TREATMENT OF AROWANA AQUACULTURE WASTEWATER USING SAND, ACTIVATED CARBON AND ZEOLITE IN A HORIZONTAL PROTOTYPE MODEL

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by

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LIST OF ABBREVIATIONS

AC	Activated carbon
Al_2O_3	Aluminum oxide
Al^{3+}	Aluminium
ANOVA	Analysis of variance
AOB	Ammonia oxidizing bacteria
APHA	American Public Health Association
BET	Brunauer–Emmett–Teller
BOD	Biochemical oxygen demand
C	Carbon
CaO	Calcium oxide
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
COD	Chemical oxygen demand
CV	Coefficient of variation
DO	Dissolved oxygen
DOE	Department of Environment
DOF	Department of Fisheries
EPA	Environmental Protection Act
Fe(II)	Iron
Fe_2O_3	Iron oxide
FTIR	Fourier Transform Infrared
HCL	Hydrochloric acid

HLR	Hydraulic loading rate
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
IUCN	International Union for Conservation of Nature and Natural Resources
K_2O	Potassium oxide
KBr	Potassium bromide
MgO	Magnesium oxide
Na_2O	Sodium oxide
NaOH	Sodium hydroxide
NAP3	Third National Agricultural Policy
NH_3	Ammonia molecule
NH_3-N	Ammoniacal nitrogen
NH_4^+	Ammonium ion
NH_4Cl	Ammonium chloride
NO-2	Nitrite
NO-3	Nitrate
NOB	Nitrite oxidizing bacteria
P	Phosphorus
PO_4	Phosphates
R^2	Coefficient of determination
RAS	Recirculating aquaculture systems
SD	Standard deviation
SEM	Scanning Electron Microscopy
Si^{4+}	Silicon ion
SiO_2	Silicon dioxide

SO_3	Sulphur trioxide
TSS	Total suspended solids
TAN	Total ammonia nitrogen
TiO_2	Titanium dioxide
TN	Total nitrogen
TP	Total phosphorus
XRF	X-Ray Fluorescence

RAWATAN AIR SISA AKUAKULTUR AROWANA MENGGUNAKAN PASIR, KARBON TERAKTIF DAN ZEOLIT DALAM MODEL PROTOTAIP MENDATAR

ABSTRAK

Industri akuakultur Arowana telah berkembang di Malaysia sejak tahun 2008 dan pengeluaran ikan hiasan ini telah menyumbang ke arah pertumbuhan ekonomi negara. Spesies Arowana yang paling berharga ialah Arowana Emas kerana nilai tara hakikinya yang hanya boleh membiak di Bukit Merah. Ini menimbulkan kebimbangan terhadap kekurangan air akibat penggunaan konjunktif antara industri akuakultur Arowana dengan industri pertanian padi di Empangan Bukit Merah. Penggunaan dan pengitaran semula air kumbahan dari kolam Arowana dapat mengurangkan penggunaan sumber air dari Empangan Bukit Merah. Oleh itu, model prototaip mendatar yang menggunakan pasir, karbon teraktif dan zeolit untuk merawat ammonia nitrogen (NH_3-N), pepejal terampai (TSS), jumlah fosforus (TP) dan ferum (Fe (II)) telah dihasilkan. Satu set sasaran penyingkiran telah ditentukan untuk setiap bahan pencemar melalui pemantauan kualiti air di punca air dan air kumbahan kolam Arowana. Dikenalpasti bahawa kualiti air kumbahan perlu mencapai sasaran penyingkiran bagi NH_3-N, TSS, Fe (II) dan TP masing-masing sebanyak 62%, 73%, 35% dan 33% untuk mendapatkan kualiti air yang lebih baik supaya boleh dijadikan sumber air. Kajian kelompok dilakukan untuk menentukan prestasi setiap penjerap. Proses penjerapan dalam zeolit merawat NH_3-N dengan peratusan sebanyak 86%. Penjerapan karbon teraktif dapat merawat Fe (II) dengan penyingkiran 70% dan penjerapan pasir merawat TP dengan peratusan sebanyak 39%. Seterusnya, kedalaman lapisan media yang optimum untuk setiap media ditentukan dengan menggunakan reka bentuk Campuran Simpleks Kekisi oleh perisian ‘Design Expert’. Kedalaman lapisan media optimum yang diperolehi untuk pasir, karbon teraktif dan zeolit adalah dalam nisbah 5 sm: 5 sm: 20 sm dan telah disahkan dengan menggunakan kajian turus dengan kadar aliran air 30 ml/min. Kedalaman lapisan media yang optimum kemudiannya digunakan di dalam model prototaip mendatar. Kajian model prototaip mendatar dijalankan selama 60 hari (1440 jam). Peratusan penyingkiran yang disasarkan dengan masa diperolehi mengikut susunan berikut TSS<TP<Fe (II)<NH_3-N dengan masa prestasi lajur masing- masing 144 jam, 480 jam, 920 jam dan 1200 jam. Keputusan ini menunjukkan gabungan dan keupayaan yang baik oleh pasir, karbon teraktif dan zeolit dalam merawat air kumbahan akuakultur Arowana khususnya NH_3-N, TSS, Fe (II) dan TP.

TREATMENT OF AROWANA AQUACULTURE WASTEWATER USING SAND, ACTIVATED CARBON AND ZEOLITE IN A HORIZONTAL PROTOTYPE MODEL

ABSTRACT

Arowana aquaculture industry have been blooming in Malaysia since 2008 and the production of the ornamental fish has contributed significantly towards the country economic growth. The most valuable Arowana species is the Golden Arowana which due to it intrinsic criteria can only breed successfully at Bukit Merah. This rises a concern towards water scarcity due to conjunctive uses between Arowana aquaculture industries with the Kerian rice growing area at Bukit Merah reservoir. Reusing and recycling the water from the Arowana Farm effluent could reduce the usage of water sources from the Bukit Merah reservoir. Therefore, a horizontal prototype model was established by incorporating sand, activated carbon (AC) and zeolite in treating ammoniacal nitrogen (NH_3-N), total suspended solids (TSS), total phosphorus (TP) and iron (Fe (II)). A set of target removal was established for each of the pollutant through monitoring of water quality at the water intake and effluent of Arowana Farm. It was identified that the effluent need to achieved target removal for NH_3-N, TSS, Fe (II) and TP of 62%, 73%, 35% and 33% respectively in order to have a better water quality as the water source intake. Batch study was performed to determine the performance of each adsorbent. The adsorption process in zeolite removed NH_3-N with percentage of 86%. Adsorption of AC removed Fe (II) with 70% removal and adsorption of sand removed TP with percentage removal of 39%. Next, the optimum bed depth for each of the media was determined using Mixture Simplex Lattice design by Design Expert software. The optimum bed depth obtained for sand, AC and zeolite was in a ratio of 5cm: 5cm: 20cm respectively and was validated by employing column study experiment using an up flow flow-rate of 30ml/min. The optimum bed depth was then applied inside a horizontal prototype model. Horizontal prototype model experiment was conducted for 60 days (1440 hours). The targeted removal percentage with respect to the breakthrough time was obtained following the following sequence TSS<TP<Fe (II)<NH_3-N with breakthrough time of 144 hours, 480 hours, 920 hours and 1200 hours respectively. These results show a good cooperation and capabilities among sand, AC and zeolite in treating Arowana aquaculture wastewater specifically for the removal of NH_3-N, TSS, Fe (II) and TP.

CHAPTER ONE

INTRODUCTION

1.1 Background Study

Aquaculture is currently generating an important booster for the economic growth of Malaysia and eventually becoming the main pillar of the nation's economy. It is estimated that the annual demand for fish will increase from 1.7 million tons in 2011 and further to 1.93 million tons by 2020 (Yusoff, 2015).

Ornamental aquaculture trade had been recognized as one of the major pathways of introduction of nonnative fishes into new regions (Mendoza et al., 2015). This happen because most of the native ornamental fish produced are usually imported for the purpose of commercialization. The increasing popularity of the aquarium hobby is fuelling the growth of this ornamental fish industry (Moorhead, 2015). As a result, there are 259 of ornamental fish exporters in Malaysia (Ng, 2016).

The Asian Arowana (*Scleropages formosus*) is one of the ornamental fish species that has exist among the earliest during the Carboniferous period about 340 million years ago. Their existence continue until today (Sun et al., 2015), however their population were declining rapidly since 1970s due to the extensive hunting in their native habitat. This trigger an international agreement among the world governments to classified Asian Arowana as one of the most highly endangered fish species that had threatened with extinction in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) under Appendix 1 since 1980 (Goh and Chua, 2000).

Basically, there are three main varieties colour of this species which are Golden Arowana (Figure 1.1), Red Arowana (Figure 1.2) and Green Arowana (Figure 1.3). Among those varieties, Golden Arowana possessed the best quality which explained the higher price of this variety compared to the other two. Further, this variety specifically inhabit in Bukit Merah Lake in the state of Perak, Malaysia (Suleiman, 2003).

Figure 1.1 Golden Arowana (Source: Google Image, 2018(a))

Figure 1.2 Red Arowana (Source: Google Image, 2018(b))

Figure 1.3 Green Arowana (Source: Google Image, 2018(c))

As aquacultures industry growing, it produces wastewater where the major components were nitrogenous elements comprise of ammoniacal nitrogen (NH_3-N), nitrite, nitrate, total phosphorus (TP) and organic carbon (Nasir et al., 2015). The nitrogenous elements were mainly from residual food, metabolites of aquatic products, and the fishpond sediments (Liu et al., 2016). Those components if accumulate and present in high concentrations could cause detrimental effect to the environment and the inhabitant nearby. However, Arowana aquaculture similar to other aquaculture wastewater produces a low concentration of pollutants if compare to other industry that involving the discharge of wastewater. Table 1.1 shows the different between the concentration of ammoniacal nitrogen (NH_3-N), total phosphorus (TP) and total suspended solids (TSS) with other industry. Nevertheless, this aquaculture industry still produces a large volume of wastewater due to the nature of the fish that needed continuous water supply throughout the year (Zhang et al., 2016).

Table 1.1 Concentration of NH_3-N, TP and TSS at different industry

Parameter	**Aquaculture**	**Dairy Farm**	**Olive mill wastewater**
NH_3-N (mg/L)	0.45 -0.91	62.30	3.45
TP (mg/L)	0.42- 0.76	6.80	420
TSS (mg/L)	63-289	457.4	6100

Reference: Nasir et al., 2015; Gao et al., 2016; Jegatheesan et al., 2007; Corrales et al., 2015; Healy et al., 2007; Achak et al., 2009.

The discharge of this large volume of untreated wastewater in clean water body had caused eutrophication which deteriorate the natural ecosystem (Nasir et al., 2015). It also poses a threat to downstream waters and for irrigation purpose. Currently at Bukit Merah, the wastewater from the Arowana ponds were directly discharged to the nearest river which is Sungai Kurau without any further treatment. Since the concentration of the discharge from Arowana farm are mainly in low concentration, there are a high probability that the discharge can be reuse and recycle back into the Arowana farm.

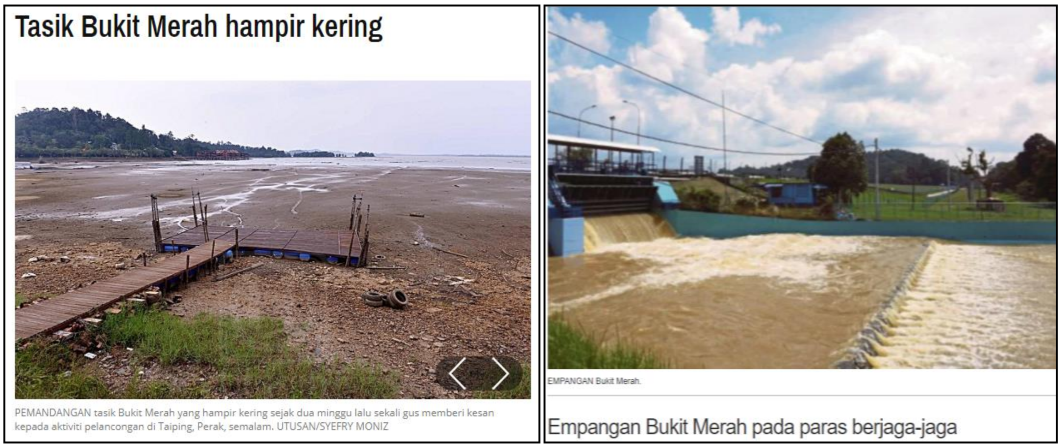
Currently, the present recirculating aquaculture systems are mainly based on biological and chemical method (Chen et al., 2015). Biological method was found to be the most practical method in allowing an eco-friendly water reuse and recycle (Kuo et al., 2016). However, it suffer some drawbacks, such as complex biological denitrification process, frequent backwashing of the biofilter and needed complicated procedures and intensive system supervision by skilled personnel under good management (Yanong, 2015). As for chemical method, for instance chemical precipitation to remove phosphorus (Ebeling et al., 2003), it produce chemical waste and toxic compound as by-product which are obviously not environmental friendly and produce pollution to the environment (Gao et al., 2016). It also a cost incurring method and further these practices are not suitable for farming or aquacultural management (Nasir et al., 2015).

With regard to that, filtration was found to be the simplest methods in removing contaminants in water (Nkwonta, 2010). Filtering technology is a physical process to treat wastewater by removing the contaminant involving low cost treatment. It was applied for a wide range application including domestic and industrial (Patil et al., 2012). In fish farming, filtering plays and important part in order to remove the accumulate faeces and unconsumed food that remain inside the water bodies. These remainder if not remove in time could generate bacteria which causes infections to the fish and subsequently lead to mortality. Basically the most use mechanical filters in aquaculture are micro-sieves filter and granular material filter. Micro-sieves filter was however found to be facing problem with clogging and causes slow filtration process (Andrei et al., 2016). As for granular material filter, the performance were dependent on the particle and pore size of the material. In view of that, this study emphasized on treating the Arowana aquaculture wastewater by using sand, activated carbon (AC) and zeolite as the material in filtering process.

1.2 Problem Statement

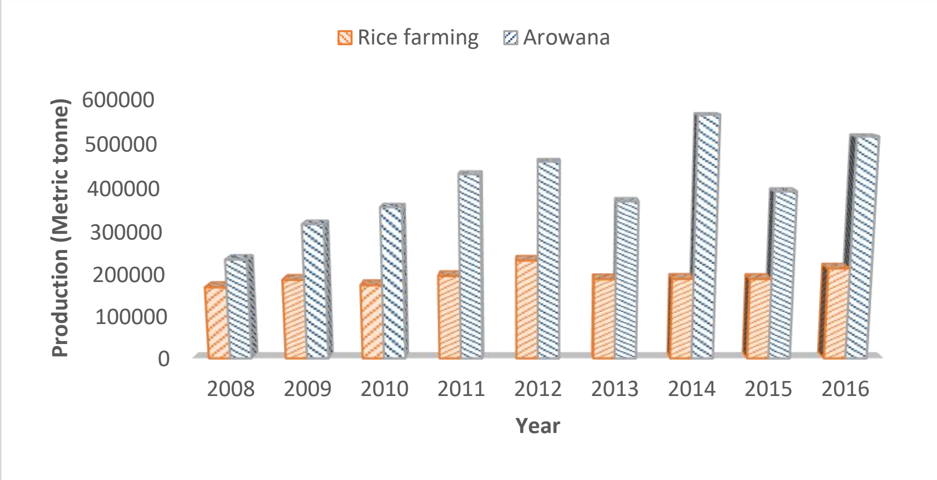
At Bukit Merah, Arowana rearing farm are the most predominant activity aside from the paddy agriculture. The water sources are mainly from the Bukit Merah Lake which were controlled by six units of slide gates of Bukit Merah dam. However, Bukit Merah reservoir had faces water stress for the past two decades (Hasan et al., 2012). Figure 1.4 shows the current occurrence of water draught during 2016 and 2018 at Bukit Merah Lake and Bukit Merah dam respectively. The reason for this occurrence is because the sole purpose of the dam was originally to provide irrigation water only for double cropping to 24,000 hectare of paddy plantation under the Krian-Sungai Manik Project and to provide 5.6 m^3/s of water for the domestic and industrial demands in

Krian District (DID, 2013). However, with the presence of Arowana industry that were rapidly growing since 2005, the water source have to be distribute to supply to more than 186 hectares of Arowana farm that needed a continuous water supply throughout the year. Therefore, since both of this industry (rice-farming and Arowana rearing farm) were depending on the water resources from Bukit Merah reservoir, sharing water resource for a long term usage would cause a concern that it will detrimentally effect the environment. Figure 1.5 shows the production of Arowana at Bukit Merah and rice farming in the Kerian district from the year 2008 to 2015. The graph shows a significantly increase trend for Arowana aquaculture production to be compare with rice farming agriculture. The factor contributed to the increase in production can be attributed to the increase in area production of Arowana fish at Bukit Merah. The area of production was 503.03 hectares in 2010 and increased to 570.81 hectares in 2016 (DOF, 2010; DOF, 2016). These indicates the potential of Arowana aquaculture in contributing to the country economic growth in a long term period.



Source: Utusan online, 2016; Berita Harian online, 2018

Figure 1.4 Occurrence of water draught problem at Bukit Merah Lake



Source: DOF, 2009; DOF, 2013; DOF, 2014; DOA, 2017

Figure 1.5 Production of Arowana and rice farming at Bukit Merah

Furthermore, Golden Arowana is only able to breed successfully at Bukit Merah due to it intrinsic condition. These factor contributes to the reason this species are facing threat with extinction and being listed as one of the endangered species. Arowana is also a monomorphic fish, which signify that this species is difficult to be differentiate between the genders before maturity which causes a complication in mating the fish (Benjaboonyazit, 2014). Therefore, preserving this species had becoming a crucial issue not just because this species brought benefits to the country economic, but also in order to avoid the extinction of this precious species.

Hence, problem with lack of water resources should not be the reason for their extinction since Arowana needed water supply throughout the year. Thus, water recycling and reusing at Arowana farm were important so that the usage of water from the Bukit Merah could be reduced. This approach is not only to sustain the aquaculture industry in Malaysia and to improve the economic prospects, but also at the same time minimize the usage of water and meeting the compliancy of the guidelines for aquaculture wastewater discharge

1.3 Gap of Knowledge

Asian Arowana despite of being the most expensive fish in the world, it's still lacking and had only relatively few scientific publication. To date, there is few about the water quality and specifically on the treatment of Arowana wastewater. Table 1.2 list out some of the previous study regarding Arowana that had been published. Most publications on Arowana fish were only related to classical studies relating to taxonomy, and physiology of a of the Arowana species (Ngili et al., 2015).

Table 1.2 Previous study on Arowana

Description	**Author**
Business proposal for Arowana breeding project	DOF, 2005
Introduction to Arowana species	Suleiman, 2011; Goh and Chua 2000
Overview of Arowana issues on market demand and the possible technologies to enhance the culture production	Medipally et al., 2016
Arowana breeding technique	Suleiman, 2003; Priyadi et al., 2010
Arowana genetic diversity	Yue et al., 2006; Manoharan et al., 2011; Shen et al., 2014; Ngili et al., 2015
Arowana genome	Bian et al., 2016; Li et al., 2016
Arowana digestive enzyme	Natalia et al., 2004
Arowana disease	Kasantikul et al., 2016
Arowana gender determination	Benjaboonyazit,2014; Saedfar et al., 2017; Esmaeili et al., 2017; Rahman et al., 2017

Hence, this study that will focus on the Arowana water quality and it treatment could be added to the contribution of knowledge on the current condition of Arowana wastewater. On the same time, the problem between the insufficient water resources especially during draught season at the paddy field versus the only place where the Golden Arowana can breed could probably be solved. Further, no studies have yet been carried out to incorporate activated carbon, zeolite and sand as a direct application of NH_3-N, TP, TSS and Fe (II) removal in aquaculture systems simultaneously. Therefore, this study was performed to evaluate the effect of these three media inside a horizontal prototype model in treating the Arowana aquaculture wastewater.

1.4 Objectives of Research

This study focused on treating Arowana effluent specifically on parameter ammoniacal nitrogen (NH_3-N), total phosphorus (TP), total suspended solids (TSS) and iron (Fe (II)) using horizontal prototype model.

The objectives of the study were listed as below:

1) To characterize and identified the water quality trend and parameters that need to be treated by comparing the water quality of intake and effluent at Arowana Aquaculture Farm;
2) To determine the performance of sand, activated carbon (AC) and zeolite in treating the identified water parameter through batch study;
3) To optimize the ratio of sand, AC and zeolite using Standard Mixture Design in removing the polluted parameter by column study;
4) To apply the best optimum ratio from the column study in a horizontal prototype model to treat the wastewater from Arowana Aquaculture farm.

1.5 Scope of Work

There are four main scopes of this study as follow:

1) The water quality monitoring involve nine water parameters which are temperature, dissolved oxygen (DO), pH, ammoniacal nitrogen (NH_3-N), total suspended solids (TSS), total phosphorus (TP), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5) and iron (Fe(II)). The guidelines from Department of Fisheries (DOF) for optimum breeding and rearing of Arowana and Department of Environment (DOE) for National water quality standard Class IIA was used as a benchmark to compare the water quality obtained from the monitoring.

2) The size of sand, AC and zeolite was set to 2 mm. The performance of these adsorbents in treating the selected pollutants were determined with batch study by varying the dosage, contact time, agitation speed and solution pH. The removal mechanism and uptake capacity were examined using isotherm and kinetic models.

3) Optimum ratio for the bed depth of the combining media (sand, AC and zeolite) was determined by column study experiment where the maximum bed depth was set to 30 cm. The optimum ratio was obtained by using Design expert software via Standard Mixture Simplex Lattice design.

4) The performance of the horizontal prototype model in term of breakthrough time was determined based on the removal percentage towards each desired target pollutants.

1.6 Layout of Thesis

The thesis is divided into the following chapters:

Chapter 1 Introduction. A brief introduction about the status of Arowana Aquaculture in Malaysia, problem statement, gap of knowledge and objectives of research.

Chapter 2 Literature review. A comprehensive review of literature regarding the Ornamental Aquaculture in Malaysia, Arowana Industry, characterization of Arowana Aquaculture wastewater, media material, adsorption process and mechanism which are described through equilibrium isotherm and kinetic study.

Chapter 3 Methodology. This chapter presents the experimental programs and procedures. Site location, sampling procedures, materials used and properties. Next, it includes the method for batch study by isotherm and kinetic model, column study for optimization of adsorbent mixture and lastly implementing the optimum ratio to horizontal prototype model.

Chapter 4 Results and Discussions. This chapter provides characterization of Arowana Aquaculture wastewater, intake water quality vs effluent water quality, batch adsorption study for sand, activated carbon and zeolite, adsorption isotherm, adsorption kinetic, optimization study via column study and lastly the horizontal prototype model study.

Chapter 5 Conclusion. This chapter provides the conclusion to the finding outputs and the recommendations for future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter highlights six crucial sections. The first section is the introduction of Golden Arowana Aquaculture as the most expensive ornamental aquaculture in Malaysia. The second section is the characterization of the Aquaculture wastewater which focuses on parameter total suspended solids (TSS), ammoniacal nitrogen (NH_3-N), total phosphorus (TP) and Iron (Fe (II)). The third section discussed the aquaculture wastewater treatment involving physical treatment, chemical treatment and biological treatment. The fourth section consists of the selection of filtration and adsorption media. The fifth section discusses about the theory and principle of adsorption, isotherms and kinetics used in this study. Lastly, the sixth section discusses about the column studies and the application of the media in horizontal prototype model.

2.2 Ornamental Aquaculture in Malaysia

Ornamental aquaculture were known worldwide as a multi-million dollar industry which were growing rapidly (Mendoza et al., 2015). These industry is predicted to be more vital industry as restrictions were implement upon collecting species from wild environment (Claudia, 2017). The ornamental aquaculture were mainly export by major exporters including Asian countries, Netherlands, Germany, Czech Republic and Russia. (Monticini, 2010). In Asian countries, the intensive breeding of the ornamental fish trade other than creating a new varieties of fish had also open up a job opportunities for the local population and to new professionals which eventually give benefits and contribute to their social-economic growth (Monticini, 2010; Claudia, 2017).

In Malaysia, the ornamental fish culture had started since the 1950s in the states of Johor, Perak and Penang where the ornamental fish production are for the exportation purpose to overseas (Zainathan et al., 2017). Since the ornamental fish production and their export values had becoming the main important industries (Yusoff, 2015), numerous effort have been conducted in order to promote the networking opportunities between the local industry culturists with the international buyers. Effort had also focused on exposing the new and existing culturist to the latest development in breeding and culture technology (Fishmail, 2011).

To date, Malaysia has 620 culturist that involved in culturing 250 species of 550 varieties including local and exotic species in a total land area of 2,724.68 Ha (DOF, 2016). The ornamental fish in Malaysia mainly comprise of species from the families of Anabantids, Callichthyids, Characins, Chichlids, Cobitids, Cyprinids, Loricariidae, Poecilids and Osteoglossids (DOF, 2016). Among those families, Arowana species is categorized under Osteoglossids family. Table 2.1 tabulated the values for each fish family with respect to the amount of production. It shows that Osteoglossids family were the fourth highest in contributing to the economic in terms of value. However, by referring to the value per piece of the fish, it can be concluded that Osteoglossids family had the highest value.

Table 2.1 Values and Production of ornamental fish by fish family

Fish family	Value (million)	Production	Value per fish (RM)
Cyprinids	RM 180.44	137,414,750	1.31
Poecilids	RM 144.18	172,516,917	0.84
Cichlids	RM 41.49	11,411,442	3.64
Osteoglossids	**RM 37.41**	**565,379**	**66.16**
Anabantids	RM 23.67	24,994,507	0.95
Callichthyids	RM 12.98	13,822,153	0.94
Charachins	RM 10.5	14,782,117	0.71
Cobitids	RM 6.67	2,782	2.40
Others	RM 5.74	26,791,183	0.21
Total	456,409,467.51	402,301,230	

Source: DOF, 2016

This ornamental fish production has grown rapidly with a 15% annual growth rate in Malaysia agriculture sector (Fishmail, 2011). The price for ornamental fish usually higher compared to the fish used for consumption. According to Ministry of Agriculture, the price ratio of ornamental fish to those reared for consumption is about 100:1 (MOA, 2012). Table 2.2 shows the production and value of ornamental fish in Malaysia from year 2003 to 2016. The production of ornamental fish for the first five years starting from 2003 showed an increasing trend with increment of 27%. In term of value, the increment reach up to 87% with the highest value was on 2009 with RM 770.12 million. The increasing of value was due to the re-adjustment of the price for the ornamental fish in 2007 especially for Arowana species throughout the country (DOF, 2007). For example, the state of Johor was the largest producer of ornamental fish including aquatic plants contributing 325,465,398 of ornamental fish valued at RM651.68 million (DOF, 2009). In 2010, the production had dropped drastically by 48% while the value dropped to 79%. However the trend were slowly increasing until 2016 and had increased to 15% from 2010 to 2016 while the value increase by 6% from RM 430.31 million to RM 456.41 million.

Table 2.2 Production and value of ornamental fishes in Malaysia

Year	Production	Value (million)
2003a	428,298,151	RM 97.64
2004a	455,723,540	RM 106.03
2006b	644,099,783	RM 181.74
2007b	558,178,294	RM 647.05
2008c	590,139,150	RM 748.50
2009c	507,216,127	RM 770.12
2010c	341,757,064	RM 430.31
2012d	376,679,177	RM 631.51
2013d	346,592,173	RM 353.20
2014e	393,050,770	RM 352.66
2015f	383,689,326	RM 341.14
2016g	402,301,230	RM 456.41

Sources: a: DOF, 2004, b: DOF, 2007, c: DOF, 2009, d: DOF, 2013, e: DOF, 2014, f: DOF, 2015, g: DOF, 2016

On the other hand, Table 2.3 tabulated the production of Arowana in Malaysia from year 2008 to 2016. According to DOF (2011), Arowana is one of the aquaculture commodities that had been given a priority in the Third National Agricultural Policy (NAP3). It is a high value industry with a wide range of market. In 2016 the values of Arowana fish worth RM 37.4 million where Perak contributed RM 29 million of the totals (DOF, 2016). By comparing Table 2.2 and Table 2.3, it shows that on 2012, Arowana had contributed 48% (RM327 million) from the total values of ornamental fish (RM 631.51 million) to the country economic. The high value of Arowana in 2012 was due to the market value of the fish at that time. According to DOF, (2005), the market value of the Arowana fish was highly influenced by the preferences of fish enthusiasts.

Table 2.3 Production and value of Arowana in Malaysia

Year	Production	Value (million)
2008a	234,700	RM 96
2009a	316,572	RM 146
2010b	355,740	RM 151
2011b	431,106	RM 292
2012b	459,631	RM 327
2013c	369,218	RM 107
2014c	564,194	RM 115
2015d	392,044	RM 57
2016d	565,379	RM 37

Sources: a: DOF, 2009, b: DOF, 2013, c: DOF, 2014, d: DOF, 2016

Although it showed a declination of pattern in the valuation of ornamental fish and specifically for Arowana fish, Malaysia is increasing its effort to overcome this issues by promoting regrowth in the ornamental fish industry. This including the development of the Economic Transformation Programme and several other biosecurity measures (Ayson et al 2015; Zainathan et al., 2016).

2.3 Asian Arowana

Asian arowana or dragonfish which have a scientific name of *Scleropages formosus* belongs to an ancient family of fishes Osteoglossidae (Medipally et al., 2016). Figure 2.1 depicts the sequence background for Arowana family. It is within the order of Osteoglossiformes, which literally means bonytongues. The family contains two subfamilies which is Osteoglossinae and Heterotidinae and further divided into four genera which is Scleropages, Osteoglossum, Arapaima, and Heterotis (Shen et al., 2014). Asian arowana is a carnivorous fish that lives in fresh water (Saeedfar et al., 2017). The Arowana fish has three varieties of basic colour which is gold, red and green (Ngili et al., 2015).

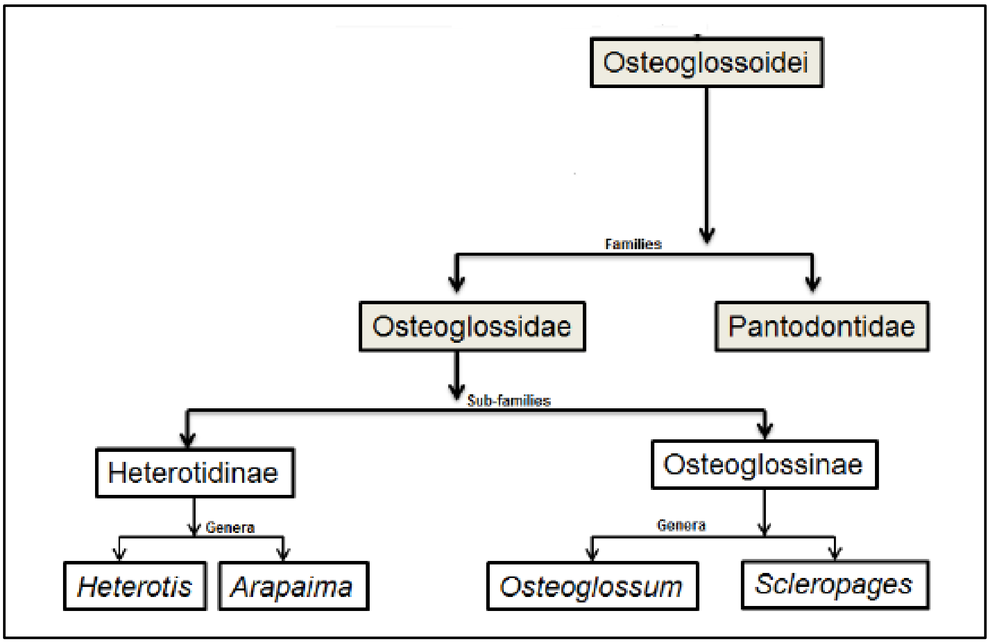


Figure 2.1 Diagram for Arowana families (Medipally et al., 2016)

2.3.1 History of Arowana

In the early 1970s, Arowana were previously known as 'Kelisa' fish which is relatively abundant in the wild and can be easily found trapped in a rice field drainage. At that time, Arowana was only regarded as a cheap food fish in market and only occasionally seen in the aquarium trade (Suleiman, 2011). However, during early 1980s the sudden popularity of this species had become an Asian phenomenon. It is believe by the Chinese superstitious believer that by owing this fish will bring prosperity and good luck (Ng and Tan, 1997). This was due to resemblance of the fish as a dragon figure. Other than that, the deep gold and the bright red colors of some Arowanas, which Chinese and Japanese regard it relation to good luck and prosperity. This sudden phenomenon, were the reason for hobbyist especially businessmen were paying higher price to own this Arowana in order to have a good luck charm (Goh and Chua, 2000).

2.3.2 Asian Arowana Status as Endangered Species

Asian Arowana is an important fish species due to its unusual breeding biology and high economic value in the ornamental fish markets (Shen et al., 2014). Due to the great demand and Arowana popularity, this fish are vulnerable to overexploitation because have been fiercely hunted in their native habitat for profits. This causes declination of this fish population in their natural habitat especially for Malaysian Golden Arowanas and Red Arowanas, which have reached a stage of near extinction since 1980 (Dawes et al., 1999). Other than that, several reproductive characteristics such as low fecundity, oral brooding habit and open-water spawner habit were the reasons for their extinctions (Kottelat and Whitten, 1996; Fernando et al., 1997). Basically, Arowana is individualistic and territorial. Thus, they are scattered over a wide area, making their collection difficult.

Due to the extinctions of this species, it is listed by the Convention on International Trades in Endangered Species of Wild Fauna and Flora (CITES) in Appendix I as a highly endangered species where a special permit is required for farms dealing with its culture (Yue et al., 2006). Arowana were also placed on the Red List of the 2006 International Union for Conservation of Nature and Natural Resources (IUCN) (Hilton-Taylor, 2000; Hu et al., 2009).

CITES is an international agreement among the world governments which aims to ensure that international trade in specimens of wild animals and plants does not threaten their survivability. Levels of exploitation of some animal and plant species are high and brought some species close to extinction. Many wildlife species in trade are not endangered, but the existence of an agreement to ensure the sustainability of the trade is important in order to safeguard these resources for the future (CITES, 2011). CITES operates mainly through three Appendices, each reflecting a different level of perceived threat and defining specific controls with regard to trade (Dawes, 1999).

On the other hand, IUCN Red List of Threatened Species is the most comprehensive resource detailing the global conservation status of plants and animals (Rodrigues et al., 2006). It is among the most widely used tools available to conservationists worldwide for focusing attention on species of conservation concern (Gärdenfors et al., 2001). Only the F2 generation from the commercially captive-bred individuals can legally be exported (Rahman et al., 2008). According to CITES under the Animal Production Systems & CITES Source Codes, the source code F represent the animals born in captivity (CITES, 2013). In Arowana, there are F0, F1, F2 and F3 which indicates the stage of pure breed generation. Table 2.4 simplifies the definition for each generation.

Table 2.4 Details on Arowana generation

Generation	**Details**
F0	Wild habitat from river or lake
	Not for traded market, only for breeding purpose
F1	Variations from F0
	Traded within the producer country
F2	Variation from F1
	Traded world wide
F3	Variation from F2
	Traded worldwide

Source: CITES, 2013

2.3.3 Golden Arowana at Bukit Merah

In Malaysia, Golden Arowana is the most in demand and pricey ornamental fish. The finest trait of the crossed-back full scale Arowana is the Malaysian Golden Arowana. This species can only be found in Bukit Merah, Perak and had a natural breeding season from August to October yearly (Suleiman, 2003). The government had gazette 186 hactares of land to be reserved as Arowana Aquaculture Zone at Bukit Merah (DOF, 2011). Arowana breeding activities are carried out commercially for the purpose of export to the international market and one of the agencies involved is the Department of Fisheries. The main export countries are Japan, Hong Kong, China, Taiwan, Canada, Vietnam and Singapore (DOF, 2011). Arowana were also marketed at local request where the local market does not require any regulation. The market value of the Arowana fish is also influenced by the preferences of fish enthusiasts. However, currently the demand and prices remain high, especially in the international market.

2.3.4 The Habitat of Arowana

The Golden Arowana commonly inhabits Sungai Kerian and its tributaries in Perak. In its natural habitat the fish prefer slightly acidic clean water and unpolluted natural surroundings, especially shallow and fast flowing rivers with overhanging vegetation on the river bank. Golden Arowana breeds successfully in pond and the production are highly depending on the water quality. A continuous water supply is needed throughout the year and therefore it is crucial to know the appropriate water quality for this species (Suleiman, 2003).

At Bukit Merah the water sources are from the Bukit Merah dam. Sandy clay with 55% to 60% of clay is the most suitable condition for pond breeding. Arowana will require at least 10 to 12 hours of strong sunlight each day in order to live healthily and breed. Average temperature during daytime should be between 28 to 32° C and should not be below 24° C during night time. Non-compliancy of those range will cause the Arowana to fall sick and being inactive. For example, Japan which is the highest Arowana importing country could not breed them on a commercial scale considering having the four season climate each year (Goh and Chua, 2000). Table 2.5 shows the water quality at the Arowana farm, Bukit Merah Lake and Bukit Merah Rice Field being compared with the Arowana guidelines from the DOF (DOF, 2005) and National Water Quality Standards for Malaysia under Class IIA from DOE (DOE,2011). It shows that the temperature, pH and ammoniacal nitrogen (NH_3-N) were within the suggested guidelines by DOF. However, for DO the reading for Bukit Merah rice field were the only that did not comply with the guidelines while the other two (Arowana farm and Bukit Merah Lake) follow the guidelines. As for TSS, both Arowana farm and Bukit Merah Field slightly exceeded the guidelines.

Table 2.5 Water Quality at Bukit Merah (Arowana farm, lake and rice field)

Water quality parameter	**Arowana Farm (Nur Atiqah,2013)**	**Bukit Merah Lake (Shuhaimi-Othman et al., 2010)**	**Bukit Merah Rice Field (Al-Shami et al., 2010)**	**Arowana Guidelines (DOF, 2005)**	**NWQS Class IIA for Malaysia (DOE, 2011)**
Temperature (°C)	29.3	29.6	29.2	29 – 31	-
pH	8.08	6.3	6.3	6.5 - 8.5	6-9
Dissolved oxygen (mg/L)	5.51	5.9	2.9	5	5-7
Ammonia (mg/L)	0.62	-	-	1	0.3
Total suspended solids (mg/L)	31.3	-	48	30	50
Conductivity (μs/cm)	40.4	18.7	84.1	-	-

2.4 Characterization of Aquaculture Wastewater

Aquaculture industry had been developing rapidly and eventually had brought some drawbacks to the environment especially concerning the wastewater issue (Chen et al., 2015; Nasir et al., 2015). It produces a great volume of low-strength wastewater (Zhang et al., 2016). Aquaculture production and water are dependent to each other. Therefore the status of the water quality reflected the aquaculture themselves. The contents of aquaculture wastewaters usually consists of nitrogenous compounds such as total nitrogen (TN), total phosphorus (TP), SS and carbon content that are notably lower compare to other wastewater (Chiu et al., 2015; Liu et al., 2016; Kuo et al., 2016). It also contains low concentration of heavy metals and few pathogenic microorganisms (Kuo et al., 2016). The nutrients from aquaculture wastewater usually contain ammonia, nitrates, phosphate and TSS that were categorized as intermediate range of nutrients (Turcios and Papenbrock, 2014; Gao et al., 2016; Ansari et al., 2017). Table 2.6 tabulated the range concentration of nutrients in aquaculture wastewater.

Table 2.6 Nutrient concentration in aquaculture wastewater

Pollutant	**Concentration (mg/L)**
Ammonia	3-7
Nitrates	2-110
Phosphate	2-50
Total suspended solids	5-50

Sources: Turcios and Papenbrock, 2014; Nasir et al., 2015; Gao et al., 2016; Ansari et al., 2017

Wastewater that consist of high nutrient eventually causes toxicity in the water due to the high turbidity causes by the limited light penetration (Ansari et al., 2017). Further, the discharge of this untreated aquaculture wastewater to water body could pose a threat to the downstream waters such as eutrophication and deteriorated the natural ecosystem (Zhang et al., 2016). Hence, the water quality for total suspended solids (TSS), ammoniacal nitrogen (NH_3-N), total phosphorus (TP) and iron (Fe (II)) in aquaculture system will be focus to discuss in the next section.

2.4.1 Total Suspended Solids (TSS)

Total suspended solid (TSS) is one of the most dominant pollutant in aquaculture wastewater and a key water quality since it impact the activities such as the wastewater treatment, sediment control and disinfection (Amosa et al., 2016). The sources of TSS are mainly from the feed residue and fish feces (Brager et al., 2015) which may contain components which is harmful to the water bodies such as heavy metal, nitrogen, phosphorus and pathogens (Bao et al., 2018). As a result, most countries had listed TSS content as one of the paramount parameters to be taking account in water pollution index (Amosa et al., 2016). Typically, the concentration of TSS in untreated aquaculture farm were in range of 5-50 mg/L. However, these concentration can differ accordingly depending on the aquaculture system management (Turcios and Papenbrock, 2014). In Malaysia, the concentrations of TSS for Arowana aquaculture should be in range of 30mg/L as been highlighted by Department of Fisheries (DOF, 2005).

A mortality rate of fish was observed at TSS level higher than 200 mg/L (Othman et al., 2002). At that concentration, fish may suffer clogging and abrasive damage to gills and other respiratory surfaces. The fish community usually avoids areas with higher TSS by moving away from the sources of TSS. Thus, degree of injury and the actual effects observed to fish fauna in a given level of TSS may be less due to the avoidance behavior (Othman et al., 2002). In addition, the presence of TSS causes toxic components to accumulate at the bottom of the water. This contaminated sediments consequently could pose a risk not just to the fish within the water bodies but also to the small living creature that live within the sediments such as crustaceans and insect larva (Mulligan et al., 2009). These high TSS content also prevented sunlight to penetrate into water and increase heat absorption which eventually disturb the biological process in the water body (Avvannavar and Shrihari, 2008).

Further, TSS concentration influence the concentration of other water quality since the solid structure possibly contain the trace metals, pesticides and toxic substances that were adsorbed on the surface (Amosa et al., 2016). For instance, the high specific surface area of TSS particles stimulate heavy metals to be attached to it in high concentration where it was reported about 40%, 62%, 80% and 92%, of the total amounts of Cu, Cd, Zn and Pb are carried by TSS (Mulligan et al., 2009). Hence, the removal of TSS is crucial for the clarity of aquaculture wastewater.

2.4.2 Ammoniacal Nitrogen (NH_3-N)

Ammoniacal nitrogen (NH_3-N) will affect the performance of fish and therefore was been regard as the most crucial parameter after oxygen concentration (Aly et al., 2016). Two main sources of NH_3-N from aquaculture ponds were mainly from nitrogen excretion by fish and secondly due to the microorganisms degradation from unconsumed feed and feces (Bernardi et al., 2018). Nitrogen excretion happened when the fish consume the oxygen and excreted carbon dioxide and ammonia through the gill membrane and in urine (Aly et al., 2016). As for microorganism degradation, the NH_3-N were caused by the bacterial ammonification process in fish pond by the nitrogenous organic matter in water column under aerobic condition. On the other hand,