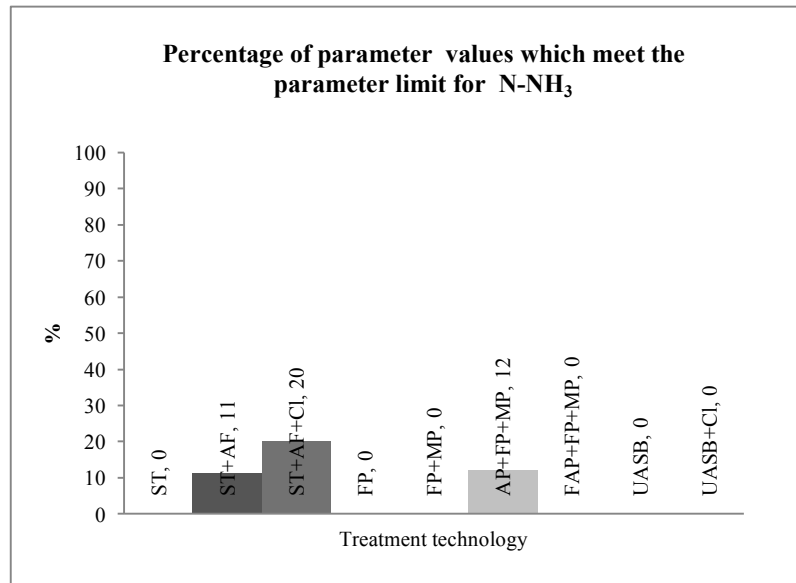
**Figure 4.13** Percentage of parameter values within each wastewater treatment technology meeting *E. coli* parameter limits for aquaculture and restricted irrigation



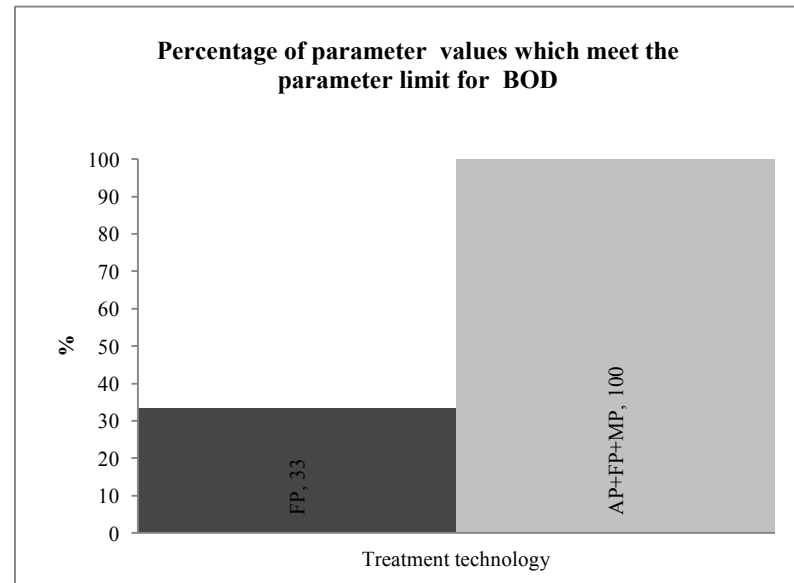
**Figure 4.14** Percentage of parameter values within each wastewater treatment technology meeting TTC parameter limits for unrestricted irrigation



**Figure 4.15** Percentage of parameter values within each wastewater treatment technology meeting TTC parameter limits for restricted irrigation and aquaculture



**Figure 4.16** Percentage of parameter values within each wastewater treatment technology meeting N-NH<sub>3</sub> parameter limits for aquaculture



**Figure 4.17** Percentage of parameter values within each FP and AP+FP+MP treatment technologies meeting BOD parameter limits for unrestricted and restricted irrigation

### 4.3 Interpretation of the coefficient of reliability

In order to comprehend fully how the concept of reliability works, Table 4 and Figure 19 have been prepared, establishing the connection between CV values and different reliability levels as demonstrated by Oliveira & Von Sperling (2007).

For example, if an effluent concentration with a mean CV value of 0.8, a reliability level of 80% ( $\alpha = 20$ ) and consequently, a percentile value of  $Z_{1-\alpha} = 0.842$  (as obtained from Table 1) are selected, then the result would give a COR value of 0.71, as calculated when Eq. 4 is applied:

$$COR = \sqrt{0.8^2 + 1} \times \exp \left\{ -0.842 \sqrt{\ln(0.8^2 + 1)} \right\} = 0.71$$

The same value would be obtained from Figure 19 and Table 4 under  $CV = 0.8$ , at an 80% reliability level (Oliveira & Von Sperling, 2007).

In other words, in order for the WWTP to comply an 80% of the time with the required parameter limits, the mean effluent concentration should be, as shown by Eq. 3:

$$m_x = (COR)X_s = 0.71 \times X_s$$

For a standard of 200 mg/L, this means that the design effluent concentration (assumed to be equal to that of the mean value) should be:

$$m_x = (COR)X_s = 0.71 \times 200 = 142 \text{ mg/L}$$

If a higher reliability is selected, such as 95%, as applied by Oliveira and Von Sperling (2009), as the required level for release of treated wastewaters to surface waters, and the same CV value (0.8), one obtains the following mean effluent concentration:

$$m_x = (COR)X_s = 0.40 \times 200 = 80 \text{ mg/L}$$

As expected, the value required would be lower, as more stringent levels will be required if the mean effluent is to comply with the set parameter limits a 95% of the time. Nevertheless, for the reliability level of 80%, if CV values are higher, for example, CV = 1.4, then the COR value would be 0.72 and thus presenting a mean effluent concentration of:

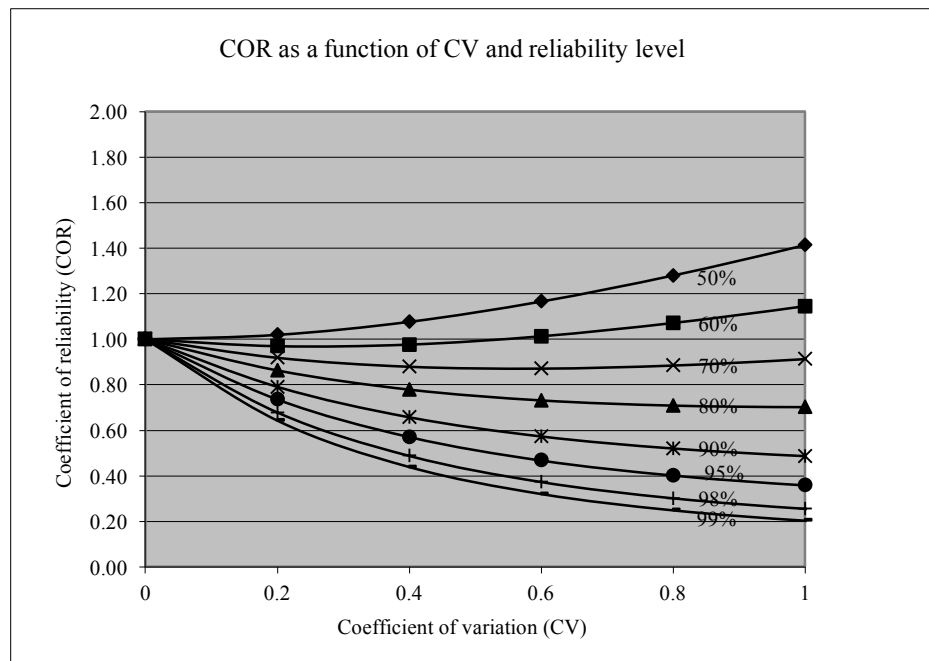
$$m_x = (COR)X_s = 0.72 \times 200 = 144 \text{ mg/L}$$

This way similar calculations can be done with different CV values and different reliability levels.

By looking at Table 4.1 and Fig 4.17, it is clear that for reliability levels of 80% and above, and CV values found in practice (below 1.0) according to Oliveira and Von Sperling (2007), show a trend of decreasing COR values as CV values increase. This means that, the higher the reliability and effluent unevenness, the lower the COR values should be and consequently implying, the lower the mean value of effluent concentrations (Oliveira and Von Sperling, 2007). More on the interpretation of COR for different CV and reliability levels are discussed further on.

**Table 4.3 Reliability Coefficients (COR) as a function of CV and reliability level – Adapted from Oliveira & Von Sperling (2007)**

Reliability level %	CV (coefficient variation) values													
	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.5	3	3.5
50	1.00	1.02	1.08	1.17	1.28	1.41	1.56	1.72	1.89	2.06	2.24	2.69	3.16	3.64
60	1.00	0.97	0.98	1.01	1.07	1.15	1.23	1.32	1.42	1.52	1.62	1.89	2.15	2.42
70	1.00	0.92	0.88	0.87	0.89	0.91	0.95	1.00	1.04	1.10	1.15	1.29	1.43	1.57
80	1.00	0.86	0.78	0.73	0.71	0.70	0.71	0.72	0.73	0.75	0.77	0.82	0.88	0.94
90	1.00	0.79	0.66	0.57	0.52	0.49	0.47	0.45	0.44	0.44	0.44	0.44	0.45	0.46
95	1.00	0.74	0.57	0.47	0.40	0.36	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.26
98	1.00	0.68	0.49	0.37	0.30	0.26	0.22	0.20	0.19	0.17	0.17	0.15	0.14	0.13
99	1.00	0.64	0.44	0.32	0.25	0.20	0.17	0.15	0.14	0.13	0.12	0.10	0.09	0.09



**Figure 4.18 Coefficients of reliability as a function of CV and reliability levels - Adapted from Oliveira & Von Sperling (2007)**



#### **4.4 CV and COR values obtained**

The COR values in this study have been calculated from the CV values obtained from each of WWTPs from each treatment technology and applying an 80% reliability level, instead of a 95 % reliability - as applied for treated wastewater release to surface waters (Oliveira & Von Sperling, 2007). As in this case the wastewater effluents will be reused in irrigation and aquaculture, reliability levels do not require be as stringent and as shown in section 4.3, less stringent values would be more appropriate (Dos Santos, 2009).

The mean CV values and COR values of the nine wastewater treatment technologies for each parameter have been compiled in Table 4.3 and as box whisker plots (Fig. 4.18 – 4.25), presenting all the values of the WWTPs from each treatment technology.

By looking at Table 4.3 it is clear that there are great differences between mean CV and COR values in each parameter when the different wastewater treatment technologies are compared. The differences are even more extreme when the box whisker plots are analysed (Fig. 4.18 – 4.25), illustrating the great ranges from the maximum and minimum values. Most mean CV values do not fall below 1.0 as would be expected according to Oliveira & Von Sperling (2007). This difference is mainly due to the fact that there is great variance and unevenness in the effluent values, representative of high standard deviations. On a general basis, such is the case in most anaerobic treatment technologies, when compared to the aerobic systems as seen especially in Figures 4.18, 4.19, 4.21 and 4.22. These high mean CV values are thus

representative of unstable operational levels by these technologies which could be caused by a lack of maintenance or affluent disturbances (Fan & Berthou, 1986; Oliveira & Von Sperling, 2007) - applying especially also to FP+MP as seen in Figure 4.21. The most stable operational values according to the CV values are presented by FAP+FP+MP (as its only 1 WWTP) and the WSP system (6 WWTPs), followed by the other pond systems (FP and FP+MP); then by the UASB+CI and UASB systems; and finally by the Septic tank systems, which alternate between themselves with high and low values for different parameters.

Values which did present CV values below 1.0 and were fairly equal in all wastewater treatment technologies were those attributed to conductivity (Table 4.3), which showed little variances between the effluent values as shown in Figure 4.20.

Additionally, increasing CV values showed little correlation with decreasing COR values.

COR values were higher than those presented by Oliveira and Von Sperling (2007) as effluent values were lower and due to the fact that a lower reliability level was applied (80%), presenting less stringent levels to be met. Furthermore, many of the effluent values as shown in the reliability analysis were found to be well below the required parameter limits, and thus explaining some of the very high COR values. This means that the lower the effluent value, then the higher the COR, surpassing the value of 1.0 when the effluent value is lower than that of the parameter limit - suggesting that even higher levels of reliability (higher than 80%) could be applied for these parameters

if required. This was especially the case for *E. coli* (Fig. 4.22) and TTC (Fig. 4.23) values which generally vary in orders of magnitude.

High values were found for mean N-NH<sub>3</sub> CVs and CORs (Table 4.4) for ST+AF, ST+AF+Cl and AP+FP+MP treatment technologies (CVs and CORs above 1) when compared with the other treatment technologies, as expected from the previous analysis. This wide difference between the technologies does not refer to a great difference in performance, but to the fact that none of these technologies were designed specifically for N-NH<sub>3</sub> removal and are thus subject to great effluent value differences determined by the affluent entering the WWTPs – which in this case is unknown. This is most obvious in the case of ST+AF and ST+AF+Cl, as these systems are known to be very limited in the removal of ammonia as compared to the WSP system, as already explained in section 4.2 (Mota *et al.*, 2007). The reason behind the great variations in the COR values obtained from these wastewater treatment technologies compared to the rest of the systems, lays in the great differences between effluent values and as mentioned, its high CV values. Although most of their values are found well above the parameter limit (5 mg/L), with a maximum of 115.09 mg/L in the case of ST+AF+Cl and are representative of a high arithmetic mean value (Table 4.2), a few extremely low values, such as 0.10 mg/L as seen for ST+AF+Cl (CD Appendix – Reliability spreadsheet) result in these systems characterization as high reliability treatment technologies (especially for ST+AF+Cl as shown in Table 4.4 and 4.5). This is attributed to the behaviour of the non-symmetrical pattern of lognormal distribution, which allows different CV values (ranging from 0.1 – 3.3, in the case of the 80% reliability level) to present the same arithmetic means under the same reliability level, as well as the same COR values (Table 4.3). It is important to note that low CV values

(lower than 0.16667) will bear a resemblance to normal distribution symmetry in a PDF of the lognormal probability model, whilst higher CV values are represented with substantial skewness as stated by Ott (1995). These mentioned different scenarios would consequently be seen as identical from a legislative point of view, as they would be providing the same effluent quality if expressed in terms of arithmetic mean or in percentages of compliance with the parameter limits. However, the differences between the individual effluents are evident from a practical point of view, all in relation to the variance of the effluent values from the different WWTPs. Consequently, it should bear in mind that the arithmetic means of these wastewater treatment technologies reach these values because of a few, but extremely low concentrations found.

Low COR values as suggested by Oliveira & Von Sperling (2007) represent the need for lower effluent concentrations and thus the need to improve operational methods or maintenance of the WWTPs. COR values in this study did not fall below 0.75, as compared to 0.29 in the study conducted by Oliveira and Von Sperling (2007), thus suggesting that it will be easier for the treatment technologies to produce the required effluent values, which will be developed by multiplying the COR values by the parameter limits (see section 4.5).

**Table 4.4 CV and COR values from the 9 WWTP technologies at an 80% reliability level**

Technologies	Coefficient of variation (CV)								Coefficient of reliability (COR)							
	COD	EC*	Turbidity	BOD	TSS	N-NH3	<i>E. coli</i>	TTC	COD	EC	Turbidity	BOD	TSS	N-NH3	<i>E. coli</i>	TTC
ST	1.06	0.15	0.83	-	1.15	0.92	2.72	27.54	1.06	0.89	0.89	-	0.76	0.78	0.99	4.90
ST + AF	2.74	0.27	1.41	-	5.52	14.74	6.44	12.57	1.15	0.83	1.28	-	1.14	1.52	1.90	2.32
ST + AF + CI	2.01	0.24	1.15	-	2.21	52.23	9.61	5.69	1.30	0.98	1.38	-	0.91	16.45	2.11	1.65
FP	0.77	0.19	0.66	0.63	0.48	0.60	3.34	5.54	0.88	0.87	1.05	0.75	0.79	0.76	0.97	1.58
FP + MP	1.01	0.24	0.85	-	0.78	0.76	0.31	1.55	1.34	0.24	1.30	-	0.77	0.94	1.31	0.86
AP + FP + MP	0.71	0.28	0.68	0.22	0.84	9.20	0.70	0.50	0.88	0.83	1.18	1.02	0.78	9.59	0.84	0.77
AFP + FP + MP	0.48	0.20	0.30	-	0.48	0.88	0.67	0.36	1.15	0.80	1.05	-	0.78	0.85	0.75	0.79
UASB	0.51	0.18	1.18	-	1.54	0.76	2.19	26.94	0.97	0.87	1.39	-	0.80	0.92	1.16	3.37
UASB + CI	0.83	0.25	0.81	-	1.05	1.33	6.60	6.90	0.79	0.84	1.12	-	0.76	0.80	1.56	2.03

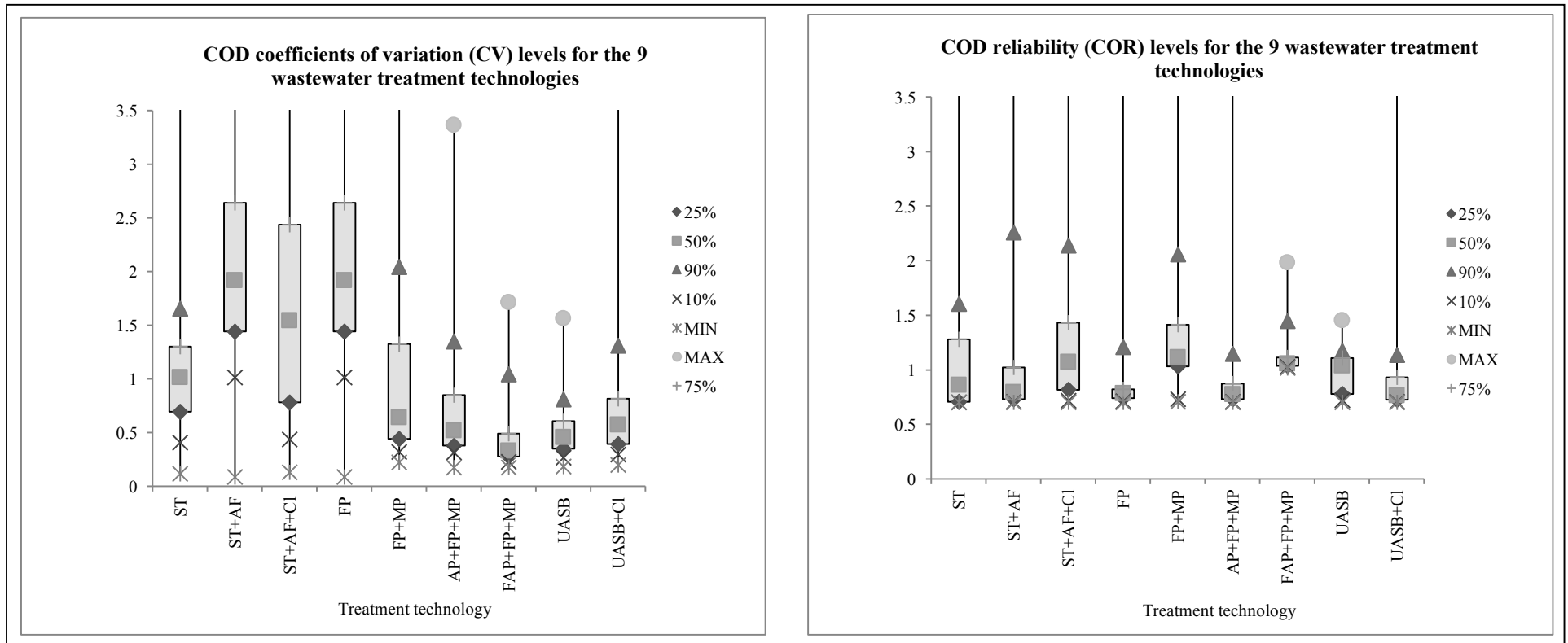


Figure 4.19 COD coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies

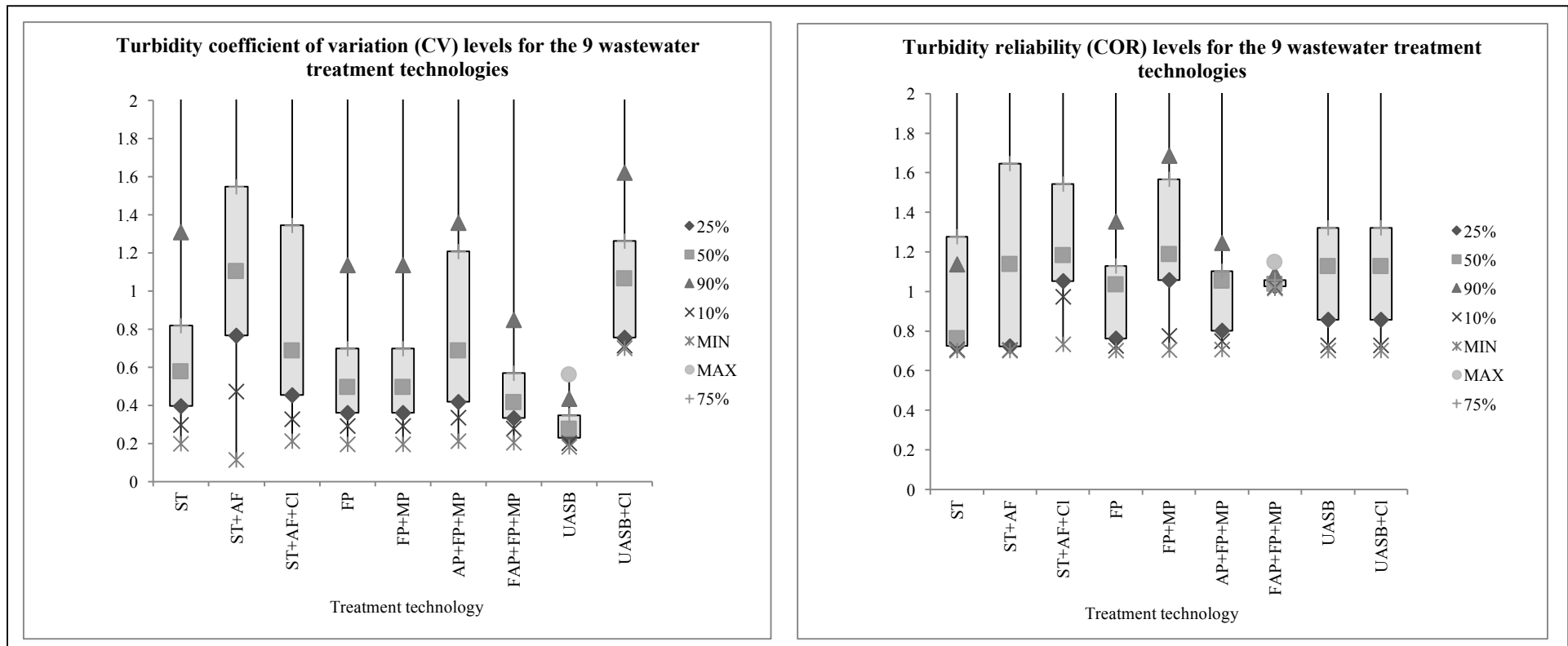
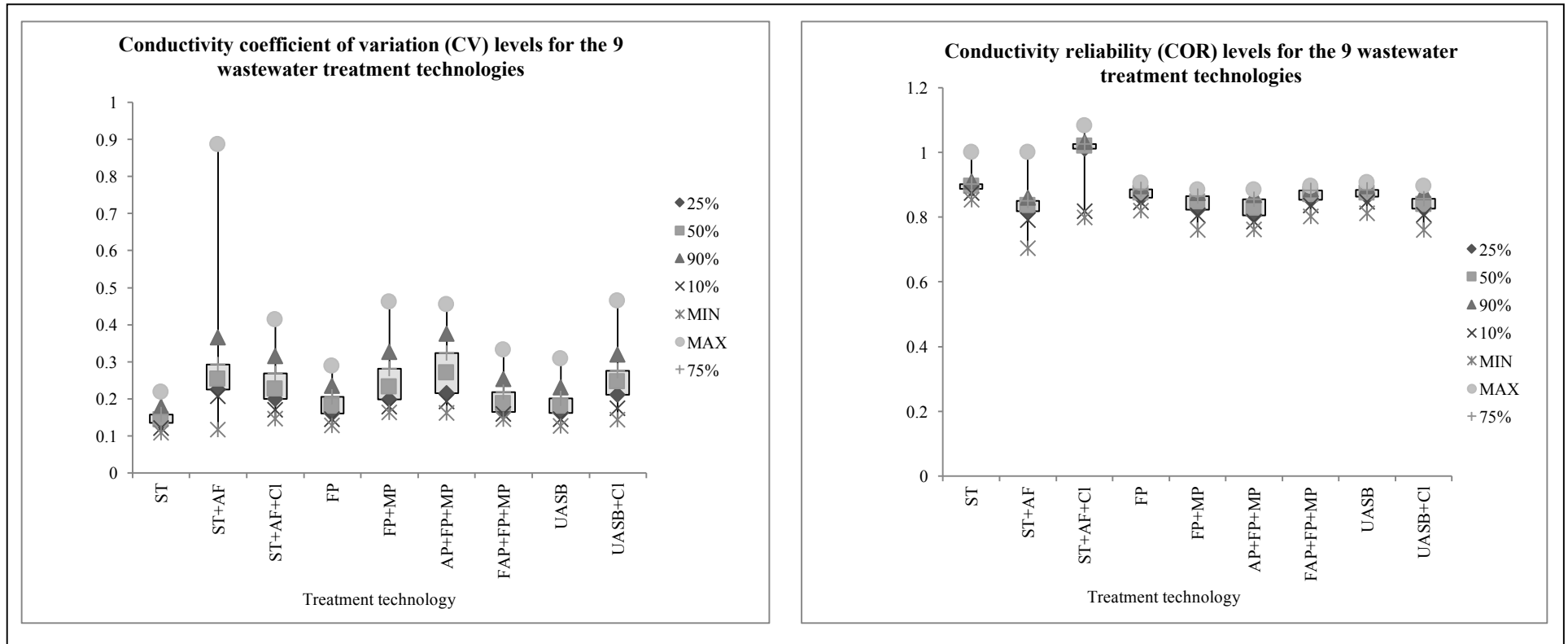


Figure 4.20 Turbidity coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies



**Figure 4.21** Conductivity coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies



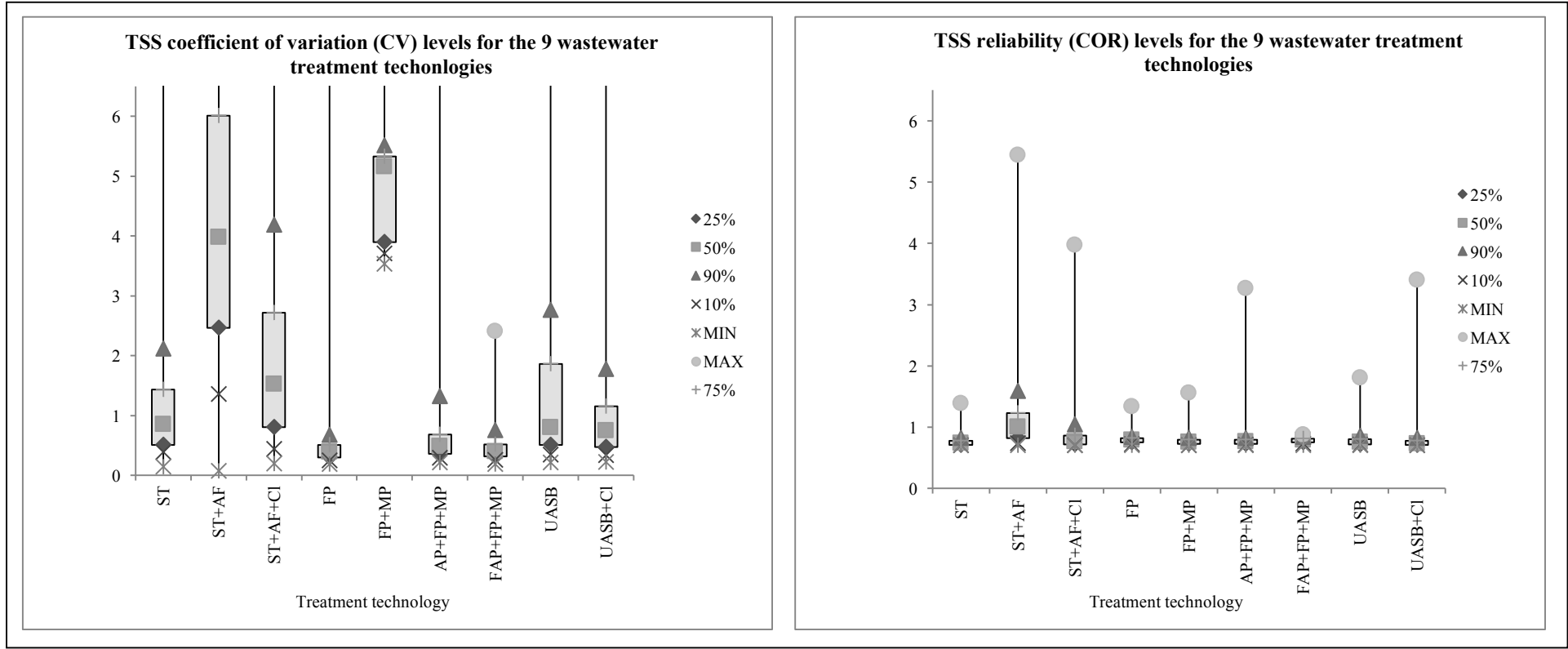


Figure 4.22 TSS coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies

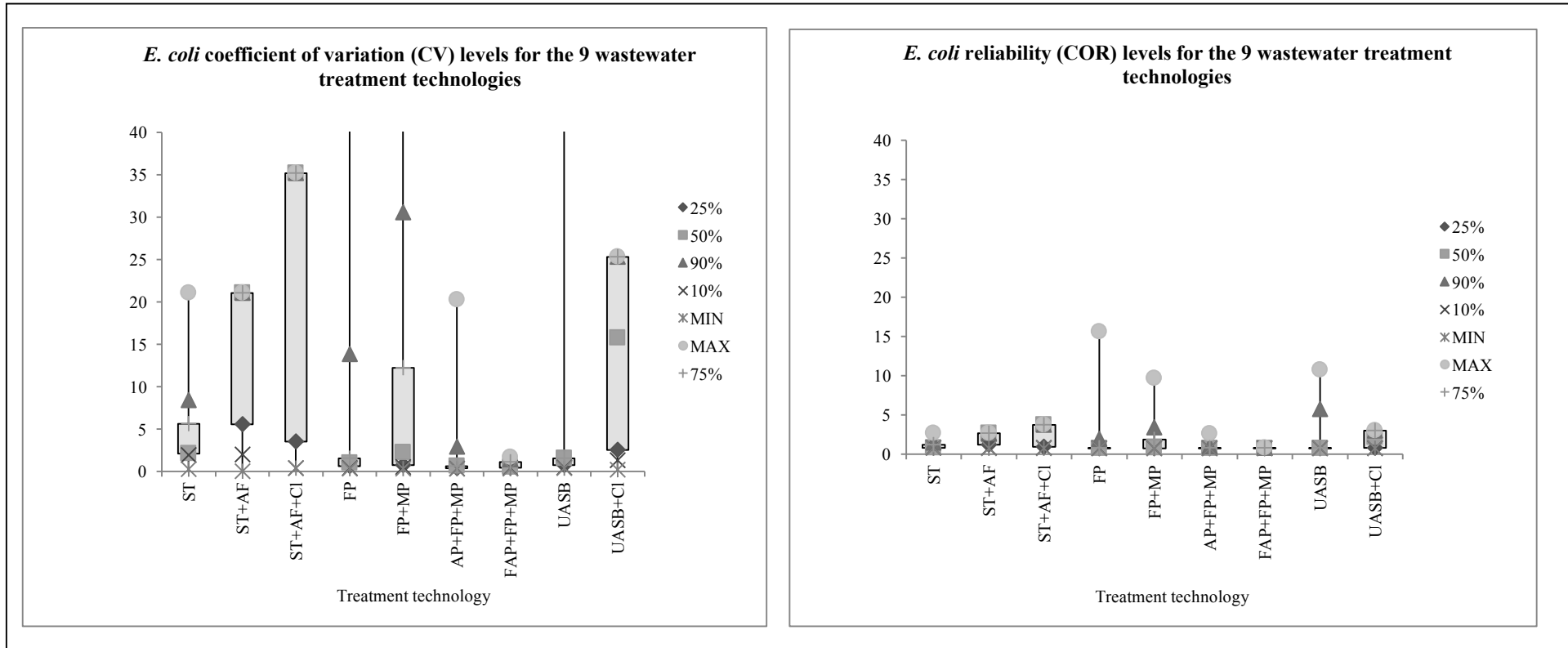


Figure 4.23 *E. coli* coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies

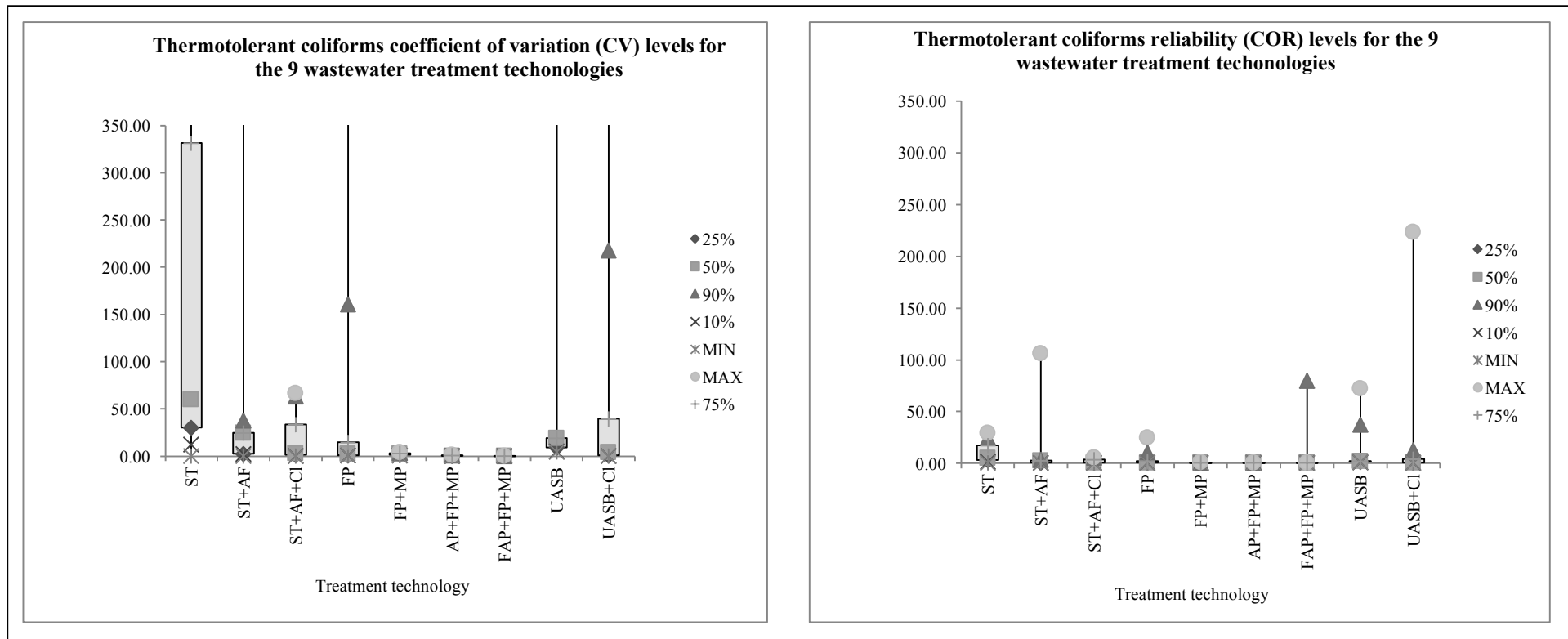


Figure 4.24 TTC coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies

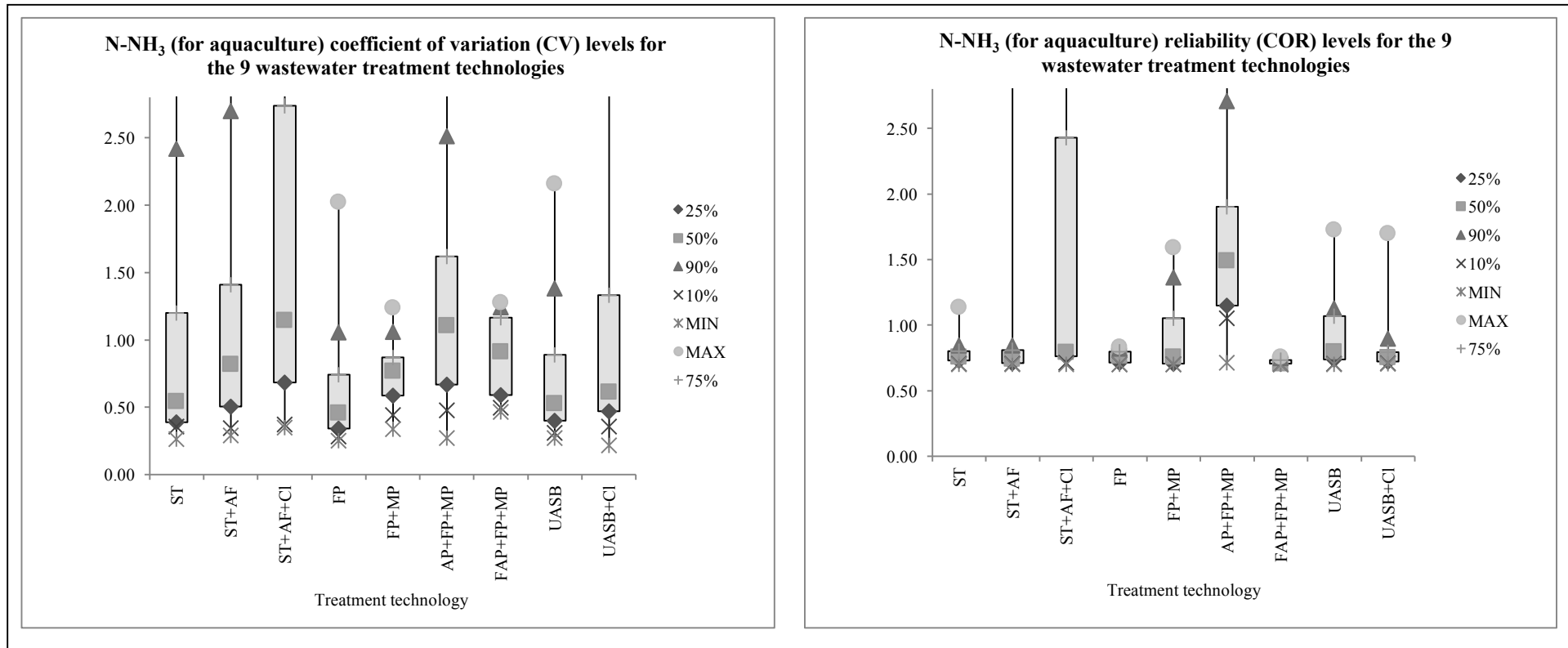


Figure 4.25 N-NH<sub>3</sub> coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies

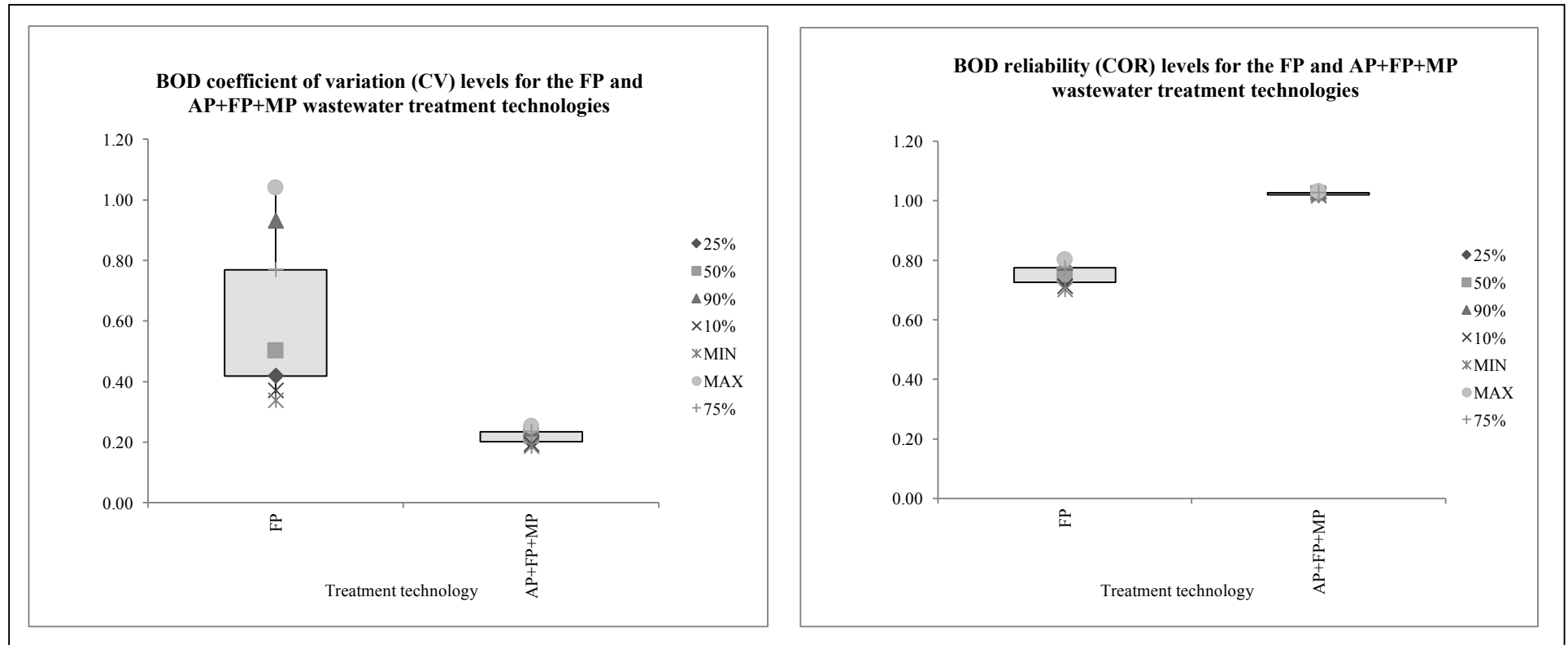


Figure 4.26 BOD coefficients of variation (CV) and coefficients of reliability (COR) values for the FP and AP+FP+MP wastewater treatment technologies

#### 4.5 Effluent values required to reach the parameter limits

The effluent values required for the parameter limits were calculated using Eq. 3 for each wastewater treatment technology, by applying their mean CV value and  $\alpha = 20$ . As already mentioned in section 3.1, these values are hypothetical limits set by compiling different Brazilian values for each parameter, having chosen the less stringent values, in order to make them as realistic and achievable as possible without jeopardizing human health and performances of both reuse practices.

Box whisker plots (Fig. 4.28 – 4.37) have been prepared to illustrate the differences between the ideal required effluent values to meet the 80% reliability level against the actual effluent values of each wastewater treatment technologies. It is clear that in most cases the actual effluent levels exceed those required to obtain the desired reliability; referring especially to the anaerobic systems for COD (Fig. 4.28), the anaerobic systems and the simpler pond systems (FP, FP+MP) for turbidity (Fig 4.29), the anaerobic systems for conductivity required for aquaculture and all of the wastewater treatment technologies (especially the anaerobic) for N-NH<sub>3</sub> (Fig. 4.36).

On the contrary, levels required for parameters such as conductivity intended for irrigation purposes (Fig. 4.30), *E. coli* values (Fig. 4.32 & 4.33) and TTC values (Fig. 4.34 & 4.35) were higher than those being produced by most wastewater treatment technologies, except for FP in *E. coli* (Fig. 4.32 & 4.33); and FP and FP+MP for TTC (Fig. 4.34 & 4.35). This as already mentioned in the efficiency analysis, is representative of their lack of maintenance and lack of data, especially in the case of FP+MP in TTC (only 3 values from 1 WWTP).

As expected, the WSP system provided most of its actual mean effluent values below those considered to be the ideal effluent values to achieve the 80% reliability. The superiority of the WSP system over the FP systems is clear for example, when the BOD values (Fig. 4.37) are looked at. Whilst the actual effluent values from the FPs are above those representing the ideal effluent values, the WSP systems provide an effluent below than that required to achieve an 80% reliability. This suggests that even more stringent reliability standards could be set for the WSP systems for this parameter and the other 7, were its values have fallen below ideal effluent values. These include COD (Fig. 4.27), EC for irrigation (Fig. 4.30), N-NH<sub>3</sub> (Fig. 4.36), *E. coli* standards (Fig. 4.32 & 4.33) and TTC standards (Fig. 4.34 & 4.35).

The high values obtained as the mean ideal effluent concentrations for N-NH<sub>3</sub> for ST+AF+Cl and the WSP systems, relates to what has been already mentioned in section 4.4. Their high variances in effluent values and very low concentrations found in certain WWTPs influencing their COR values, has directly resulted in their influence of these values – high COR values result in high mean ideal effluent values (Oliveira & Von Sperling, 2007). As a result, both ideal mean design concentrations calculated cannot be considered as they are unrealistically high, and as shown in Figure 4.16 percentages of compliance with the parameter limits are very low.

It is important to note, that all of the wastewater treatment technologies are far from producing suitable EC effluents for aquaculture, which could greatly limit their utility for this kind of reuse.

**Table 4.5 Mean ideal design effluent concentrations required to achieve 80% compliance with the standards against the actual effluent levels being produced**

Technology	COD (mg/L)		EC - irrigation* (µS/cm)		EC - aquaculture (µS/cm)		Turbidity (NTU)		BOD (mg/L)		TSS (mg/L)		N-NH <sub>3</sub> - aquaculture (mg/L)		<i>E. coli</i> - aquaculture & restricted irrigation (MPN/100mL)		<i>E. coli</i> - unrestricted irrigation (MPN/100mL)		TTC - aquaculture & restricted irrigation (MPN/100mL)		TTC - unrestricted irrigation (MPN/100mL)	
	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC	MDC	AMC
ST	211	646	2680	1850	895	1722	4	400	-	-	46	295	4	84	9.86E+03	7.74E+02	9.86E+02	7.74E+02	4.90E+04	4.38E+02	4.90E+03	4.38E+02
ST + AF	231	656	2492	1612	832	1612	6	306	-	-	69	323	8	75	1.90E+04	3.27E+02	1.90E+03	3.27E+02	2.32E+04	3.88E+02	2.32E+03	3.88E+02
ST + AF + CI	260	299	2538	1309	975	1309	7	104	-	-	55	66	82	43	2.11E+04	3.66E+02	2.11E+03	3.66E+02	1.65E+04	1.17E+03	1.65E+03	1.17E+03
FP	176	284	2616	1255	872	1255	5	331	45	109	47	149	4	45	9.74E+03	7.74E+04	9.74E+02	7.74E+04	1.58E+04	5.28E+04	1.58E+03	5.28E+04
FP + MP	268	209	2529	1246	244	1246	7	190	-	-	46	93	5	32	1.31E+04	4.00E+03	1.31E+03	4.00E+03	8.55E+03	6.20E+05	8.55E+02	6.20E+05
AP + FP + MP	177	137	2485	1300	828	1300	6	96	61	50	47	61	48	25	8.39E+03	8.63E+01	8.39E+02	8.63E+01	7.69E+03	1.39E+03	7.69E+02	1.39E+03
AFP + FP + MP	229	188	2596	1033	865	1033	5	177	-	-	47	94	4	27	7.50E+03	4.89E+02	7.50E+02	4.89E+02	7.92E+03	2.57E+03	7.92E+02	2.57E+03
UASB	194	266	2618	1891	873	1891	7	197	-	-	48	131	5	49	1.16E+04	7.09E+02	1.16E+03	7.09E+02	3.37E+04	7.09E+02	3.37E+03	7.09E+02
UASB + CI	179	364	2524	1703	841	1703	6	202	-	-	46	148	4	93	1.56E+04	3.83E+02	1.56E+03	3.83E+02	2.03E+04	1.15E+03	2.03E+03	1.15E+03

\*Refers to both; unrestricted and restricted irrigation

Discharge standards: COD = 200 mg/L; EC - irrigation\* = 3000 µS/cm; EC - aquaculture = 1000 µS/cm; Turbidity = 5 NTU; TSS = 50 mg/L; N-NH<sub>3</sub> = 5 mg/L; *E. coli* - aquaculture & restricted irrigation = 10000 MPN/100 mL; *E. coli* - unrestricted irrigation = 1000 MPN/100 mL; TTC - aquaculture & restricted irrigation = 10000 MPN/100mL; TTC - unrestricted irrigation = 1000 MPN/100 mL

Where MDC = Mean ideal design concentrations; and

AMC = Actual mean concentrations.



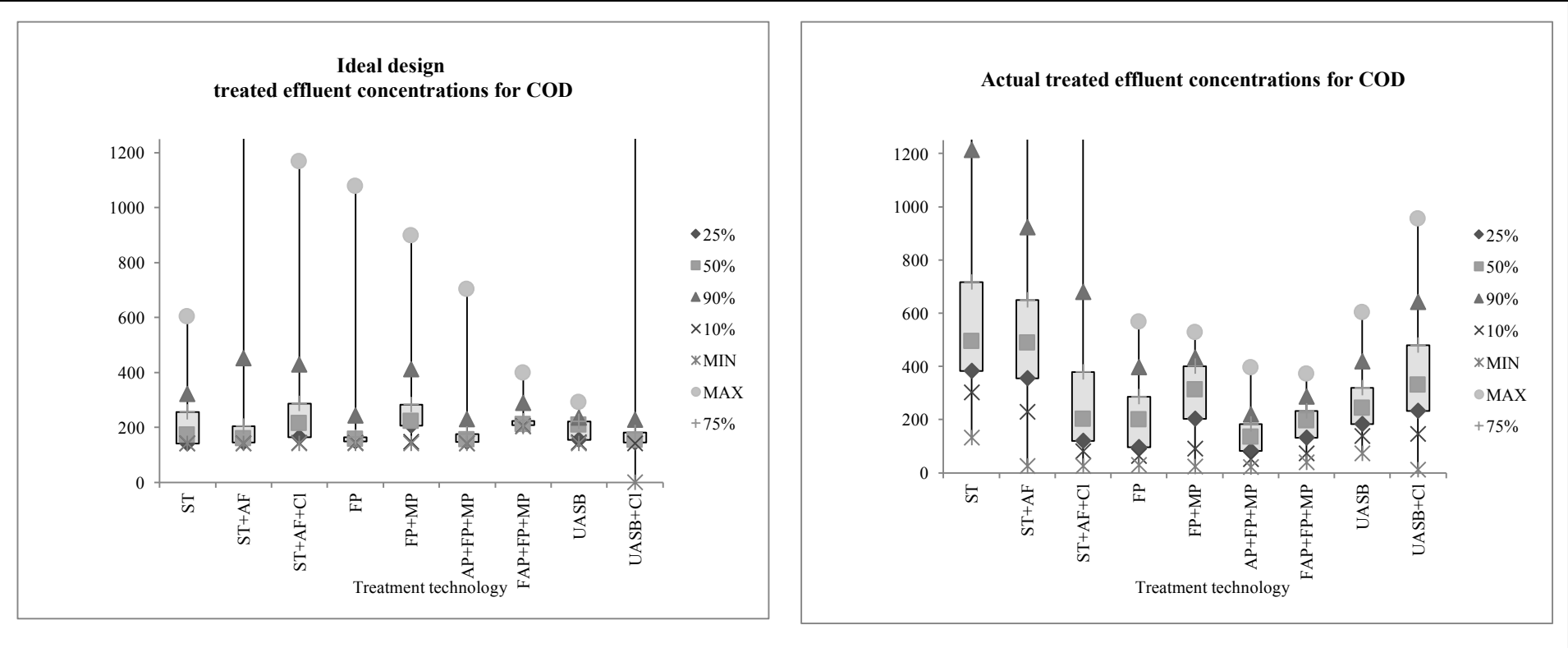


Figure 4.27 COD ideal design concentrations to meet an 80% reliability level against actual effluent values

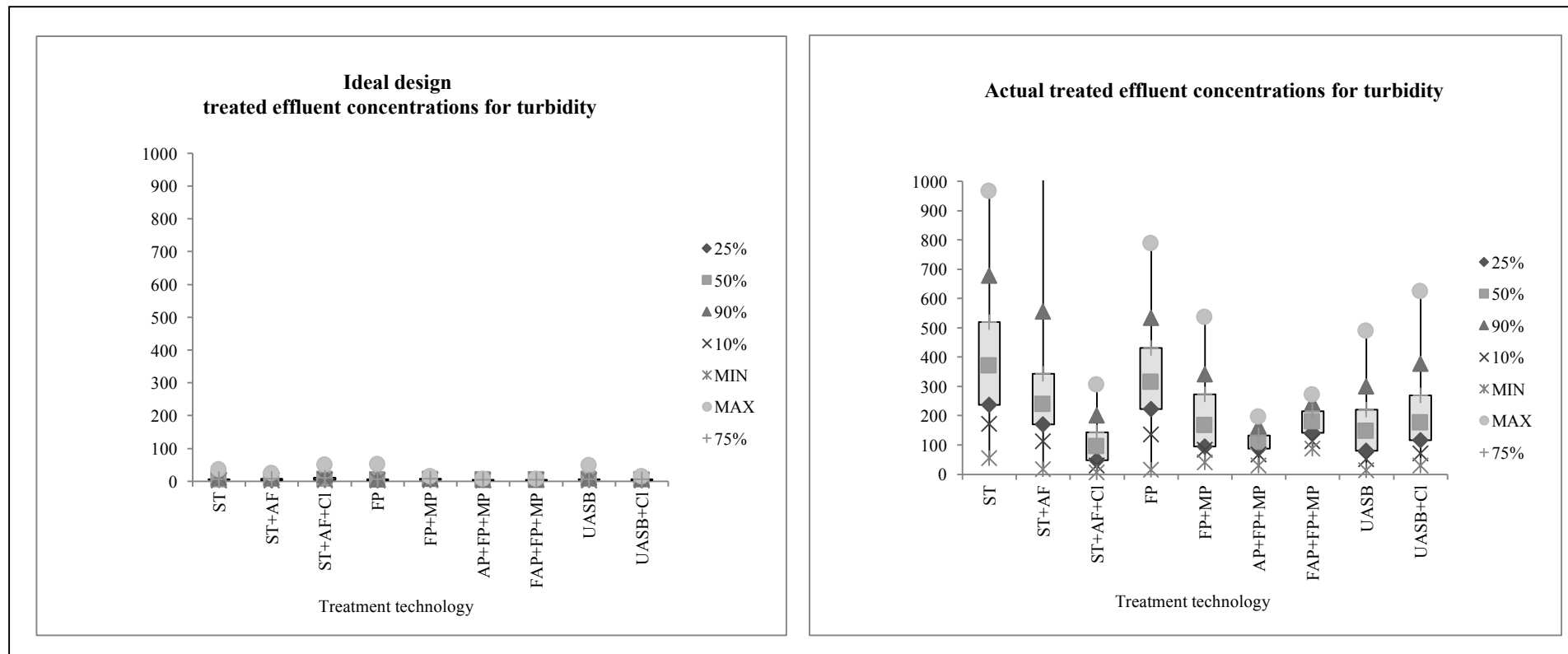


Figure 4.28 Turbidity ideal design concentrations to meet an 80% reliability level against actual effluent values

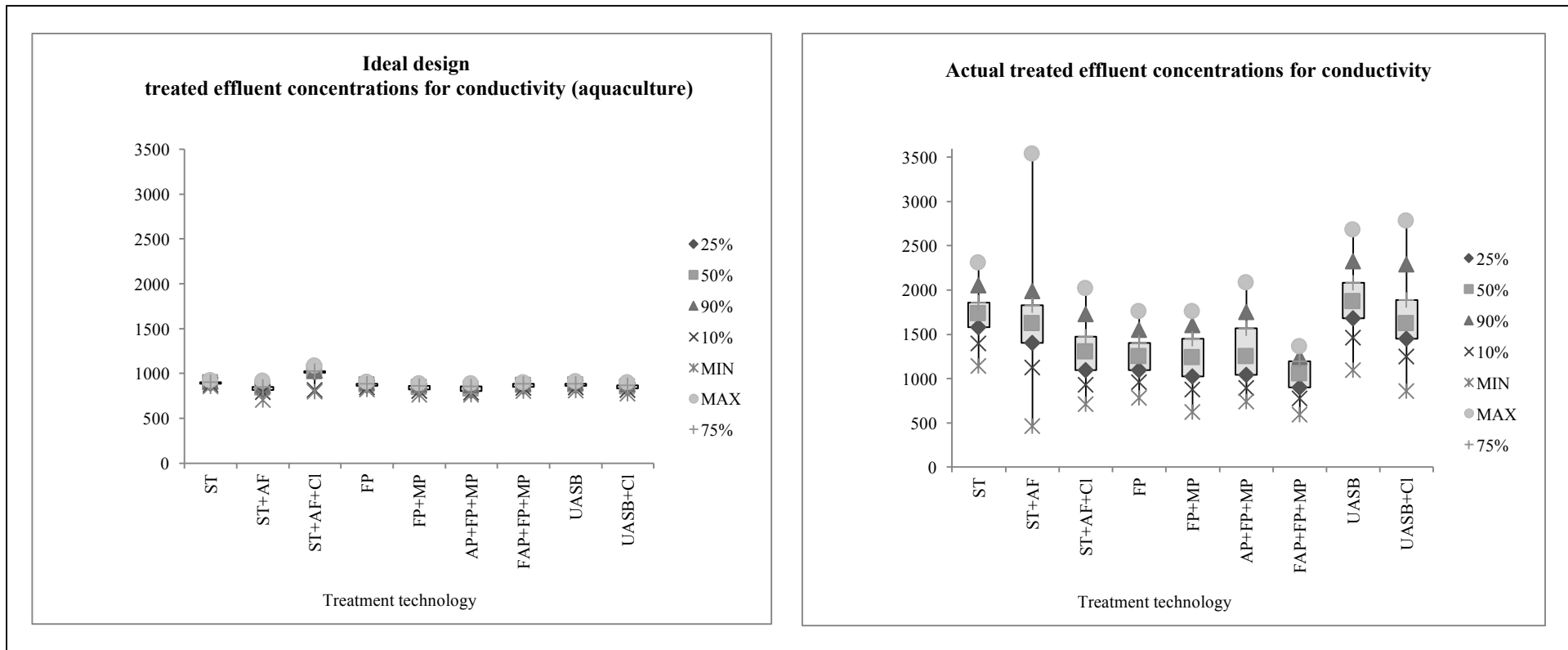


Figure 4.29 Conductivity ideal design concentrations for aquaculture reuse to meet an 80% reliability level against actual effluent values

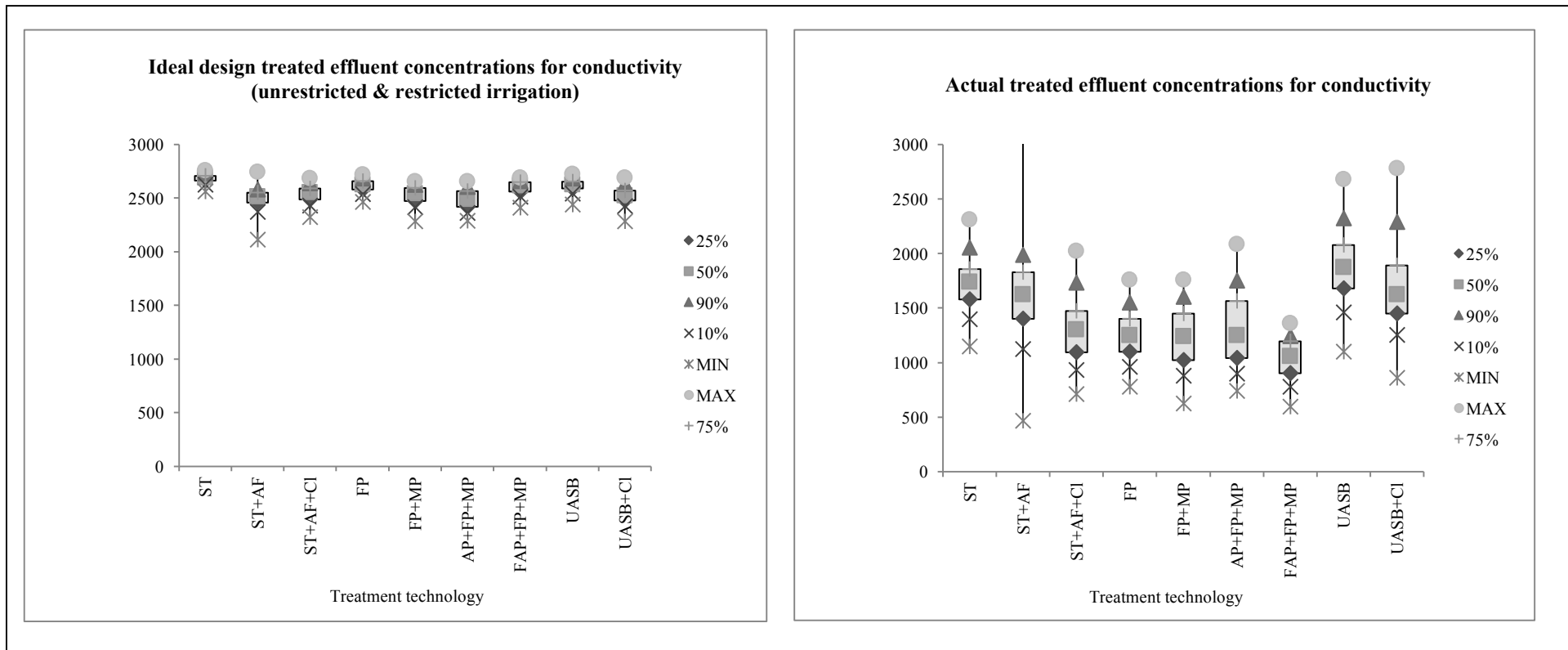


Figure 4.30 Conductivity ideal design concentrations for unrestricted and restricted irrigation reuse to meet an 80% reliability level against actual effluent values

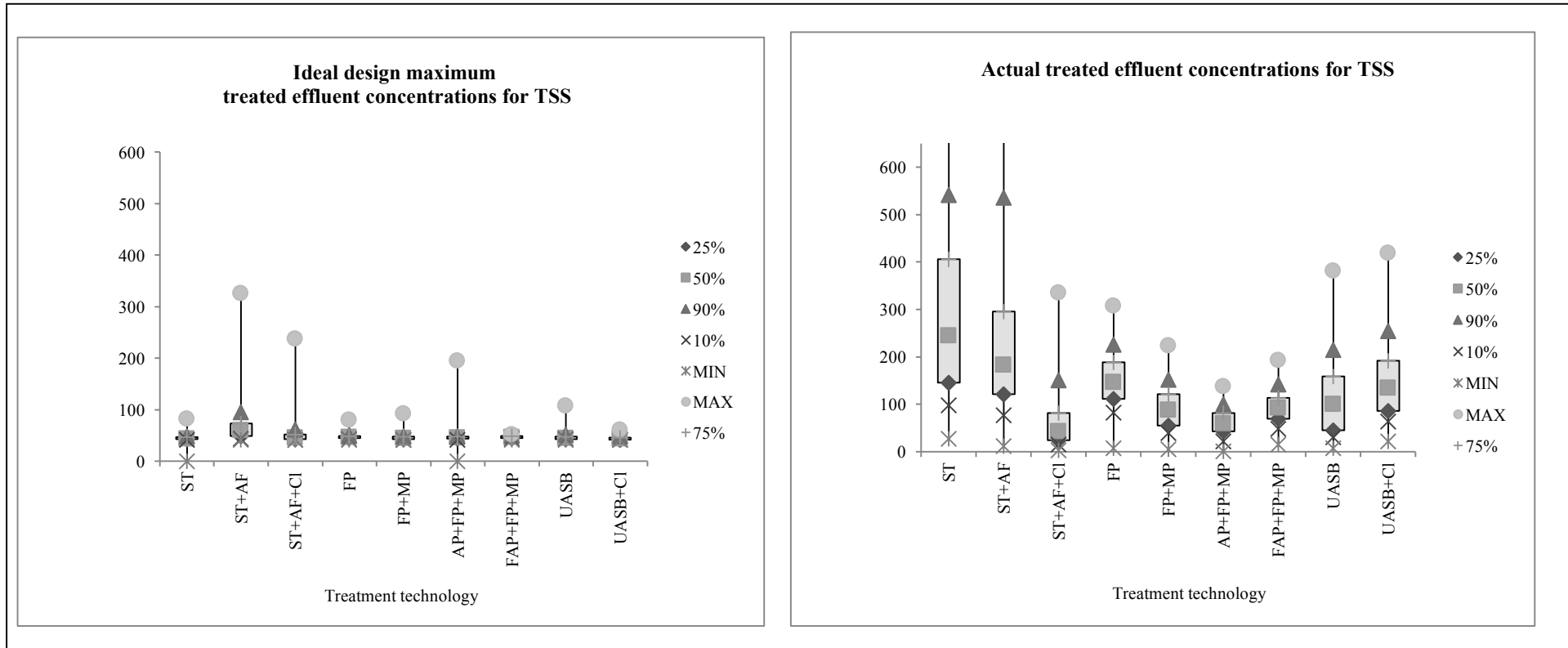


Figure 4.31 TSS ideal design concentrations to meet an 80% reliability level against actual effluent values

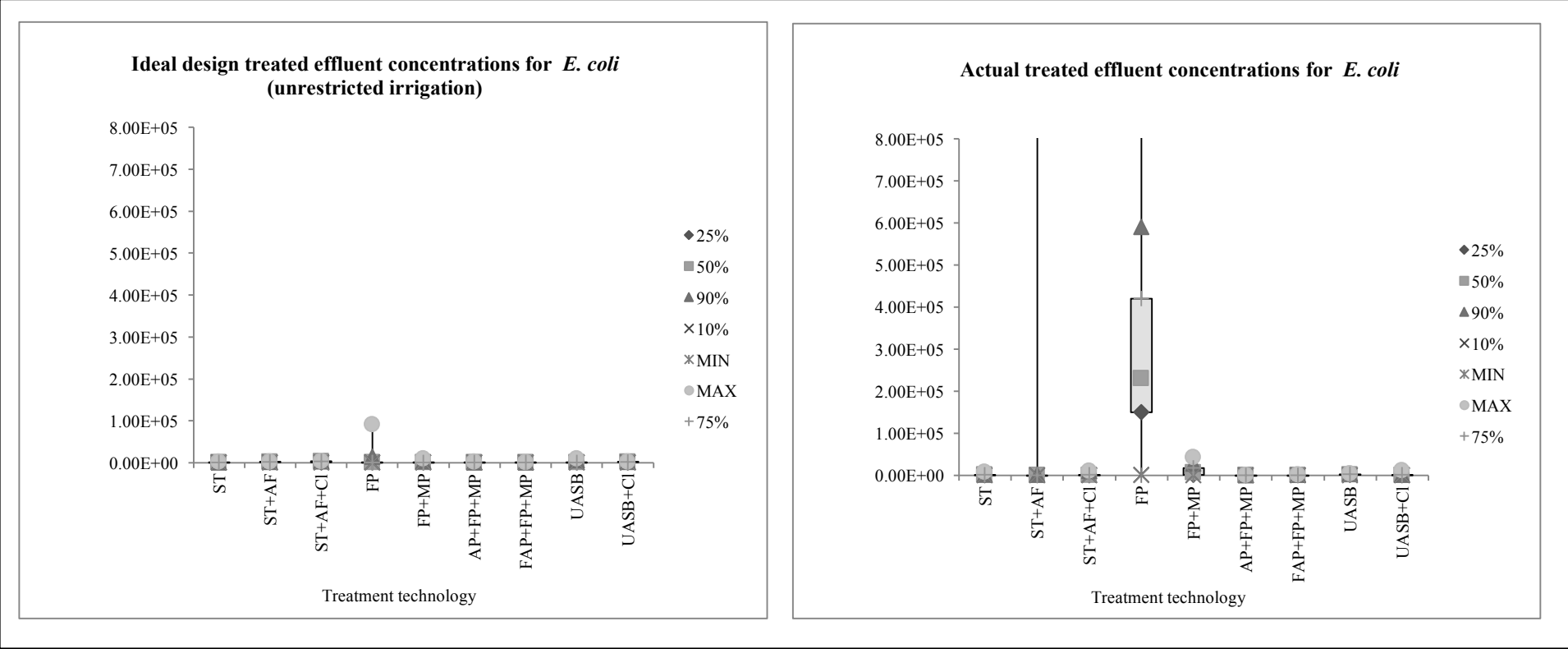


Figure 4.32 *E. coli* ideal design concentrations for unrestricted irrigation to meet an 80% reliability level against actual effluent values

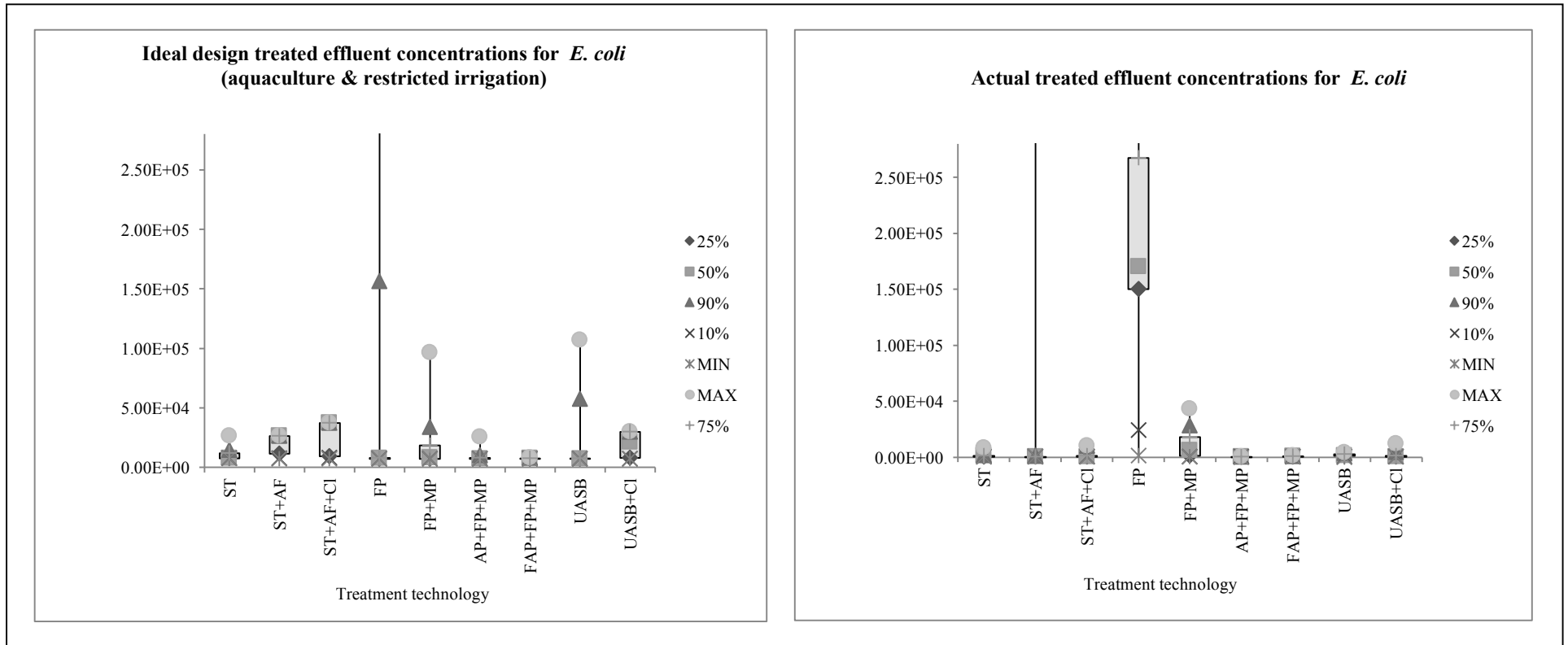


Figure 4.33 *E. coli* ideal design concentrations for aquaculture and restricted irrigation to meet an 80% reliability level against actual effluent values

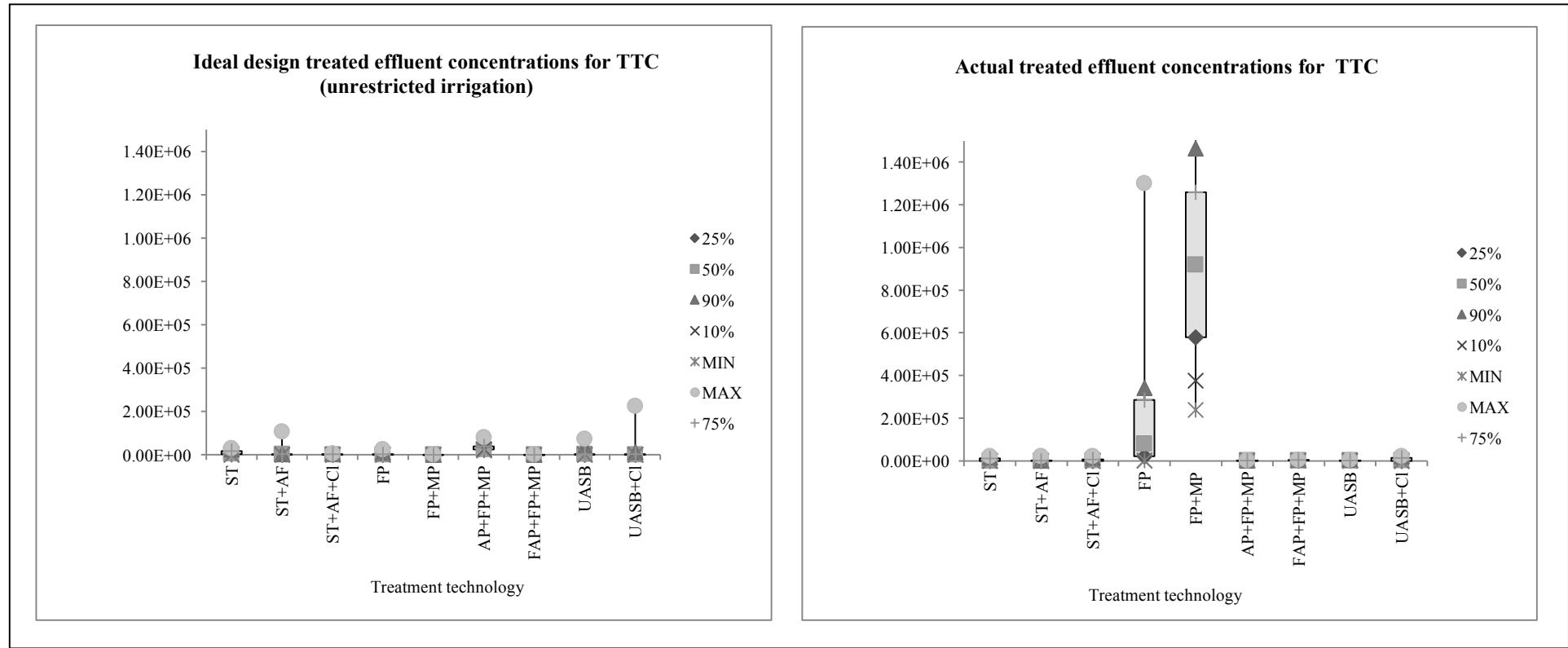


Figure 4.34 TTC ideal design concentrations for unrestricted irrigation to meet an 80% reliability level against actual effluent values



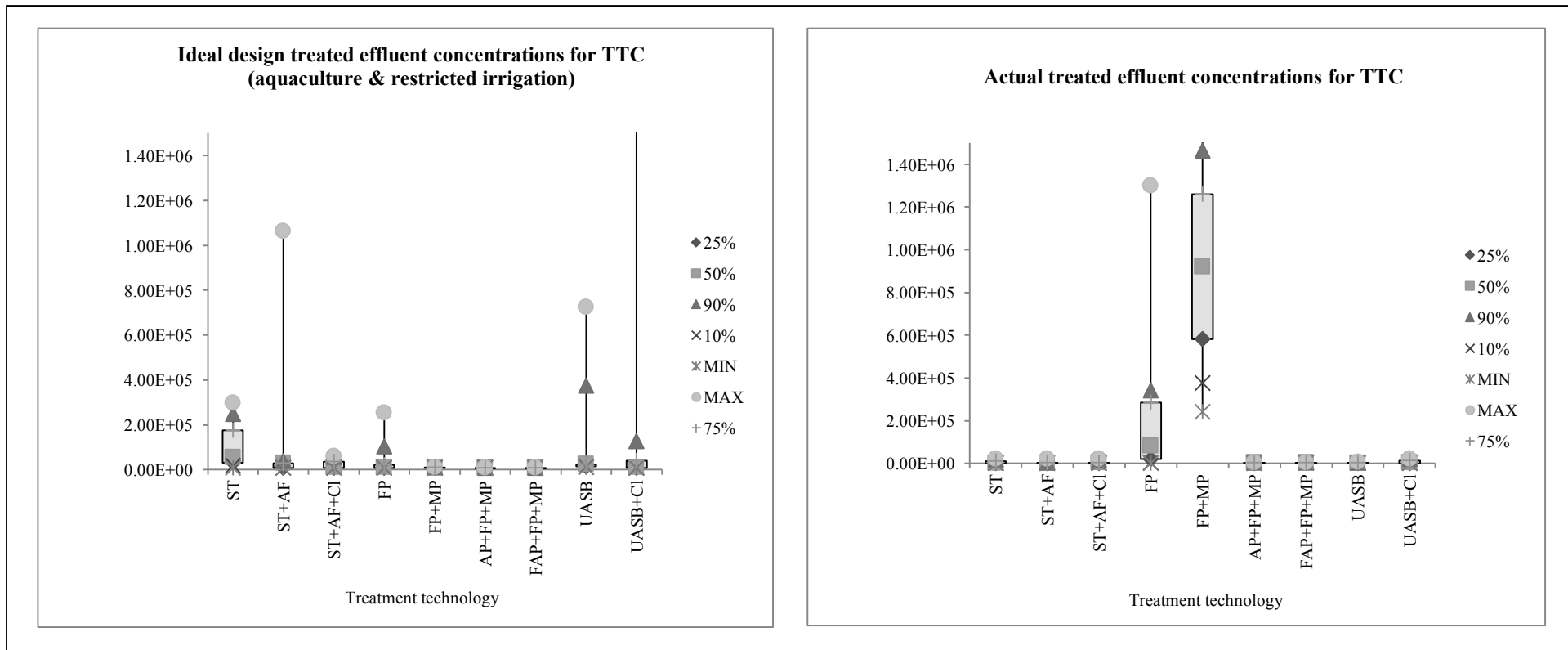


Figure 4.35 TTC ideal design concentrations for aquaculture and restricted irrigation to meet an 80% reliability level against actual effluent values

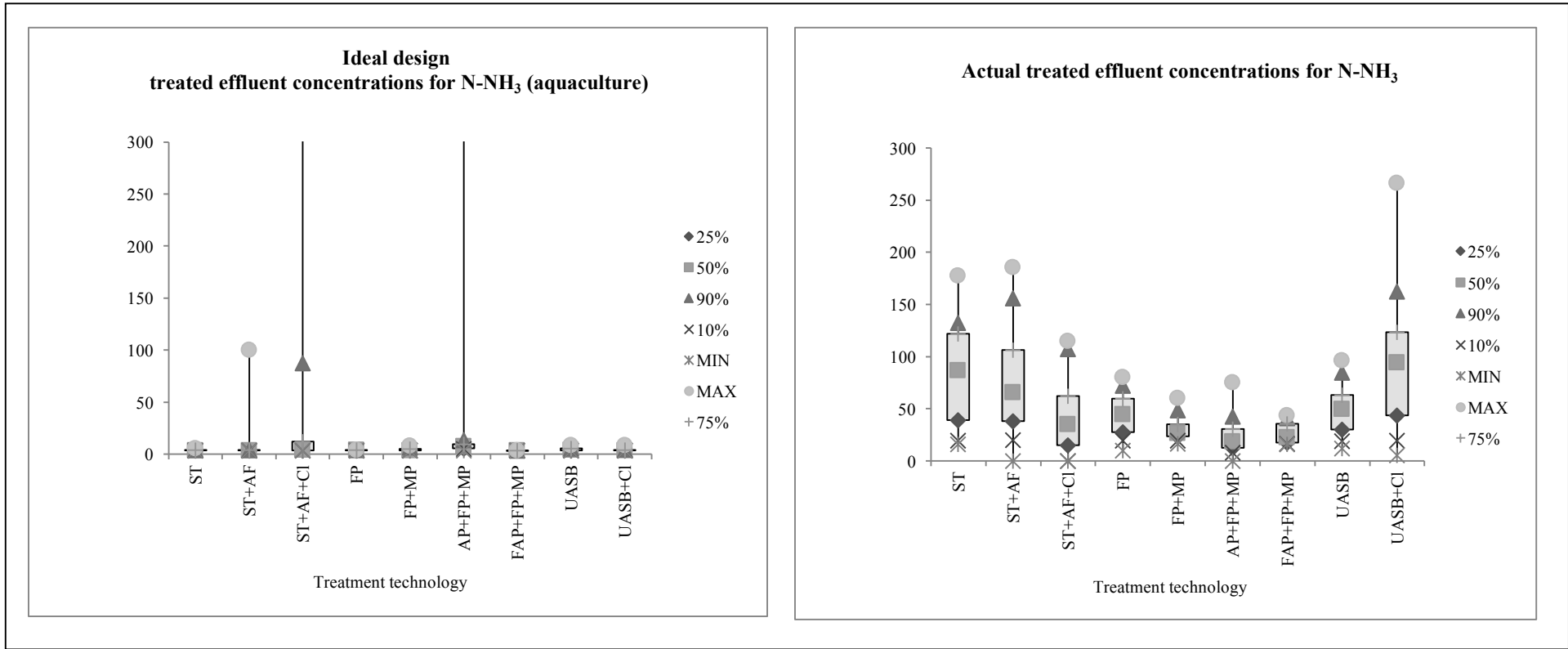


Figure 4.36 N-NH<sub>3</sub> ideal design concentrations for aquaculture to meet an 80% reliability level against actual effluent values

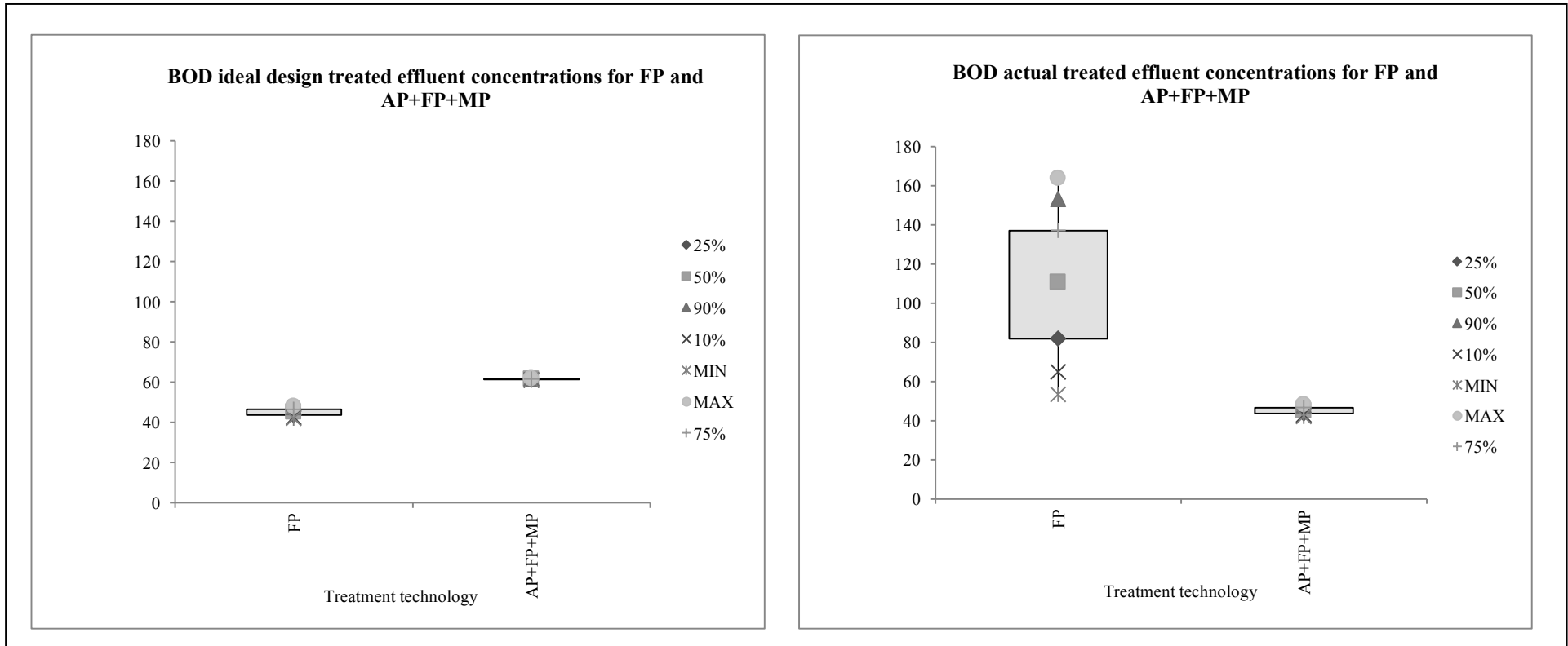


Figure 4.37 BOD ideal design concentrations for FP and AP+FP+MP wastewater treatment technologies to meet an 80% reliability level against actual effluent values

#### **4.6 Percentage of compliance with the parameter limits at an 80% reliability level**

As seen on section 4.2, a percentage of compliance has been calculated, but this time taking into consideration the performance of the WWTPs at an 80% reliability level. It should be noted that the results are representative of the WWTPs performance if they were to maintain their operational levels.

The percentage of compliance levels were calculated for each effluent value using Eq. 5; Table 4.6 has been made to present the mean results and box whisker plots (Fig. 4.38 - 4.48) have been prepared to show in more detail the performance of each wastewater treatment technology.

As expected, in general, values which fall within the parameter limits have increased when compared with the data from section 4.2. The 80% reliability level means that effluent values required are now less stringent and are more realistic targets for developing countries to achieve, such as Brazil.

The great fluctuations between individual values as seen in the previous results are also represented in these box whisker plots (Fig. 4.38 - 4.48), and as expected, represent the suitability and superiority of the WSP systems over the anaerobic and more simple aerobic systems (Von Sperling & Oliveira, 2009). The highest compliance values were obtained by this system (Table 4.6), especially in its compliance with COD limits; presenting a mean compliance level of 77%, and having 75% of its values above

66.75%. Septic tanks on the other hand presented the lowest mean compliance standards for the same parameter (27%) with 75% of its values below 43.8% compliance.

For COD, conductivity for aquaculture, the anaerobic systems were the best options (excluding ST+AF+Cl), with more WWTPs presenting higher overall values. All complied with levels required for conductivity implemented in irrigation. The two most complete anaerobic systems (WSPs and FAP+FP+MP) also presented the best values for *E. coli* and TTC, whilst FP+MP underperformed greatly (representing low maintenance of the single WWTP studied for this parameter). The discrepancies in the data were representative of the high levels of FAP+FP+MP in TTC for unrestricted irrigation and its low levels for aquaculture and restricted irrigation. These discrepancies were also representative of the high levels of compliance with *E. coli* and TTC values for ST, which questions the validity of the data for these WWTPs. As a result, the analysis for these treatment technologies has to be discarded as values are unreliable.

ST+AF+Cl was the best of the anaerobic systems, proving superior than the simpler aerobic systems (FP and FP+MP) for COD, and presenting the highest percentages of compliance for turbidity (Fig. 4.39), with a maximum value of 83% and with 90% of its values at a compliance level of 24 % (CD Appendix – Reliability spreadsheet). For this parameter the anaerobic technologies performed better than the aerobic. In TSS, the best performances were provided by the anaerobic technologies ST+AF+Cl, ST+AF as supported by Von Sperling & Oliveira (2009), followed by the WSP system.

In order to see with greater ease the differentiations mentioned between the performances of the wastewater treatment technologies, and their data discrepancies, Figures 4.49 & 4.50 have been made to represent their expected behaviour and in some cases their unusual results as pointed out.

It is important to stress that although the WSP systems provided the best compliance and best overall removal efficiencies, it still failed to achieve a 50% compliance with three parameter limits within an 80% reliability level. These included: turbidity (4% - Fig. 4.39), electrical conductivity for aquaculture (29% - Fig. 4.41) and ammonical nitrogen (24% - 4.47). This would consequently exclude the suitability of what has been qualified as the best treatment technology for these reuses, especially for aquaculture. This, as shown in past studies would be inappropriate, as these technologies have proved to be suitable for this kind of reuse implementations (Dos Santos *et al.*, 2009). This thus provides a matter of interest towards the validity of the data, urging an insight of it to be made.

It is essential to comprehend that this study has focused in comparing treatment technologies, composed of varying number of WWTPs, which will all have undergone different maintenance standards, differing in frequency and quality. Some might not be maintained appropriately or as well as others - due to the already mentioned reasons – consequently causing these data fluctuations, resulting in the great ranges between maximum and minimum values (as well as high CV values) and presenting unexpected results about the performance of the wastewater treatment technologies. Furthermore, the fact that there is a wide difference in the number of WWTPs included in the analysis per treatment technology, can make the results biased depending on the number of

measurements each one presented for individual parameters. This was perfectly demonstrated in the values provided by FAP+FP+MP for TTC for example, where only 1 WWTP analysed with only 2 measurement readings provided 100% compliance with the required limit for aquaculture and restricted irrigation, but only complied by 4% for unrestricted irrigation limits. This explains why in certain occasions, technologies such as ST, provided better results than technologies considered to be superior, such as FP+MP, which has greatly underperformed according to this study. Oppositely, overall value consistency from AP+FP+MP, ST+AF+Cl (except for N-NH<sub>3</sub>), UASB and UASB+Cl agreed with their expected performance levels as mentioned in the literature (Von Sperling & Oliveira, 2007, 2009).

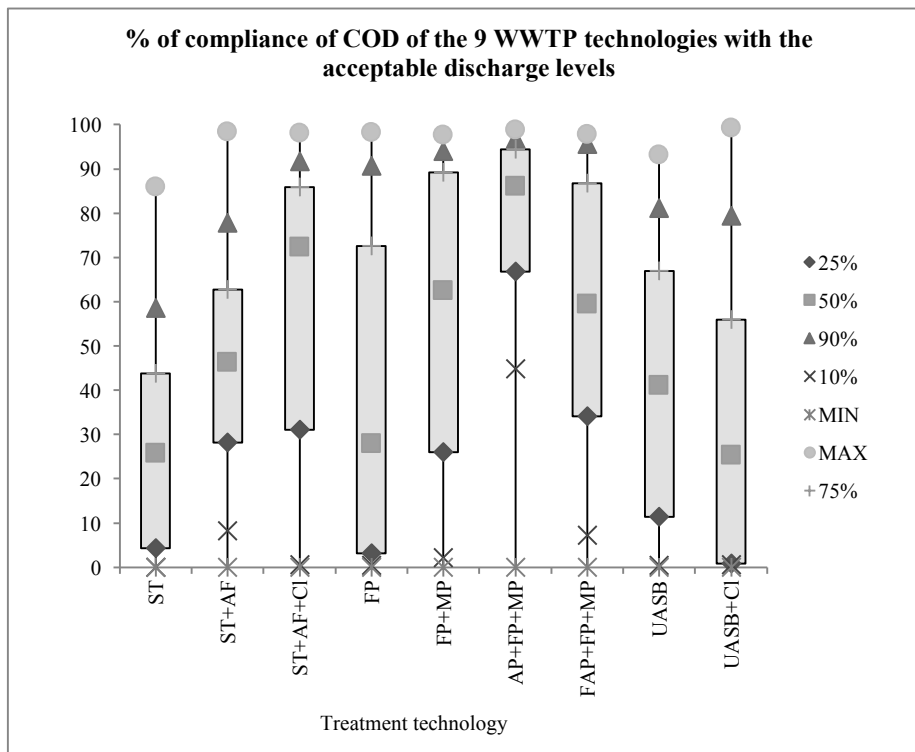
These points mentioned sustain the idea that further studies should be carried out aimed to analyse the efficiency and reliability of individual WWTPs within each wastewater treatment technology, which possess enough measurements for each parameter mentioned and have undergone measurements of more parameters, pertinent to each reuse practice. This would then determine the suitability of the effluent produced more specifically and allow a consideration of its implementation for the reuse practices mentioned.

**Table 4.6 Mean percentage of compliance with the discharge standard at an 80% reliability level**

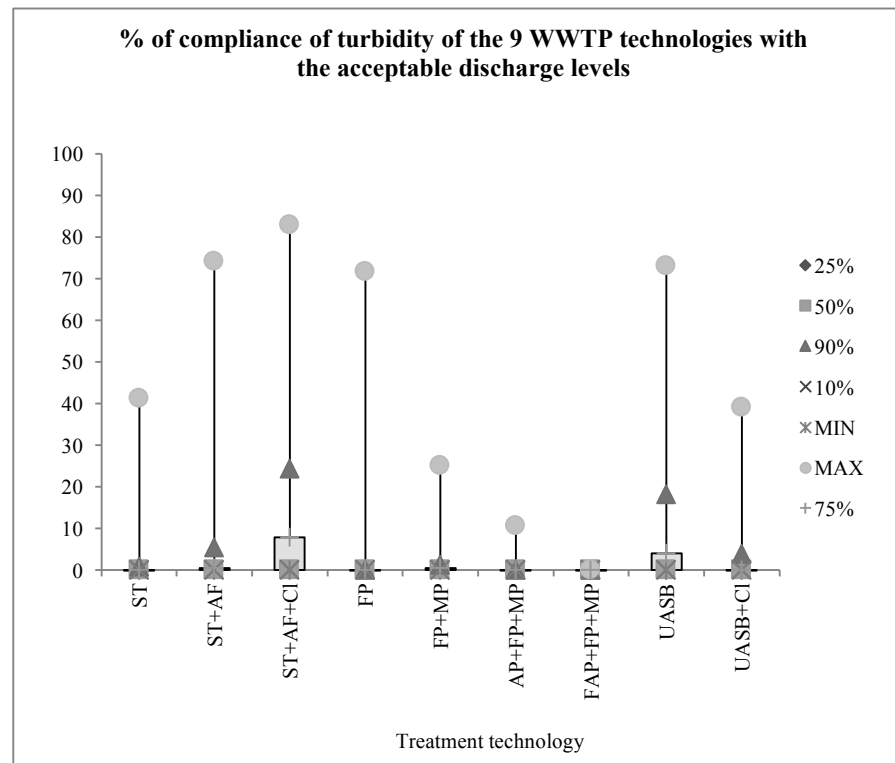
Technology	COD	EC - irrigation*	EC - aquaculture	Turbidity	BOD	TSS	N-NH3 - aquaculture	<i>E. coli</i> - aquaculture & restricted irrigation	<i>E. coli</i> - unrestricted irrigation	TTC - aquaculture & restricted irrigation	TTC - unrestricted irrigation
ST	27	100	2	1	-	20	7	98	73	98	66
ST + AF	45	98	13	2	-	51	12	92	86	92	80
ST + AF + CI	58	100	24	8	-	66	31	93	75	93	60
FP	39	100	22	1	29	12	4	24	22	42	26
FP + MP	56	100	29	1	-	36	5	63	42	63	0
AP + FP + MP	77	100	29	4	79	54	24	100	100	100	95
AFP + FP + MP	56	100	45	0	-	28	10	100	84	100	4
UASB	40	99	3	5	-	38	7	93	52	93	81
UASB + CI	32	98	9	1	-	30	10	96	78	96	57

\*Refers to both; unrestricted and restricted irrigation

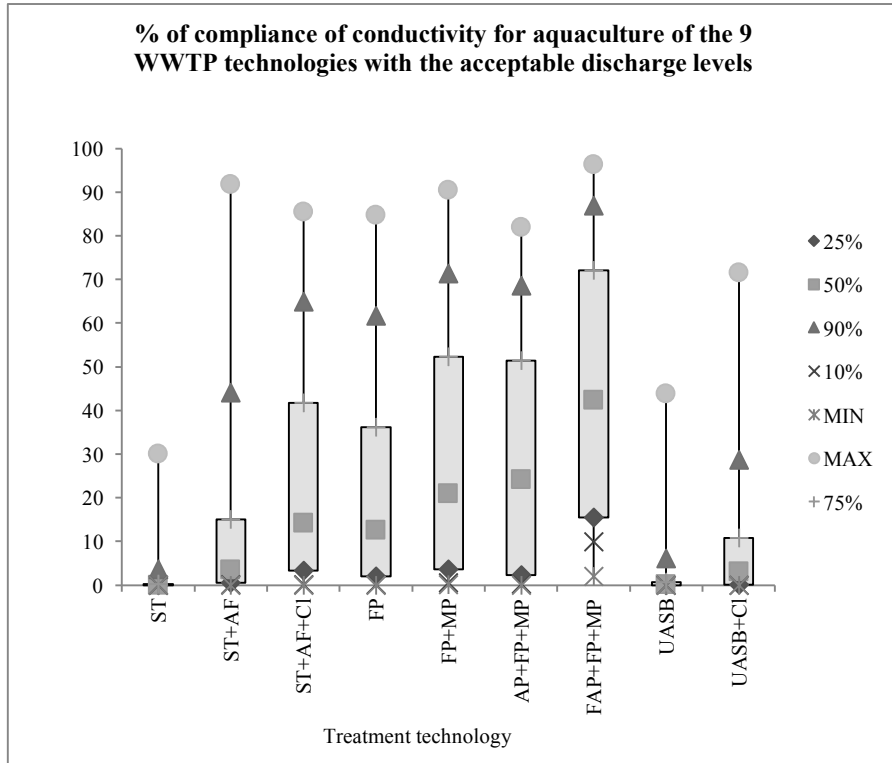




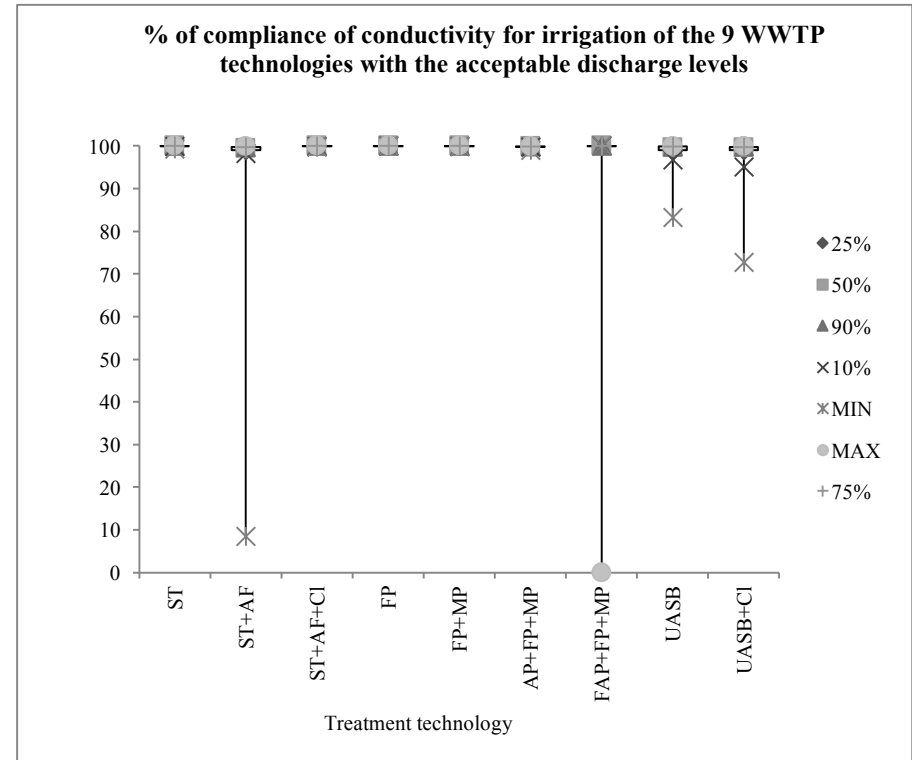
**Figure 4.38 COD percentage of compliance with the discharge standards at an 80% reliability level.**



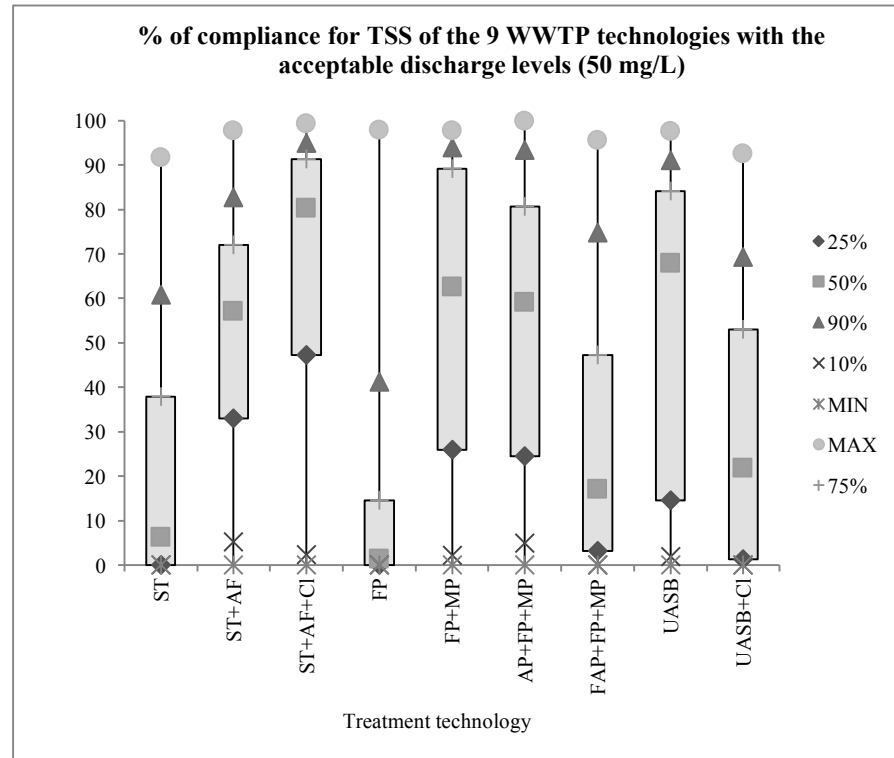
**Figure 4.39 Turbidity percentage of compliance with the discharge standards at an 80% reliability level.**



**Figure 4.40** Conductivity for aquaculture percentage of compliance with the discharge standards at an 80% reliability level.



**Figure 4.41** Conductivity for irrigation percentage of compliance with the discharge standards at an 80% reliability level.



**Figure 4.42 TSS percentage of compliance with the discharge standards at an 80% reliability level.**

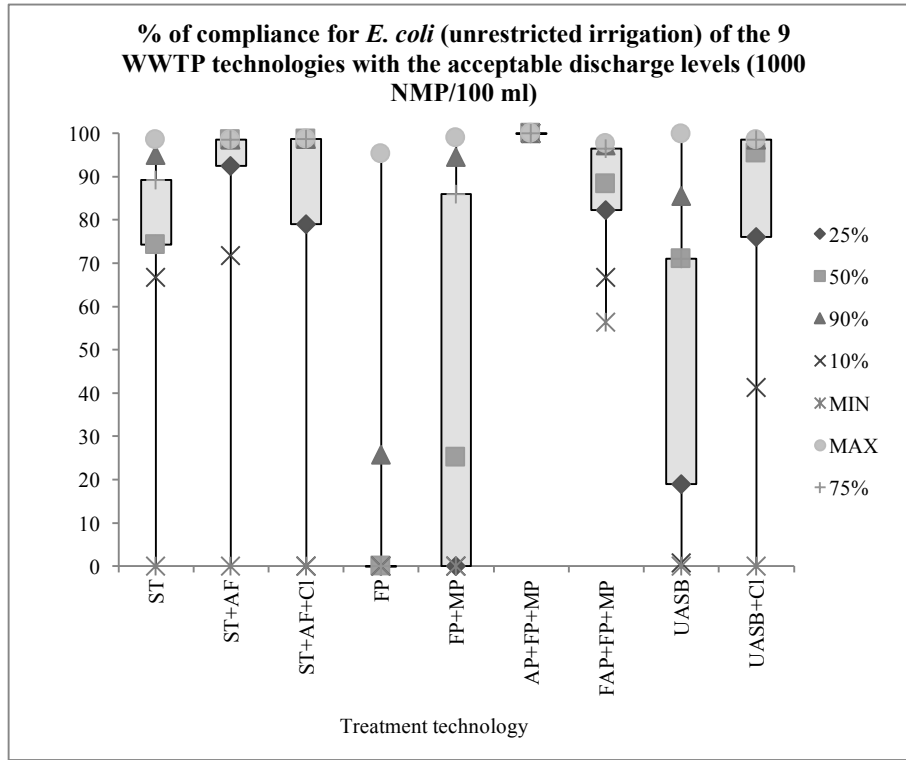


Figure 4.43 *E. coli* for unrestricted irrigation percentage of compliance with the discharge standards at an 80% reliability level.

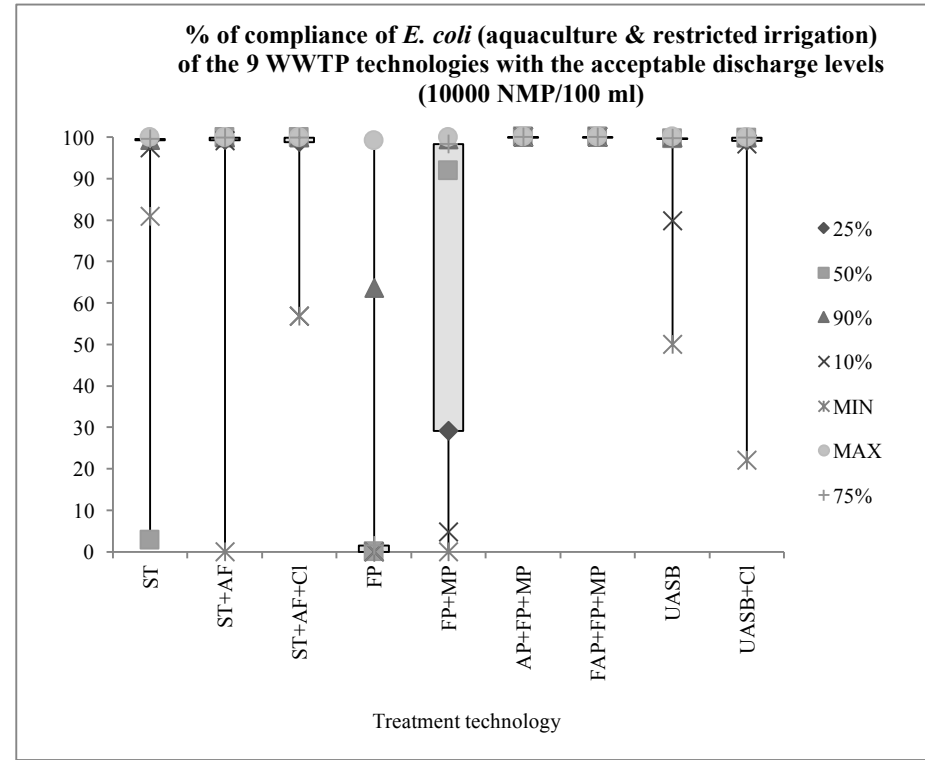


Figure 4.44 *E. coli* for aquaculture & restricted irrigation percentage of compliance with the discharge standards at an 80% reliability level.

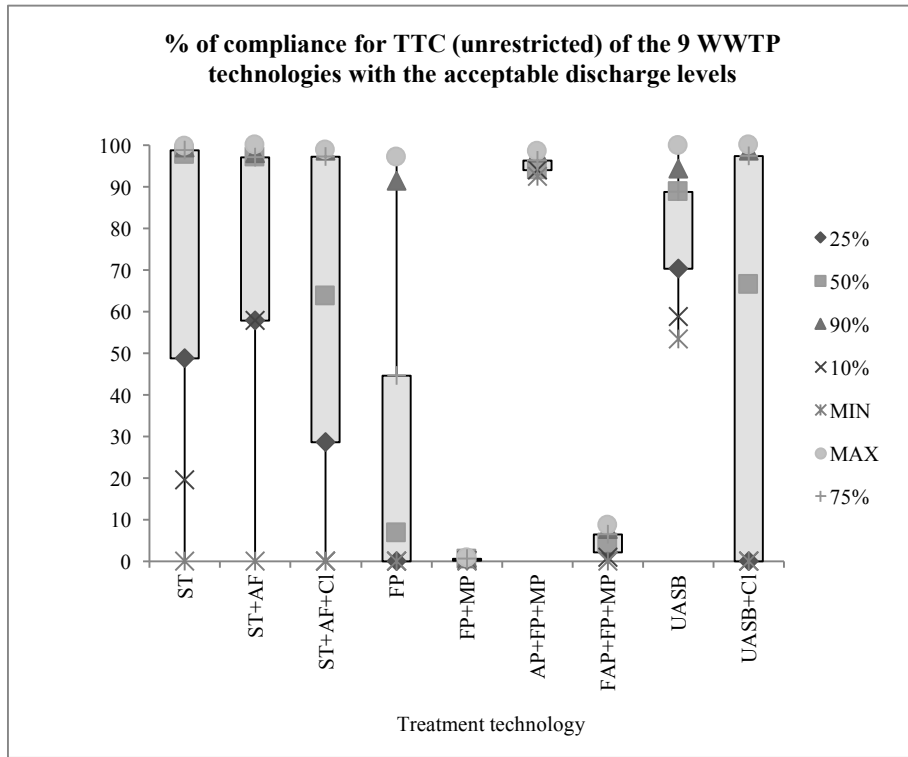


Figure 4.45 TTC for unrestricted irrigation percentage of compliance with the discharge standards at an 80% reliability level.

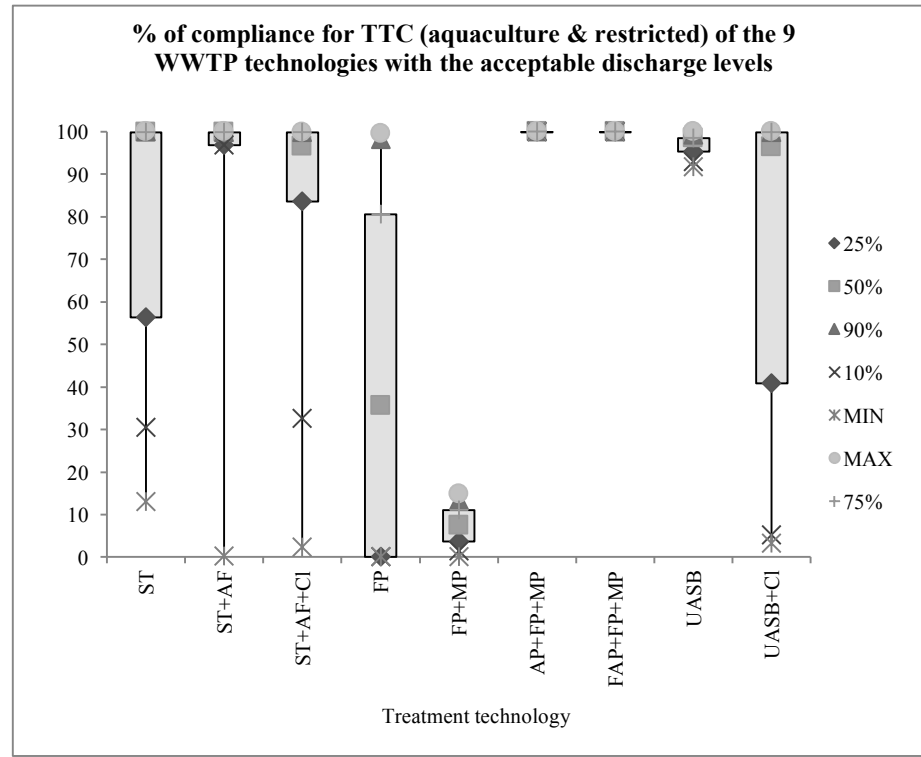
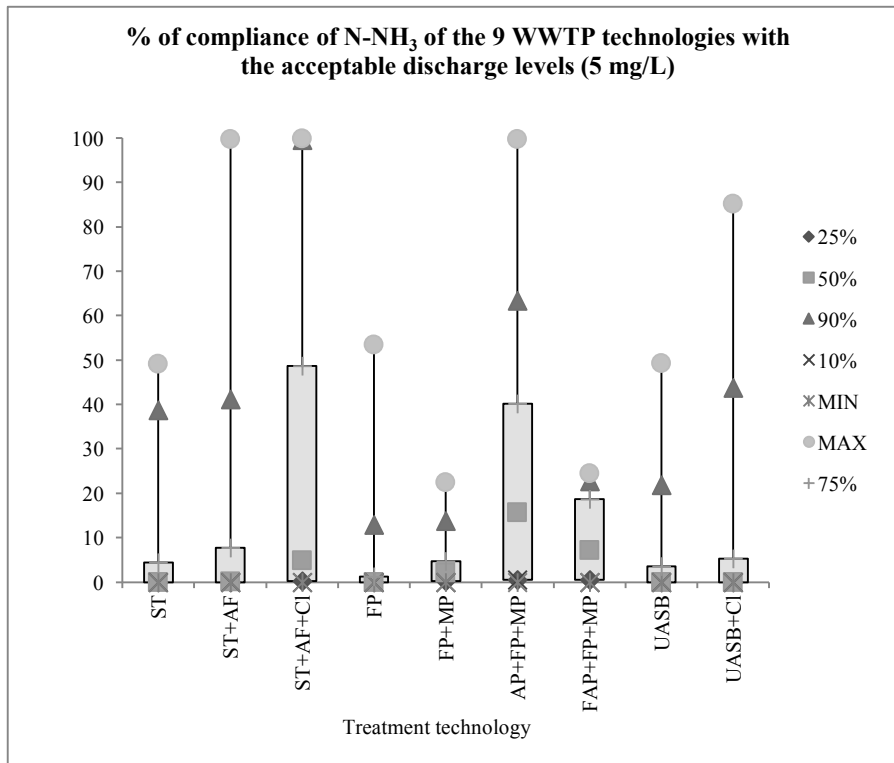
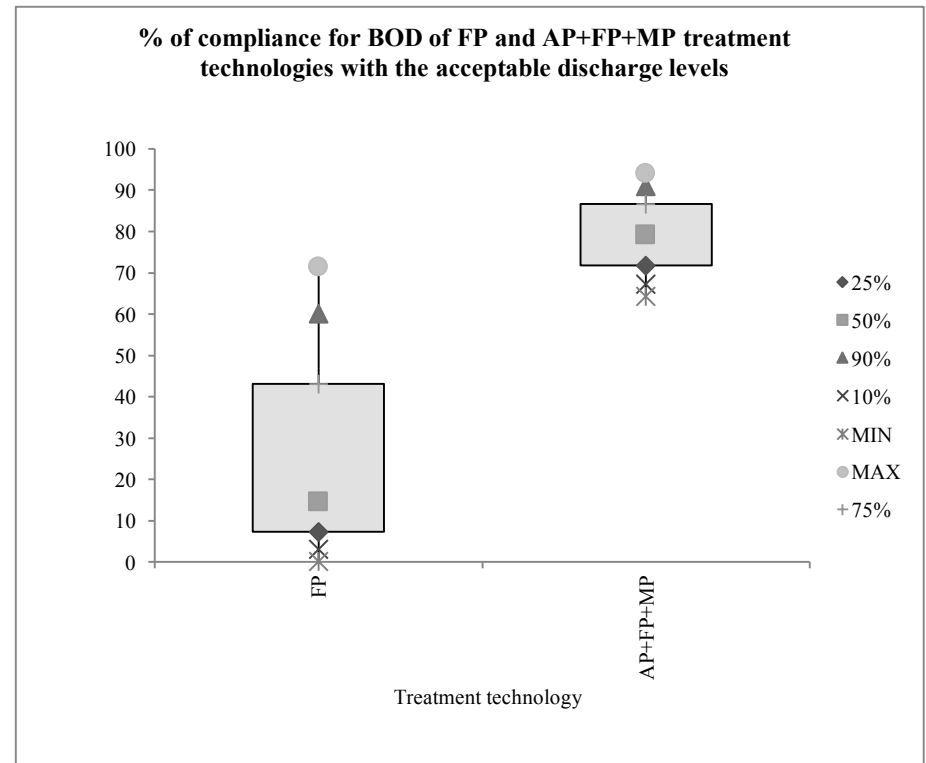


Figure 4.46 TTC for aquaculture & restricted irrigation percentage of compliance with the discharge standards at an 80% reliability level.



**Figure 4.47 N-NH<sub>3</sub> percentage of compliance with the discharge standards at an 80% reliability level.**



**Figure 4.48 BOD percentage of compliance with the discharge standards at an 80% reliability level for FP and AP+FP+MP treatment technologies.**

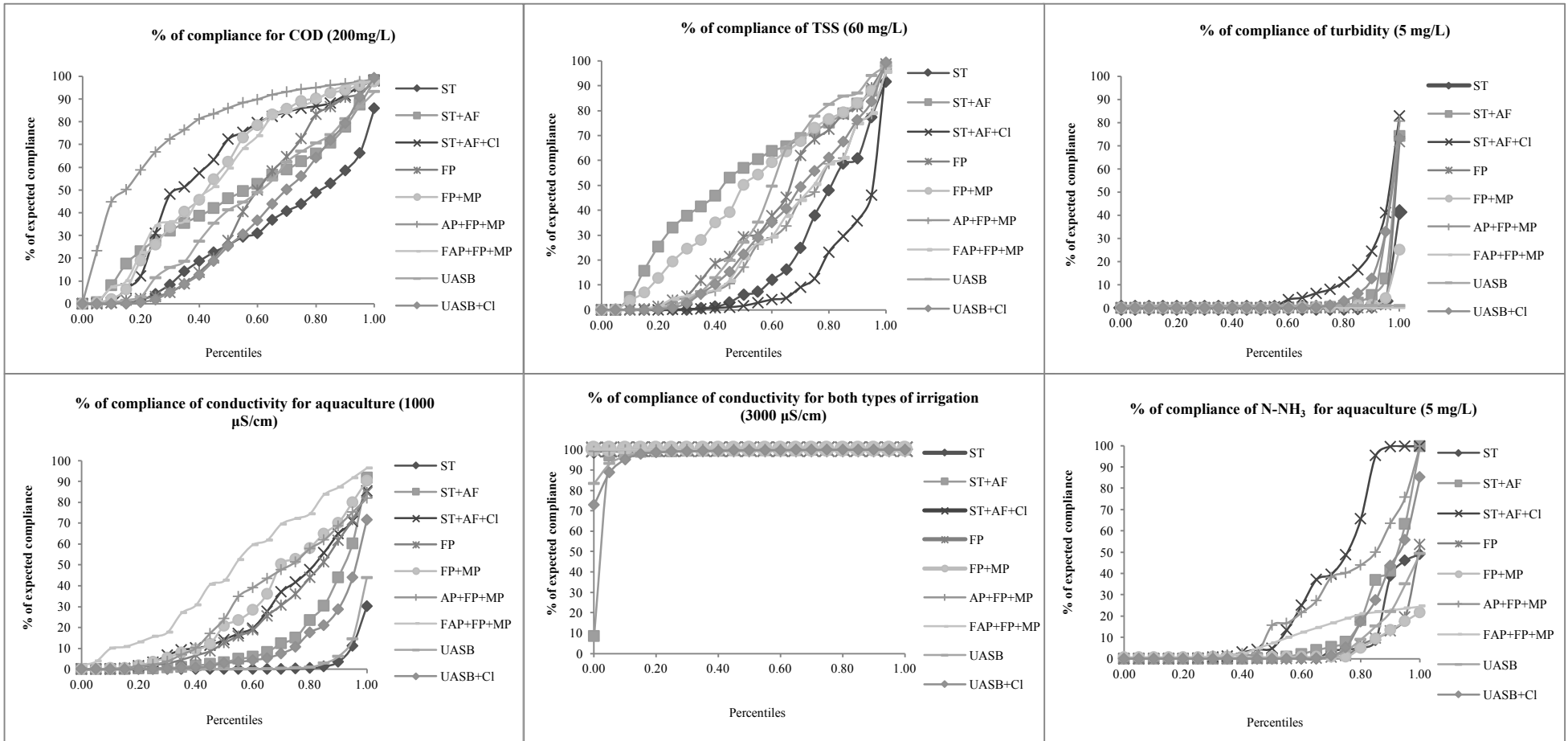


Figure 4.49 Percentile values for the expected compliance with the standards for COD, TSS, turbidity, conductivity values and N-NH<sub>3</sub>, at a reliability level of 80%

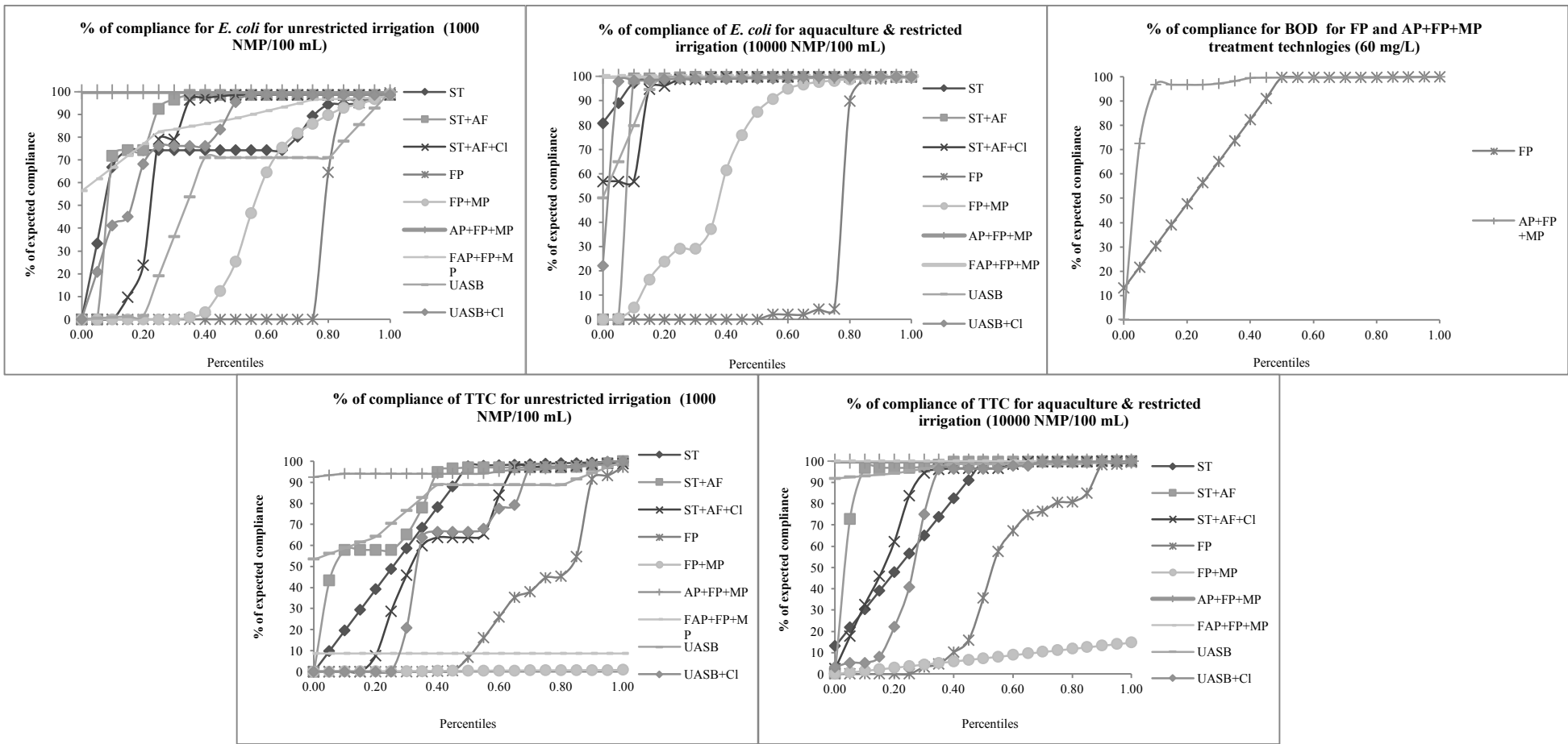


Figure 4.50 Percentile values for the expected compliance with the standards for *E. coli* values, BOD and TTC values, at a reliability level of 80%



## 5. CONCLUSION

The reliability analysis has provided overall, lower levels of compliance and performance than those presented by the efficiency analysis for each of the wastewater treatment technologies. The former, supports the idea that legal requirements or setting of parameter limits should consider statistical variations in accordance to probability, thus enabling the setting of more flexible parameter limits, instead of setting definite values. This approach is suitable for developing countries facing difficulties in this matter, as it ensures that the mentioned technologies have a greater chance in providing suitable effluents for reuse in aquaculture and irrigation - they have in other terms, a higher chance to comply with the requirements.

According to both analysis, the most appropriate technologies for reuse practices in aquaculture and irrigation would be the AP+FP+MP (WSP) system, followed by ST+AF+Cl, then by FAP+FP+MP. The performance of ST+AF places it as the next preferable system, followed by the UASB and the UASB+Cl treatment technologies. The WWTPs with the worst overall results were the FPs, followed by the FP+MP and the ST treatment technology. Nevertheless, the discrepancies in the data as a result of differences in measurement numbers and WWTPs included per treatment technologies, means that the values of FAP+FP+MP (only 1 WWTP analysed) may be biased, as well as those presented by ST for *E. coli* and TTC measurements, as effluent values were excessively low. The low performance recorded by FP+MP represented the lack of maintenance of the two WWTPs analysed. Furthermore, the great variances in parameter values presented by individual WWTPs within each treatment technology

have greatly affected the mean values of each treatment technology, limiting their suitability in parameters such as conductivity for aquaculture, turbidity and ammoniacal nitrogen. This suggests that in order to ensure the success of these reuse practices, the best maintained and designed WWTPs would have to be selected from the mentioned technologies.

In order to determine these mentioned preferable WWTPs, further research focusing on analysing the individual plants would have to be carried out. However, it is possible to state that the WWTPs most likely to succeed in their implementation of these reuse practices are those belonging to the AP+FP+MP (WSP) systems.

Still, in order to determine the most appropriate wastewater treatment technology for these reuse practices, other factors should be also considered in addition to their effluents composition and quality. These factors fall within the category of socio-economic characteristics of the regions were being applied, considering the costs of construction and maintenance of the WWTPs, the climate of the region, the population, within many other factors which have not been covered as they go beyond the scope of this project.

## 6. FUTURE WORK

As mentioned in the results & discussion (section 4) and the conclusion (section 5), the limitations of the data were of a negative influence in determining the suitability of the wastewater treatment technologies - referring to the number of WWTPs available for the representation of systems such as FP+MP and FAP+FP+MP on a general basis, and for ST in the case of TTC. This also influenced the selection of the parameters used to determine the suitability of the effluents for reuse in aquaculture and irrigation; these were selected on the basis of availability, thus excluding important parameters which would be of importance for both practices. A clear example of this was BOD – parameter which was only measured for FP and AP+FP+MP.

The project would be best followed out analysing in greater detail the suitability of the parameter limits chosen, as some of the values applied belonged to surface water discharge legislation levels. This came as a result of lack of data in the literature concerning the maximum permissible values for these parameters. This thus suggests that limits were in some cases too low even if they agreed with the literature provided, as in the case of ammoniacal nitrogen and COD (discharge to surface waters levels applied). In other cases they might have been too high, such as the level chosen for conductivity for irrigation practices. This being said, it should be noted that all values applied were chosen from the literature read, which in this mentioned cases varied significantly concerning their values set.

As previously suggested, further research should be conducted firstly to the individual WWTPs included in this analysis of treatment technologies. The research carried out could also focus individually in each of the reuse practices mentioned, referring to aquaculture and irrigation. These factors would make the study more succinct and allow a more reliable

analysis of the treatment technologies suitability towards producing quality effluents for each reuse practice to be carried out, once a more complete set of parameter values has been measured and compiled from each WWTP.

The results obtained in this study serve as a source which points out that AP+FP+MPs (WSP systems) are the most suitable of the treatment technologies mentioned, in providing an effluent applicable for aquaculture and irrigation practices, but taking into consideration that some parameter limits were exceeded. They also represent some of the limiting factors - typical of developing countries - in their treatment of wastewaters, concerning the maintenance of their WWTPs. These findings could potentially serve as a reference for other developing countries – especially those in South America, which share the same climatic and socio-economic characteristics – about the feasibility of these technologies in providing reusable waters for the mentioned practices, which in the years to come will be of crucial importance due to the effects of climate change and the expected water shortages that this will bring.

## 7. SUMMARY

- Two analyses: Removal efficiency and reliability, of the 9 wastewater treatment technologies from Fortaleza - Brazil determined their and performances, including the variations between both analyses.
- Efficiency removal follows a more stringent analysis of WWTPs - referring to their performance if they were to keep their same operational conditions against the maximum allowable parameter limits, as compared to reliability - which considers the tangible probability of these exceeding the finite parameter limits set, setting a reliability level to meet (80% reliability level in this case) and thus allows a more realistic concept in the analysis of treatment technologies for developing countries.
- Affluent values and effluent values were in general above the technical literature (Arceivala, 1981; Qasim, 1985; Mara, 2003; Metcalf & Eddy, 2003; Mota *et al.*, 2007; WEF & ASCE, 1992; Von Sperling & Chernicharo, 2005), but were lower (of higher quality) than those recorded in southern Brazil by Von Sperling & Oliveira (2007, 2009).
- Results showed the great variability between individual WWTPs, and this was related to their maintenance levels and differences in affluent compositions (Oliveira & Von Sperling, 2007). Consequently CV values for the reliability analysis were especially high for ST+AF, ST+AF+Cl and AP+FP+MP for N-NH<sub>3</sub>.
- Lack of measurements influenced the final results and made some results unreliable and unrealistic due to potential bias. This was the case for BOD were only FP and AP+FP+MP presented measurements; also applying to

ST values for *E. coli* and TTC; and FAP+FP+MP for TTC (only 1 WWTP with 3 measurements).

- Extremely high COR values such as those from ST+AF+Cl and AP+FP+MP for N-NH<sub>3</sub>, showed the influence of high data differences in the behaviour of the lognormal distribution and the relationship between high and low CV values at the same reliability level and the arithmetic mean. The latter could be equal even when situations were highly differentiating, influencing the final value as a result of a few extreme values. This led to the excessive ideal mean design concentrations to meet the N-NH<sub>3</sub> standard at an 80% reliability level - making it an unrealistic result.
- Both analyses results determined that AP+FP+MP, followed by ST+AF+Cl and FAP+FP+MP were the treatment systems providing the best effluents for these reuse practices. Followed by UASB, UASB+Cl, ST+AF, ST, FP+MP and finally FP – presenting the lowest quality effluent.
- Research should be continued, focusing in analysing the individual WWTPs possessing the correct type and number of parameter measurements in order to determine the suitability of the treatment technologies for these reuses in a more succinct and reliable way.

## 8. REFERENCES

- DOS SANTOS, A. B. 2009. Outliers. (ALDERSON. M., Interviewer)
- ARCEIVALA, S. J. 1981. *Wastewater Treatment and Disposal. Engineering and Ecology in Pollution Control*. New York: Marcel Dekker.
- BASTPS, R. K. 2003a. Introdução. In R. K. Bastos, *Utilização de esgotos tratados em fertirrigação, hidroponia e piscicultura: PROSAB*. ABES. Rio de Janeiro. 1-22 pp.
- Bastos, R. K. (2003b). Utilização de Esgotos Sanitários em Piscicultura. In R. K. Bastos, *Utilização de esgotos tratados em fertirrigação, hidroponia e piscicultura* (pp. 193-223). Rio de Janeiro: ABES.
- Bastos, R. K. (2003). *Utilização de esgotos tratados em fertirrigação, hidroponia e piscicultura: PROSAB*.
- Ceará, G. d. (2002, December 23). *Portarias*. Retrieved June 25, 2009, from Semace:  
[http://www.semace.ce.gov.br/biblioteca/legislacao/conteudo\\_legislacao.asp?cd=95](http://www.semace.ce.gov.br/biblioteca/legislacao/conteudo_legislacao.asp?cd=95)
- Dean, R. F. (1976a). Estimating the realibility of advanced waste treatment. Part 1. *Water Sewage Works* , 87-89.
- Dean, R. F. (1976b). Estimating the reliability of advanced waste treatment. Part 2. *Water Swage Works* , 87-89.
- Dos Santos, A. M. (2009). Fruits produced with wastewater treated in stabilization ponds systems: evaluation in a quality prospective. Fortaleza, Brazil.
- Dos Santos, M. L. (2006). *Tratamento e utilização de esgotos sanitários*. Rio de Janeiro: ABES.

Dos Santos, M. L. (2006). *Tratamento e utilização de esgotos sanitários*. . Rio de Janeiro: ABES.

Eddy, M. &. (2003). *Wastewater Engineering: Treatment and Reuse*. New York: Metcalf & Eddy Inc.

Feenstra, S. H. (2000). Health risks of irrigation with untreated urban wastewater in the Southern Punjab. *IWMI Pakistan Report* .

Feigin, A. R. (1991). Irrigation with Treated Sewage Effluent. *Management for Environmental Protection* .

IWMI. (2000a). Urban wastewater reuse for crop production in the water-short Guanajuato River Basin, Mexico. *IWMI Research Report 41* .

Jhonstone, D. W. (1994). Standards, costs and benefits: an international perspective. *IWEM* , 450-458.

Johnston, D. W. (1996). Institutional developments, standards and riques quality: A UK history and some lessons for industrialising countries. *Wat. Sci. Tech.* , 211-222.

Lenntech. (2008, September 12). *Disinfectants: Chlorine*. Retrieved August 25, 2009, from Lenntech: <http://www.lenntech.com/water-disinfection/disinfectants-chlorine.htm#ixzz0QFO5GIJ9>

Ludwig, S. (1998). DEWATS: Decentralised wastewater treatment in developing countries. *BORDA* .

Mara, D. (2003). *Domestic Wastewater Treatment in Developing Countries*. London: Earthscan.

Mota S., D. d. (2007). *Reúso de Águas em Irrigação e Piscicultura*. Fortaleza.

Mota, S. D. (2009). Water and fish quality during the reuse in aquaculture of sewage treated in stabilization ponds: experience of Ceará state, Brazil . *8th IWA Specialist Group Conference on Waste Stabilization Ponds*. Belo Horizonte: IWA.



Nascimento L.V., v. S. (1999). Comparação entre os limites de detecção dos métodos analíticos e os padrões de qualidade das águas e de lançamento de efluentes da Resolução CONAMA 20/86. *Congresso Brasileiro de Engenharia Sanitária e Ambiental*, (pp. 2407 -2412). Rio de Janeiro.

Nascimento L.V., v. S. (1998). Comparação entre padrões de qualidade das águas e critérios para proteção da vida aquática e da saúde humana e animal. *Anais, XXVI Congreso Interamericano de Ingeniería Sanitaria y Ambiental*. Lima: AIDIS.

Oliveira S. C., V. S. (2007). Reliability analysis of wastewater treatment plants. *IWA Water Research* .

Oliveira, S. V. (2006). Wastewater characteristics in a developing country, based on a large survey (166 treatment plants). *Proceedings of the fifth IWA world Water Congress*. China: IWA.

Parr, J. H. (1996). Selection for wastewater treatment processes for newly industrialising countries. *Environmental waste management: A European Perspective* .

Quasim, S. R. (1985). *Wastewater Treatment Plants: Planning Design and Operation*. New York: John Wiley and Sons.

Shuval, H. A. (1986). Wastewater irrigation in developing countries: Health effects and technical solutions. *World Bank Technical Paper No. 51* .

Silva, F. J. (2001). Qualidade da água na Piscicultura. *Boletim de Extensão da UFLA, Lavras, MG, n. 94* .

Tilley E., L. C. (2008). *Compendium of Sanitation Systems and Technologies*. Dübendorf: Eawag: The Swiss Federal Institute of Aquatic Science and Technology.

UNEP. (2004). *Guidelines on Municipal Wastewater Management*.

Van Haandel A.C., L. G. (1994). *Anaerobic Sewage Treatment: A Practical Guide for Regions with a Hot Climate*. Chichester: John Wiley & Sons.

Von Sperling M. V., C. C. (2005). Biological Wastewater Treatment in Warm Climate Regions. *International Water Association* (p. 1496). London: IWA.

Von Sperling, M. (1998). Análise dos padrões brasileiros de qualidade de corpos d'água e de lançamento de efluentes líquidos. *Revista Brasileira de Recursos Hídricos* , 111-132.

Von Sperling, M. C. (2000). A comparison between wastewater treatment processes in terms of compliance with effluent quality standards. *XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental* (pp. 1-12). ABES.

Von Sperling, M. (2005). *Princípios do tratamento biológico de águas residuárias - Volume 1: Introdução à qualidade das águas e ao tratamento de esgotos*. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental - UFMG.

WCED. (1987). *Our common future*. Oxford: Oxford University Press.

WEF, & ASCE. (1991). Design of municipal wastewater treatment plants. *Water Environment Federation/American Society of Civil Engineers* , 1592.

**Require adding:**

Alabaster, J. S., Lloyd, R. (1982) Water Quality Criteria for Freshwater fish. 2<sup>nd</sup> Ed. London: FAO. pp. 361.

Araujo, L. F. P. (2000) Reúso com lagoas de Estabilização: potencialidade no Ceará . Fortaleza – CE: SEMACE. pp. 132.

Kellner, E., Pires, E. C., (1998) Lagoas de Estabilização: Projeto e Operacao. Rio de Janeiro: ABES. pp 244.

Mara, D. D., Pearson, H. (1986) *Biotechnology*, H. J. Rehm and G. Reed (ed.), 8.

Paganini, W. S. (1997) *Disposição de Esgotos no Solo (Escoamento à superfície)*. 2a Edição. São Paulo. AESABESP. 1997. pp 232

**CEARÁ (2009) Secretaria de Desenvolvimento Rural. Rumo ao desenvolvimento rural do Ceará – 1999/2002. Fortaleza, 1999. 97p.**

**Mayorga, D., Oliveira Mayorga, M. I., Melo C. S., Folhes, M. T. (2001) Public policies and the vulnerability of rural man in the State of Ceará, Brazil**

Ott, W. R. (1995) *Environmental Statistics and Data Analysis*. Lewis Publishers, New York, pp. 313

**Already added:**

Silva, F. J. A., Ferreira, M., W., Logato, P.V.R Q (2001) (Silva, 2001). Available on: <<http://www.editora.ufla.br>>

Von Sperling, M. V & Chernichero, C. A. L. 2005 *Biological Wastewater Treatment in Warm Climate Regions*, (1). IWA Publishing, London, UK, pp. 1496

WEF & ASCE 1992 *Design of municipal wastewater treatment plants*. Water Environment Federation/American Society of Civil Engineers, pp. 1592.

School handbook:

<https://ce-gs14.ncl.ac.uk/CeG.Internal/teaching/handbooks/2009-2010/PGT%20Environmental%20engineering.pdf>