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The Use of Fish Biomarkers for Assessing Textile Effluent Contamination of Aquatic Ecosystems: A Review

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ABSTRACT

The effluent emission from textile industries has become a foremost concern in accordance with the growth of global industrial sectors. Although the textile industries have a major role in economic development, they cause quality deterioration of ecosystems. Several studies have discussed the environmental consequences of textile effluents and attempted to characterize the textile wastewaters. The main pollutants formed from the textile industry include dyes, surfactants, salts, metal complexes, biocides, hydrocarbons, resins, waxes, etc. Most of the pollutants are of aromatic and heterocyclic compounds of stable complicated structure with non-degradability. The water contaminated with textile effluents shows massive variation in water quality. The methods based on qualitative and quantitative observations of living organisms in their natural habitats were efficient in compensating deficiencies of physico-chemical analysis. Therefore, the biological approach arrived in the water quality determination such as bioindicators and biomarkers. Fish are particularly sensitive to the water contamination and, therefore, pollutants may significantly interfere with several of their biochemical processes. So the recent trend in biomarker studies focuses on the behavioural, physiological and biochemical changes of fish. In this review, the impacts of textile effluents on freshwater ecosystems and the fish biomarkers (biochemical, haematological, histological parameters) used for the assessment of these undesirable changes have been discussed.

INTRODUCTION

The aquatic ecosystems form an ultimate sink for several industrial and domestic contaminants due to either direct discharges or atmospheric deposition (Stegemen & Hahn 1994). Synthetic chemicals in industrial effluents are not only poisonous to human health, but also found to be toxic to aquatic life rendering serious environmental issues. Most of the ecosystems of the world are loaded with xenobiotics frequently by several industrial activities. Textile industry, a very diverse industrial sector have key role in terms of both economy and ecology. This industry forms a complicated industrial chain by means of its raw materials, processes, products, technologies and equipments. Therefore, it compasses enormous employment opportunities, which can accelerate the economy of several countries in the world. In an ecological view, the impacts on the environment by textile industry have recognized in terms of both pollutant discharge and high consumption of water and energy (Lacasse & Baumann 2004, Savin & Butnaru 2008). In line with the improvement of people's living standard, market pressure also raised and leads to the introduction of an extensive range of new products, especially dyes, and for many of them environmental and health impact data are still lacking (Marechal et al. 2012). The characterization of textile effluents and their impact on aquatic environment is a matter of concern to develop strategies for wastewater treatment and reuse, and to design the textile processes in eco-friendly manner.

Studies have been published on environmental pollution from textile industries and toxicity of textile effluents with respect to plants, fish and other aquatic organisms (Tufekci et al. 2007). The chemical and physical analysis of water and sediments can reveal the physico-chemical qualities of the abiotic environment. It is very difficult to assess the effects of pollutant in aquatic ecosystem in its totality, especially in the case of hydrophobic organic compounds, mainly brought by industrial activities. So environmental toxicologists were extensively using bioassay tests, also known as toxicity tests in toxicological investigations, in which the scientists study the exposure, fate and effects of chemical contaminants. The biomarkers have significance in assessing undesirable changes of the living environment. In terms of sublethal effects, the response of organisms to contamination can only be evaluated by the measurement of biological, physiological and biochemical parameters as in the case of medical diagnosis in human or veterinary toxicology (Narbonne 2000). In an aquatic ecosystem, fish forms an indicator organism, having some advantages when compared with others. They can act as an appropriate model due to their position as lowest member among vertebrates and their sensitivity towards the alterations in medium, which they live. Fish also have direct link to humans through food chain, so the lipophilic pollutants can reach directly, while there is accumulation and magnification taking place. There are some potential biomarkers in fish such as behaviour, biochemical parameters like enzymes and proteins, haematological parameters and histology of target organs and for studies on highly toxic compounds genetic approaches are also developed.

The foremost consideration is the effects of textile effluents on water quality and possible fish biomarkers for assessing the chief pollutants in them. The rivers and streams are more vulnerable to the textile effluent contamination in several developing countries, lacking sophisticated technology for effluent treatment. So the freshwater ichthyofauna are under threat, commonly used for the biomarker studies. Most of the studies included in the review are on pollution of rivers and inhabitant fish fauna of them forms the sentinel species.

Textile industry- basic processes and raw materials: Globally textile and clothing is one of the largest and oldest industries having a major task in the economy (Gereffi 2002). The industry can provide occupation to a number of people without demanding special skills, which makes the textile and clothing industry well-known for employment opportunity in undeveloped as well as developing countries like India, Bangladesh, Vietnam, Sri Lanka, Mauritius, Nigeria, etc. The complicated process and massive use of raw materials and technology can classify the textile industrial sectors to different types. Based on the raw materials used, the textile industry can be categorized into three; cellulose fibres (cotton, rayon, linen, ramine, hemp and lyocell), protein fibres (wool, angora, mohair, cashmere and silk) and synthetic fibres (polyester, nylon, spandex, acetate, acrylic, indigo and polypropylene).

The final product of textile industry was formed after a series of procedures which includes; sizing, desizing, scouring, bleaching, mercerizing, dyeing and printing (Dey & Islam 2015). For the production, in a typical textile industry, in the first stage the raw materials or fibres are subjected to size for the further processes. In the next stage, desizing is the process for removing size chemicals from textiles and requires high amount of water. Scouring is also a cleaning process for removing impurities of fibres and it is performed in alkali medium. The chemical processes start with bleaching in which unwanted coloured matter from the material is removed. In this stage several chemicals are used based on the material and oxidizing agents are important. Mercerizing improves the strength, lustures and increases affinity of dyes for cotton fabrics. Dyeing is the addition of colours into the textile materials and can be carried out in a batch of practices. The continuous procedure of dyeing includes preparation of dye, dyeing, fixation, washing and drying. Dyeing or colouring is a vital course, which makes the products more attractive. There are a number of synthetic dyes available for textiles. The next step of printing is also like dyeing, applying colour to substrate using certain pigments. This process requires small volume of water because there is no washing stage. So the wastewater generation is also lesser. The final process of finishing covers the treatments for improving certain properties and serviceability of fibre. The process consists of mechanical, physical and chemical treatments performed on fibre, yarn or fabric to improve appearance, texture or performance (Marechal et al. 2012).

The dyes, thickeners, pigments and stabilizers used in textile industries are numerous depending upon the fabrics produced. The colours can raise product's aesthetic value, hence the colouring agents and dyes have importance in the textile industry. The global usage of dyes has increased from 60,000 tonnes in 1988 to 178,000 tonnes in 2000s (Philips 1996). The export and import of direct dyes and preparations show rise from 53,848 tonnes in 1992 to 181,998 tonnes in 2011 (UNSD 2013). Annual world production of indigo dye is 80,000 tonnes and world marketing of naphthol dyes was about 112,000 tonnes per year. (Franssen et al. 2010). There are several ways for classification of dyes (Gregory 1990). It is very important that each class of dye has a unique chemistry, structure and a particular way of bonding. While some dyes can react chemically with the substrates forming strong bonds in the process, others can be holding on the action of physical forces.

Some of the prominent ways of classification include: organic and inorganic; natural and synthetic; by area and method of application; chemical classification- based on the nature of their respective chromophores; by nature of the electronic excitation (i.e., energy transfer, colorants, absorption, colorants and fluorescent colourants); according to the dyeing method (anionic- protein fibre; direct- cellulose and disperse- polyamide fibres) etc. However, the US International Trade Commission (1994) advocates the most popular classification. There are 12 types of dyes according to their chemical composition and properties. The industrial classification, based on the application on different fibres, is the most popular one (Ghaly et al. 2014) and is given in Table 1.

Textile effluents' characteristics and water pollution: Generally, a textile industry requires a huge amount of water for several processes and nearby water bodies, forms the sink

Table 1: List of dyes used in various fibres and the properties of dyes.

Dyes	Fibers	Properties of dyes	Examples
Reactive dyes	Cellulose	Covalent bond with the fibre molecule	Procion MX, Cibacron C,
Direct dyes	Cellulose (Rayon, Linen)	Lack property of quick drying due to absence of strong bonds with fibre molecule. So apply at high temperature	Congo red, Direct yellow, Direct blue 86
Indigo dyes	Cellulose (cotton)	Water insoluble dark blue crystalline powder	Indigo white, Tyrin purpleIndigo carmine
Naphtol dyes	Cellulose (rayon, cotton), silk	Formed by the combination of diazo salts and naphthol. Contains more hazardous chemicals	Fast yellow GC, Fast scarlet R, Fast blue B
Azo dyes	Protein fibres	Contains azo group give out bright and high intensity colours	Amido black, Orange G, Amaranth
Triarylmethane Dyes	Protein fibres (nylon, wool, silk)	Intensely coloured compounds with slow fasness.	Basic violet 14, Malachite green, Acid blue 90
Anthraquinone Dyes	Protein fibres	They are vat dyes of second most important class derived from anthraquinone.	Carminic acid, Indanthrone blue, Vat Yellow 1
Basic dyes	Synthetic fibres	Act as bases and are aniline dyes	Basic orange 1, Basic red 1 Crystal violet
Dispersed dyes	Synthetic fibres (Polyester)	Less water-soluble having smallest molecules among all the dyes. Gives strong bright colours with wash fastness	Disperse yellow 218 Disperse Navy 35, Disperse violet 28

for discharging the effluents. The water bodies such as river, streams, ponds, lakes and marine ecosystems are also receiving the pollutants. There are guidelines and policies for industrial discharge standards in several countries. However, these strategies are not applicable in case of developing and underdeveloped countries thus making vulnerability of aquatic ecosystems beyond the boundaries of nations. The textile and associated industries exploit a wide variety of artificial composite dyes and discharge large amounts of highly coloured wastewater (Nabi Bidhendi et al. 2007). There are several studies on the textile effluents' characteristics and their effects on the physico-chemical properties of natural waters. In general, the wastewater refused by textile industry, posses high suspended solids, chemical oxygen demand, colour, salinity, heat, acidity and large range of organic chemicals of low biodegradability (Savin & Butnaru 2008, Vencelasu et al. 1999, World Bank 2007). There are studies which indicate the heavy metal presence in textile effluents (Tamburlini et al. 2002, Das et al. 2011). The processes like dyeing and finishing are the chief contributors of pollution in textile wastewater. These processes need an input of complex structured organics such as synthetic dyes, formaldehyde, dioxins, etc., most of them are originated from petrochemicals.

One of the sacred Indian rivers, Kshipra in Ujjain city, is an example for pollution caused by textile dye industry Bhairav Garh Prints (Madhya Pradesh). The physico-chemical analysis of water shows abnormal variation in dissolved oxygen (0 to 2 mg/L), pH (8.6 to 9.0), chemical oxygen demand (310 mg/L to 345 mg/L), chlorides (549.9 mg/L to 669.9 mg/L) and total solids (1475.6 mg/L to 13499.2mg/L). The samples collected from nearby the industry indicate that the effluents affect the water quality which leads to an imperative environmental and health risk to the rural population that depends on the untreated river water for their domestic needs (Ahmed et al. 2012). Ravi et al. (2013) reported the characteristics of textile dyeing industry effluent from Tirupur industrial chain, Tamil Nadu, India. It was bluish coloured with considerable amounts of total solids (9745 mg/L), bicarbonate (280 mg/L), biochemical oxygen demand (54.4 mg/L), chemical oxygen demand (64.00 mg/L) and chlorides (1760 mg/L).

Imtiazuddin et al. (2012) analysed the wastewater characteristics of textile effluents of ten textile industries in and around Karachi, Pakistan. The sample collections have been done based on various textile-processing regions such as desizing, bleaching, mercerizing, dyeing, printing and finishing. Analysed parameters, temperature, total dissolved solids, pH, electrical conductivity, biochemical oxygen demand, chemical oxygen demand, total suspended solids and heavy metals (Cd, Cr, Cu, Fe, Ni, Mn and Zn) proved the undesirable alterations.

The river Karnatoli at Savar, Dhaka City, Bangladesh, getting polluted by heavy metals such as Zn, As, Cd, Pb, Ni, Cr and Cu from adjacent textile industry effluent (Das et al. 2011). The concentration of different heavy metals in effluent was in the order of Zn> Cu> As> Ni> Cr> Pb> Cd and in surface water of Karnatoli river as Cu> Zn> Ni> Cr> pb> As>

Cd. The textile effluent contains heavy metals such as chromium, copper, zinc and mercury (EPA 1979). Mainly the dyeing process can contribute Cr, Pb, Zn and Cu to the wastewater. The surface water of river Karnatoli in Bangladesh shows high concentration of Cu and Cr, and other heavy metals Zn, Ni, Pb, As, Cd, etc. are below the permissible limits prescribed by DoE (Department of Environment), Bangladesh (Benavides 1992).

The stream in Ibeshe, Ikorodu, Lagos State, Nigeria receives contaminants from textile industry effluents. The water quality analysis revealed the deterioration in physicochemical properties; colour, electrical conductivity, suspended solids, total dissolved solids, total suspended solids, nitrates, phosphates and chemical oxygen demand. The parameters have high values which were beyond the international quality standards while the dissolved oxygen was absent in highly polluted areas (Awomeso et al. 2010). The studies show that the textile industry effluents are highly potent to polluting the water bodies world wide. The pollutants depend on the nature of products and raw materials used in the industrial process. The major textile industry pollutants and receiving water bodies are presented in Table 2.

What are biomarkers?: Numerous organic and inorganic contaminants are repeatedly entering the aquatic environment, have capability to alter environmental quality and enter into the bodies of resident biota. So there is a need of evaluating the quality of environment in its totality. The methods for environmental quality or health monitoring can be divided into two distinct categories such as: (1) the detection of pollutants and their quantification, in physical and biological mediums, and (2) the evaluation of pollution on living organisms, either at the individual level or at the population or community level. These methods have been employed for several years, and it is clear that none of them is exclusive and alone provides reliable and complete information on environmental status. The biomarker is a promising tool for biomonitoring, both in the freshwater and marine environments (Adedeji et al. 2012). The term biomarkers can have several explanations, which is ranging from molecular level to organism level. It is a change in a biological responses (ranging from molecular through cellular and physiological responses to behavioural changes) which can be associated to exposure or toxic effects of environmental chemicals (Peakall 1994). The xenobiotic contamination in an ecosystem can be predicted through analysis of biochemical changes in organisms inhabiting that region (Tuvikene et al. 1996, Brewer et al. 2001). These changes in the organism reflected the health of habitat.

Generally, the biomarkers are classified to three categories (NRC 1987, WHO 1993) such as biomarkers of exposure, biomarkers of effect and biomarkers of susceptibility.

***Biomarkers of exposure*:** Covering the detection and measurement of an exogenous substance or its metabolite or the product of an interaction between a xenobiotic agent and some target molecule or cell that is measured in a compartment within an organism.

***Biomarkers of effect*:** Including measurable biochemical, physiological or other alterations within tissues or body fluids of an organism that can be recognized as associated with an established or possible health impairment or disease.

***Biomarkers of susceptibility*:** Representing the inherent or acquired ability of an organism to respond to the challenge of exposure to a specific xenobiotic substance, including genetic factors and changes in receptors which alter the susceptibility of an organism to that exposure (Van Der Oost et al. 1996).

Table 2: List of rivers receiving pollutants from textile industry effluents.

Rivers & Location	Industry	Pollutants	References
Ganga at Kanpur,India	Textile mills	PAHs, Heavy metals. 2-[2-(acetylamino)	Pandey et al. (2005)
Nishitakase River, Japan	Textile	-4-[bis (2-methoxyethyl)amino-5-methoxyphenyl]-5-amino-7-bromo-4-chloro-2-H-benzotriazole (PBTA- 1)	Shiozawa et al. (1999)
Lagoon Bangladesh,	Textile & dyeing	Cr, Cu, Co	Ahmed et al. (2011)
Bandi River, India	Dyeing & printing	Cu, FE, Zn, Mn, Cr, Sulphate, Chloride	Singh et al. (2000), Rathore (2011)
Hoogly, Kolkata, India	Textile	Various pollutants due to large industrial belt in banks	Pandey et al. (2005)
Juru River , Malaysia	Textile	Cr, Cu, Sulphates, Phosphates	Al-Sham et al. (2010)
River Noyyal, Tirupur, India	Textile bleaching & dying	Detergents, chlorides, formaldehydes, benzidine	Akilan (2016)
Lyari River, Pakistan	Textile	Heavy metals	Imtiazuddin (2012)
River Malir, Karachi, Pakistan	Textile	Inorganic and organic pollutants.	Imtiazuddin (2012)
Kelani River, Sri Lanka	Textile & dyeing	Dyes and heavy metals	Ileperuma (2000)

Biochemical and physiological indicators such as enzymes and proximate compositions were used as biomarkers to spot possible environmental contaminations before the health of aquatic organisms is critically affected (Powers 1989, Osman et al. 2010). Sometimes the biotransformation products are also employed as biomarkers for assessing toxicity of certain hydrocarbons. Toxicological studies have pointed out that the concentration of pollutants can change the enzyme activities and often directly induce cell damage in specific organs. Among the various types of biomarkers, cytochrome P4501A induction, DNA integrity, acetylcholine esterase activity and metallothionein induction etc. have received special attention (Adedeji 2012). The heavy metals are appealing pollutants in the various industrial discharge and metallothioneins (MTs), which are induced by toxic metals such as Cd, Hg and Cu by chelation through cysteine residues and are used in both, vertebrates and invertebrates as a biomarker of metal exposure (Sarkar et al. 2006).

Biochemical markers or biomarkers have been used in various fields of research, such as toxicology, ecotoxicology, pharmacology and medicine. Most toxicological investigations have utilized in *in vitro* assays (Fent et al. 1998) and research concerning aquatic environment employed in *in vivo* tests (White et al. 1997). There are many organisms that can be used as sentinel species such as several plants (sea weeds and bryophytes, water lilies), invertebrates (aquatic insects, crabs and molluscs), fish, aquatic birds (cranes, pelicans etc.), mammals like mice, rats, sea lions, guinea pigs and higher animals in medical and pharmaceutical experiments. In the case of aquatic environment, fishes have become a favourable subject for research.

Fish as indicators: Fish is a non-target species of xenobiotic substances of water bodies and they are largely being used for the assessment of the quality of aquatic ecosystems as such they can serve as bioindicators of environmental pollution (Lopes et al. 2001). As a bioindicator species, fish plays a vital role due to its great sensitivity and response towards the changes in aquatic environment (Siroka & Drastichova 2004). Due to the economic importance, fish received much more attention than other taxa (Cummins 1994). Changes in age and species distribution in a stockfish population are general indicators of water pollution, but there are also responses specific to a single pollutant or a group of contaminants (Svobodova 1997). Fish can metabolize, concentrate and store waterborne pollutants, these toxicants may damage some physiological and biochemical processes when they enter the organs of fish (Tulasi et al. 1992). In addition, fish being at a higher trophic level of aquatic food chain, they accumulate a significant amount of pollutants depending upon the intake and elimination from the body (Karadede et al. 2004). The edible fish can pass the accumulated toxicants to human beings through food. The hasty death of fish indicates high contamination.

Any disturbance in ecosystem health might be reflected in the biochemical, physiological and histological parameters of fish. Usually the enzyme activities are measured as sensitive biochemical indicators before the hazardous effects occur in fish and are important parameters for testing water for the presence of toxicants (Gul et al. 2004). Changes in these components indicate an unusual modification in the metabolic activities due to an external stress. Therefore, the sublethal levels of toxicants and toxicity could be measured. The studies conducted on lipid peroxidative changes in *Oreochromis mossambicus* in hydrogen sulphide contaminated water showed that changes in antioxidant enzyme activities in fishes play an important role in the quality assessment of H_2S polluted aquatic medium in which they survive (Sreejai & Jaya 2010). The hydrocarbon pollution studies in *O. mossambicus* indicate an increased activity of ethoxyresorufin-O-deethyase (ERODE) after an exposure of naphthalene in higher concentrations (Amrutha & Subramanian 2010). A suite of biochemical parameters in eel (hepatic biotransformation enzymes and cofactors, antioxidant enzymes, PAH metabolites, DNA adducts, serum transaminases) has been measured in order to determine its response to xenobiotic compounds in the environment (Van der Oost et al. 1995, 1996). The fish haematology also can be an excellent biomarker in pollution assessment. The toxicity study of herbicide clomazon in fish *Prochilodus lineatus* resulted in an anaemic condition of fish due to significant decrease of certain haematological parameters; haemoglobin (HB), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) while exposure to higher concentration of herbicide (Pereira et al. 2013).

Toxicity of textile effluents to fishes: The textile wastewater characteristics and toxicity vary depending on the processes or technologies applied within the textile industry. Not only textile wastewater, but also textile products often contain chemicals; for example formaldehyde, azo-dyes, dioxins, pesticides and heavy metals, which might pose a risk to humans and environment. The effluents of some processes have high aquatic toxicity, however the others show, slight or no toxicity. It is impossible to identify all toxic compounds used in the textile industry due to the huge variety of chemical usage and lack of data about their toxicities (Ho et al. 2012). Most of the synthetic textile dyes have designed to be resistant to microbial, chemical, thermal and photolytic degradation. In typical textile dyeing and printing procedures, 50-100% of the colour is fixed on the fibre and the residue is discarded in the form of spent dye baths or wastewater from continuous textile washing operations (Perera & Pathiratne 2010).

The xenobiotics, that are released into the aquatic environments are carried and redistributed among the different compartments in the environment, with movement across membranes into organisms being one of the processes (Heath & Claassen 1999). There are five possible routes for a toxicant to enter into the fish body such as contaminated food, non-food particles, gills, oral consumption of water and skin. Toxic chemicals like sulphide, chlorine, chromium and aniline dyes will also affect the aquatic life.

The toxicity of textile effluents poses threat to fish biota, both directly and indirectly. The direct accumulation of pollutants is the considerable issue, but water pollution induced toxicity also forms a matter of concern. The rise in physical parameters like colour, turbidity, temperature and total solids makes the most important environmental factor light as limiting factor which alters grazing food chain of fish. The textile wastewater released into natural streams leads a boost of suspended solids in water that can clog fish gills, either killing them or reducing their growth rate. The suspended solids will reduce the light penetration and destroys phytoplankton population by limiting sun light and oxygen (Tufekci et al. 2007). The extreme salt contents releasing into the water destroy the ionic equilibrium in fish and other higher organisms.

The handloom factory effluents are rich in chromium and pollute the water and sediment, and accumulate in fish, invertebrates and algae in river Churni in Ranaghat-Falia-Shantipur region of West Bengal, India. The chromium concentration in water was in a positive correlation with the peak production period of industry. In the case of sediment samples, the deposition of Cr is in a seasonal fluctuating mode and the specimens of aquatic weeds, insects and molluscs collected from the effluent discharge point have high Cr accumulation. Different tissues of fish specimens showed moderate to high Cr accumulation as in the order; liver of *Glossogobius giuris* > gill of *Mystus bleekeri* > gut of *G. giuris* > different tissues of *Eutropiichthys vacha* > gill of *Puntius sarana* > other tissues of *P. sarana* (Sanyal et al. 2015). The textile effluents cause severe changes to aquatic environment and it is reflecting in the resident biota. Among the aquatic fauna, fish biomarkers can be easily assessed.

Fish biomarkers of textile effluent contamination: Initially effluents may cause physical and chemical changes in the host environment that directly affect fish. Then the chemical compounds of effluents may cause biochemical responses in fish, and those biochemical changes can alter the growth, reproduction or survival (Olaganathan & Patterson 2013). Stress response will be characterized by physiological changes, and effect of pollutants on fish can be assessed by acute and chronic toxicity tests (Heath 1995). Haematology, biochemical changes, growth rate and oxygen consumption of fish can be used in determination of toxicity of pollutants (Wepener 1997).

The major compounds of textile industry effluent are the dyes. Therefore, several studies have been done to assess the effects of various kinds of textile dyes on fish as a representative of freshwater ecosystems. Some azo-basic, acid and direct dyes are categorized into very toxic or toxic to fishes, crustaceans, algae and bacteria, while reactive azo dyes are toxic only at very high concentrations (Novotny et al. 2006). The anthraquinone dyes have some effects on the biochemical features of muscles of two fishes; *Channa punctatus and Cyprinus carpio*. The proximate composition i.e., protein, lipid and carbohydrate shows a significant decline after the chronic exposure to anthraquinone dye (Olaganathan & Patterson 2013).

The organism behaviour can be itself considered as a biomarker (Peakall 1994), but the behaviour has a wide extent i.e., it covers many behavioural sequences such as reproductive behaviour, parental behaviour, foraging behaviour, and simply locomotion patterns. The major behavioural changes may occur due to exposure of neurotoxic substances (Caquet & Lagadic 2000). The fish *Poecilia reticulata*, commonly known as guppy, is one of the world's most widely distributed tropical aquarium fish, which shows several behavioural changes when exposed to textile dyeing industry effluent from Tirupur, Tamil Nadu, India (Selvaraj et al. 2015). The major behavioural changes include erratic swimming, hyper excitation, rapid opercular movement and excess mucous secretion inducing thick mucus covering. Adeogun & Chukwuka (2010) studied effects of textile factory effluent of Sun flag PLC, at Eric Moore, Lagos, Nigeria in fish *Oreochromis niloticus.* The general observation in exposure studies confirmed change in behavioural patterns like hyperactivity which includes erratic swimming and short darting movements and hyperventilation as evidenced by rapid opening and closure of the operculum. The common morphological change indicates the red colouration in the gills, and morphometry of otoliths show differences in exposure of higher concentration.

The fish, Nile tilapia (*Oreochromis niloticus*) shows notable biomarker responses when exposed to the effluents of selected textile industries of Sri Lanka where highly contaminated effluents entered into the Bologoda North Lake (Perera & Pathiratne 2010). Cholinesterase mainly brain acetylcholinesterase (AchE) in fish is regarded as an effective biomarker of neurotoxic chemical exposure (Van der Oost et al. 2003). A significant inhibition of brain AchE activity (24-40%) was observed in Nile tilapia exposed to textile industry effluents. The reduction of AchE activities due to textile industry effluents indicates their neurotoxic potential on fish population, but it may not directly induce fish mortality while there should be an additional stress for fish fauna inhabiting the lake receiving textile effluents. Generally, the measurement of cytochrome P4501A (CYP1A) dependent ethoxyresorufin-O-deethylase (EROD) is a phase 1 biotransformation enzyme in fish forms promising biomarkers for exposure assessment of organic pollutants. Significantly, higher hepatic CYP1A dependent ERODE activity (7-23 folds) in Nile tilapia exposed to textile effluent, point out that the effluents contain CYP1A inducing organic pollutants which might be contributed to enhance genotoxic potential. The genotoxic prospective of textile industry effluents on fish cell has been shown by evaluation of micronuclei frequencies. Micronuclei are chromosome fragments or complete chromosomes that lag at cell division due to the lack of centromere, damage, or a defect in cytokinesis. Both clastogenic substances (structural damages) and aneugenic substances (alteration in chromosome distribution) form these micronuclei. The formation of alterations in the nuclear envelope as blebbed, lobbed and notched described by Carrasco et al. (1990), has also been reported in fish erythrocytes, as an outcome of xenobiotics exposure. In Nile tilapia, there is an increase in the formation of micronuclei (4 fold), binuclei (6 fold) and nuclear abnormalities (notched, blebbed and lobbed nuclei) in peripheral erythrocytes exposed to textile effluents. The genotoxicity indicates the presence of heavy metals especially cadmium in the textile effluents, though cadmium is a known genotoxicant of fish (Cavas et al. 2005, Cavas & Ergene Gozukara 2003, Perera & Pathiratne 2010). Consequences of prolonged genotoxic stress on native fish populations can be initiation of mutations, accelerated aging of cells, ineffective adaptation to changing environmental conditions. The study of biomarker response of Nile tilapia exposed to textile effluents forms the first study, which employed the biomarkers to evaluate toxicity of textile industry effluents in Sri Lankan waters.

The genotoxicity of water contaminants can be assessed by micronuclei (MN) assay using aquatic organisms. Chlorotriazine reactive azo red 120 (CRARD) textile dyes extensively used in Slovania can induce the erythrocyte micronuclei induction in fish prussian carp, *Carassius auraus gibelio*. The micronuclei formation in the fish erythrocyte was dose and exposure time dependent. So the genotoxicity of the dye was proved and it is better to develop exposure guidelines to the dye (Al-Sabti 2000). The azo dye Reactive Red 120 (RR 120) has genotoxic effects in fingerlings of edible freshwater fish *Catla catla*. The dye exposed fish haemocytes and gill cells have high frequency MN in accordance with the increasing concentration. The gill cells are more susceptible to induction of MN while comparing with that of haemocytes and it was time dependent (Avni & Jagruti 2016).

The freshwater fish, *Mastacemelus armatus* shows notable changes in the ionic regulations of organs such as; liver, muscle and kidney due to the exposure to textile dye acid blue 92 (Karthikeyan et al. 2006). The electrolytes of body fluids contain cations and anions; Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and HCO^{3-} respectively. The maintenance of constant internal ion concentration is essential for the active regulation of water influx, ion efflux and homeostasis in aquatic organisms (Mayer 1992). The Na^+ and Cl^- ion concentration of liver, kidney and muscle was decreased while treating with the dye acid blue 92, and concentration of K^+ and Ca^{2+} was increased. So the ion concentration of body fluids also employed as the biomarker of textile effluent contamination.

The toxicological studies use the histology for the evaluation of physiological state of the animal. The textile mill effluents (TME) from Ichalkaranji, Kolhapur, India having unusual range of pH, alkalinity, hardness, chloride, sulphate, TDS, COD, BOD and heavy metals show conspicuous changes in the histopathology of fish gills (Nikalje et al. 2012). The freshwater fish, major carp *Labeo rohita* exposed to TME confirmed the destruction of gills by shortening of secondary lamella, damaged sinus in the primary gill lamella, reduced basal cell cover, spoiled mucosal cells and necrotic basal cells. The chronic doses of the TME were formed in the massive destruction in the architecture of *Labeo rohita* gill and mild gill hyperplasmia was also resulted. Histological analysis appears to be very susceptible and is crucial in determining the cellular changes that may occur in the target organs like gills, liver and kidney (Dutta 1997). The fish common carp (*Cyprinus carpio*), one of the widely cultured freshwater edible species, were exposed to textile effluents from Kanchipuram, near Chennai, India (Kowsalya et al. 2013). The histopathological changes observed in gills include; congestion, degeneration, fusion and degeneration of secondary lamellae. So histological investigation may confirmed to be a cost effective tool to determine the health of fish population, and reflects the health of the entire aquatic ecosystem in biomonitoring process.

Several histopathological changes were also observed in the fish *P. reticulata* after the exposure to the textile dyeing industry effluent. The gill, most targeted organ of pollutant covers a major portion in the body remains in contact with outer environment. The gill of treated fish shows enlargement of primary gill bar and detachment of secondary gill bar. The liver of the fish shows cytoplasmic vacuolation and clustering of nuclei after the exposure of textile dyeing industry effluent. The histological study of intestine results in the disintegration of intestinal villi and infiltration of haemocytes into the lumen. These toxicological effects were due to the sublethal concentration of TD industry effluent. There was mortality in the bioassays when the fish were treated with higher or lethal concentration of TDE (Selvaraj et al. 2015).

The textile dyeing industry effluents from Bhiwandi, Maharashtra, India causes the haematological alterations in fish *Oreochromis moassambicus* after an exposure of 96 hours (Amte & Mhaskar 2013). Fish blood is widely used in toxicological research and environmental monitoring as a capable indicator of physiological and pathological indicator. The major haematological parameters include haemoglobin (Hb), red blood corpuscles (RBCs), white blood corpuscles (WBCs), packed cell volume (PCV), MCH and mean corpuscular haemoglobin concentration (MCHC). The untreated effluent shows variation in physico-chemical parameters such as pH, TSS, BOD, COD, oil & grease, alkyl benzene sulphonate (ABS), residual chlorine and ammonical nitrogen while the treated effluents show remarkable improvement in the water quality. In the case of untreated effluent exposed fish, the Hb concentration shows dynamic variation, RBCs and WBCs count significantly decreased, PCV and MCHC increased and MCH decreased. In the fish exposed to treated effluent, the parameters were altered actively, but not in a harmful manner. The changes as in the case of untreated effluent are an adaptation to cope up with the stressful condition.

CONCLUSION

Textile industries have dreadful effects on the environment, especially in aquatic ecosystems. The chemical determination of any persistent pollutant concentration in water and sediment would not provide information on the severity of contamination, mainly in the case of sublethal levels. Therefore, biomonitoring using key species of the ecosystems has become inevitable to predict the potential risk of persistent contaminants, which is helpful in formulating the safe levels of chemicals having bioaccumulation potential. The effluents from textile industry cause undesirable changes in the physico-chemical properties of surface water almost in world around. These changes will destruct the aquatic organisms extensively. The fish, a non-target species can be successfully employed as an indicator species of water contamination by textile effluents due to their sensitivity and measurable responses to xenobiotics. For assessing textile effluent or textile chemical pollution appraisal, several biological markers are suggested which include ion concentration of body fluids, quantification of enzymes, genotoxictiy, haematology and histopathology, etc.

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