

## Chapter

# Algae Toxins and Their Treatment

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## Abstract

Algae are distributed worldwide in the sea, in freshwater and in wet situations on land. Most are microscopic algae, but some of them are so large, also some marine seaweeds that can exceed 50 m in length. The algae have chlorophyll and can make their own food through the steps of photosynthesis. Recently they are classified in the kingdom of protists, which include a variety of unicellular and some basic multinuclear and multicellular eukaryotic organisms that have cells. Algal poisoning is an intense, often lethal condition caused by high concentrations of toxic blue-green algae (more commonly known as cyanobacteria—literally blue-green bacteria) in drinking water as well as in water used for recreation, agriculture and aquaculture. The study cur in the productive dangerous from the algae toxin that productive from cyanobacteria in aquatic environment. The important contamination for water source identification and non-identification and identify on algae that responsible on productive of toxin in water that represented by *Cylindrospermum*, *Aphanizomenon Anabaena*, *Microcystis*, *Lyngbya*, *Oscillatoria*, *phormidium*, and suitable environment for algae to productive toxin. Such as temperature, pH, nutrient, salinity, density identify on the toxin concentration in water that content organisms that productive toxin between (1–100 mg/l). With the use of different methods of treating algal toxins such as (potassium permanganate, activated carbon, oxidation, chlorine and ozone), and the best treatment was the use of potassium permanganate at a concentration (2 mg/l), which gave the best treatment while preserving the ecosystem.

**Keywords:** microalgae, toxin, treatment, harmful algal bloom, cyanobacterial toxins, potassium permanganate

## 1. Introduction

The enrichment of lakes and reservoirs with nutrients leads to an increase in the growth of algae, especially cyanobacteria, forming floating masses on the surface, causing a decrease in the concentration of dissolved oxygen and death in fish, and the death of livestock and other animals as a result of ingesting algae toxins. Filamentous cyanobacteria and green algae (Chlorophytes) cause clogging in filters of water treatment systems or problems in industrial systems when such water is used. The dinoflagellates are another group of phytoplankton that can secrete toxic substances. One of the by-products of algal blooms are high concentrations of organic carbon [1]. Increased phosphorous concentration and low P:N ratio are major factors for such a condition, and several studies indicate that toxins from cyanobacteria pose a health risk. According to the World Health Organization (WHO), the maximum acceptable concentration of the toxic substance (Microcystin-LR) in tank water that may be used for drinking is

(0.5–1.0 µg/cubic decimeter), as exposure to an increase of this substance causes liver cancer. Human exposure to this type of poison is possible because it is difficult to carry out a complete treatment of cyanobacterial toxins in drinking water plants. Cyanobacteria also cause the death of animals when they ingest these toxins and also lead to a lack of oxygen and the death of fish [2]. Algae are distributed worldwide in the sea, in freshwater and in wet situations on land. Most are microscopic algae, but some of them are so large, also some marine seaweeds that can exceed 50 m in length. The algae have chlorophyll and can make their own food through the steps of photosynthesis. Recently they are classified in the kingdom of protiste, which include a variety of unicellular and some basic multinuclear and multicellular eukaryotic organisms that have cells. Algal poisoning is an intense, often lethal condition caused by high concentrations of toxic blue-green algae (more commonly known as cyanobacteria—literally blue-green bacteria) in drinking water as well as in water used for recreation, agriculture and aquaculture. Severe illness of livestock and Fatalities, birds, pets, fish and wildlife from high growths of cyanobacteria water blooms occur almost in all of the countries in the world. Severe deadly poisonings have also been notarized in people. Poisoning usually comes during warm seasons when the water blossom are more acute and of longer duration. Almost poisonings come among animals drinking cyanobacteria infested freshwater, but aquatic animals, mostly mariculture fish and prawn, are also affected. The toxins of cyanobacteria comprise six special chemical classes collectively called cyanotoxins [3]. Toxic algae, micro-algal blooms, phytoplankton blooms, red tides, or harmful algae, are all terms for normally occurring phenomena. Around 300 species of micro algae are notify at times to form mass appearance, so called blooms. About one fourth of these species are recognized to produce toxins. The scientific society points out to these events with a generic term, ‘Harmful Algal Bloom’ (HAB), understanding that, because a wide range of organisms are implicated and some species have toxic impacts at low cell intensity, not all HABs are ‘algal’ and not all occur as ‘blooms’ [4]. Many of the organisms in charge for red tides are closely distributed and, in recent years, the organisms appear to be markedly spreading. Natural events such as hurricanes can spread over organisms, and it is doubtful that some organisms may be moved long distances in ship ballast waters. Another factor that may motivate algal proliferation in both freshwater and marine systems is augmentation nutrient loading. Certain algae occur more usually in some areas than others and it is useful to know which ones are problems in particular locations. Good sources of information about algal blooms are the State public health department or the State division of marine resources or marine fisheries [5].

## **2. Pollutant removal**

### **2.1 Sources of water pollution**

Water, especially surface water, is exposed to the dangers of pollution, as the water source is considered polluted when it directly or indirectly changes its composition or condition as a result of human action, that is, if it becomes less suitable for some or all uses. These include sewage, household waste, hospital wastewater, and rainwater, where these pollutants are loaded with large quantities of various organic and inorganic materials and many types of microorganisms that cause many diseases, as well as urination, defecation, and throwing dead animals into the water, especially in rural areas, as well as picnic places represented by excreta. and food waste, where the type of sewage network systems plays a major role in the aggravation of these

pollutants, as there are two types of sewage network systems in Baghdad, which are the separate system and the combined system. Also, the term (red tide) is considered to refer to types of Plankton (phytoplankton) that are spread in high density in any water body (may reach more than ten million cells per liter) and are known as harmful algae. Of the (4400 species) of Plankton plant there are only from (50–60 poisonous species). One of the most important spread of the phenomenon of red tide is a defect in environmental factors, including the difference in the ratio of phosphorous to nitrogen through sewage pollution. The higher the phosphorous rate in the water mass, the higher the rate of red tide or harmful algae appearing with the availability of other environmental conditions. The effects of the red tide are the destruction of fish from economic fish farms if this phenomenon spreads in the farm and costs thousands or even millions of dollars annually. The eyes, nose and mouth are irritated during the presence of algae toxins in the tourist beaches. The toxins increase the toxicity rate of marine food, which is transmitted to humans through marine meals (**Figure 1**).

## 2.2 Definite sources pollution

Industrial and domestic flows result in high concentrations of pollutants that find their way into natural waters, and they are among the primary factors that lead to the deterioration of water quality. As it is known, one of the reasons for the occurrence of nutritional enrichment is the influx of these pollutants containing high concentrations of nutrients estimated at more than (four times) than what is present in natural waters. Therefore, reducing or limiting these sources of pollution is the first successful and important step for water quality management. It is easy to control the known sources of pollution using treatment methods, the most important and most effective of which is the establishment of wet areas (Wetlands) (**Figure 2**).

## 2.3 Non-definite sources pollution

Sources that cause problems that are difficult to control and unknown sources of pollution prepare more nutrients resulting from the modification that humans make



**Figure 1.**  
*Fish damage through the spread of toxin-producing algae.*



**Figure 2.**  
*Nutritional enrichment in the waters of the Iraqi marshes.*

in nature such as deforestation, agriculture, industrial and urban development. These sources supply fresh water with low concentrations of nutrients, but it is difficult to control because they are transferred to water bodies from the vast surrounding lands. The preparation of these sources increases in the heavy rainy season, which leads to erosion in the surface of the soil and then filtering of these nutrients from the soil to the aquatic organisms. Man directly and indirectly affects the occurrence of the phenomenon of food enrichment from several aspects, in addition to the industrial, household and agricultural waste it raises. There are many sources of pollutants affecting the Tigris River, including human pollutants, industrial pollutants, agricultural pollutants, and pollutants resulting from groundwater, and thus affected the physical, chemical and biological characteristics, which can be broadly classified into:

- A. Pollutants affecting the physical properties:** Some toxic pollutants lead to a change in the color, turbidity, taste or temperature of the water.
- B. Pollutants affecting chemical properties:** They represent organic and inorganic substances that make water toxic and dangerous and affect public health and aquatic life through their impact on the pH value or the water content of salts and minerals.
- C. Pollutants affecting biological properties:** Pollutants that affect aquatic organisms in general, including microorganisms that have an impact on human health (bacteria and viruses). These pollutants also play a major role in the phenomenon of eutrophication of some algae and aquatic plants.

## 2.4 Cyanobacterial toxins

Cyanobacteria create a variety of toxic secondary metabolites that are detrimental to a variety of other organisms. Scientists feel that these pollutants are currently posing a serious threat to society's health in numerous parts of the world. The toxins

produced by cyanobacteria and the species that produce them are listed in **Table 1**. Toxins produced by cyanobacteria are divided into two categories: cytotoxins and biotoxins [7]. The varieties of algal toxins produced by various blue-green algae, as well as their impacts, are listed in **Table 1**.

#### 2.4.1 Cytotoxins

This type of toxin is produced by some marine cyanobacteria species, and while it has no harmful effects on animals, it is poisonous to cells generated in cell cultures and inhibits the growth of a wide spectrum of microorganisms. Toxins such as these are examples (Tolytoxin, Tubericidin, Scytophycins and Actiphycins). Indolocarbazoles, tautazoles, microbilinisonitriles, and paracyclophares are more examples).

#### 2.4.2 Biotoxins

These compounds are made by cyanobacteria, which can have a variety of negative health consequences on humans and animals, and are frequently lethal. Toxins are categorized into three categories: neurotoxins, hepatotoxins, and endotoxins [7].

#### 2.4.3 Neurotoxins

Alkaloids are poisonous in a short amount of time and are usually lethal, as they cause paralysis of the surrounding skeletal muscles, followed by paralysis of the respiratory muscles, resulting in incapacity to breathe and death. Several forms of these toxins have been identified (e.g., *Oscillatoria* and *Trichodesmium*).

- i. **Anatoxin:** It is produced by the species (*Anabaena flos-aquae*) with a molecular weight of (765 Da), and it is also produced by species of the genus (*Oscillatoria*) as well.

Toxin types	Cyanobacteria genera	Effect of toxins
Hepatoxins Microcystin Nodularin	<i>Anabaena</i> , <i>Anabaenopsis</i> , <i>Aphanocapsa</i> , <i>Hapalosiphon</i> , <i>Microcystis</i> , <i>Nostoc</i> , <i>Oscillatoria</i> , <i>Nodularia</i>	These toxins directly affect the zooplankton community, especially those that prefer cyanobacteria species as an important food source for them
Neurotoxins Anatoxin-a Homoanatoxin-a Anatoxin-a (s) Saxitoxin	<i>Anabaena</i> , <i>Aphanizomenon</i> , <i>Cylindrospermum</i> , <i>Microcystis</i> , <i>Oscillatoria</i> , <i>Phormidium</i> . <i>Anabaena</i> , <i>Oscillatoria</i> , <i>Anabaena</i> , <i>Aphanizomenon</i> , <i>Cylindrospermopsis</i> <i>Lyngbya</i>	Infection with these types of toxins leads to the inability to breathe and then death through paralysis of the respiratory muscles
Cytotoxin Cylindrospermopsin	<i>Aphanizomenon</i> , <i>Cylindrospermopsis</i> , <i>Umezakia</i>	Its toxic effect on the liver, but it was found that it affects the kidneys as well, causing the destruction of the tissues that it attacks
Lipopolysaccharides (LPS)	Many species of Cyanobacteria	These substances have a toxic effect that causes ill health in humans, and it was also found that they are fatal to mice when injected into the peritoneal membranes

**Table 1.**  
 Cyanotoxins with public health significance from acute exposures [6].

- ii. **Homoantoxin:** It is also produced by the type (*Oscillatoria rubescence*), and it is less toxic than the first type [8].
- iii. **Anatoxin-a(s):** It is produced by species of the genus (*Anabaena*), which is about ten times more toxic than the first and differs from it in its chemical composition and has a molecular weight of 252 Da.
- iv. **Paralytic Shellfish Poisons (PSPs):** The complicated set of 18 toxins that paralyze crustaceans is grouped into three classes (saxitoxin, gongyautoxins, and C-toxins), and these toxins are usually produced by species (*Aphanizomenon flos-aquae* and *Anabaena circinalis*). These toxins are thought to have a quick neurological effect by interrupting nerve communication by closing sodium channels, but they have no effect on potassium permeability.

## 2.5 Hepatotoxins

Toxins of this sort cause a variety of types and strains that belong to the genera (*Microcystis*, *Anabaena*, *Nodularia*, *Cylindrospermopsis*, *Oscillatoria* and *Nostoc*). These toxins are the most frequent among cyanobacterial toxins, and they have a strong toxic impact. However, they take longer to kill than neurotoxins, and death can take anywhere from 5 min to a few days, depending on numerous factors such as the animal's weight, the type of poison, and the dose. These toxins are divided into three categories [9].

### 2.5.1 Microcystins

They're monocyclic seven-chain peptides with an unique amino acid named Adda connecting the side chains. Because the peptide ring comprises five amino acids that are used in the synthesis of all forms of microcystins produced by the species (*Microcystis aeruginosa*), it was named after it. Other species from the genera (*Oscillatoria*, *Nodularia*, *Anabaena*, *Nostoc*) and others are used to make it. So far, more than a million microcystins have been identified (60 species). Microcystins MC-LR, MC-RR, and MC-YR are the most frequent and poisonous kinds of microcystins. Microcystins have a molecular weight of 909–1044 Da, depending on the species. Microcystins are known for their long-term resilience to high temperatures, however it has been discovered that they can tolerate boiling without denaturation. It withstands pH changes and dissolves easily in water, ethanol, methanol, and acetone, and cells require energy to consume the poison [10].

### 2.5.2 Nodularin

It's a pentacyclic monocyclic peptide that looks a lot like MC-LR but is smaller. The peptide ring has a molecular weight of 824 Da and comprises amino acids similar to those found in MC-LR. Only one variety has been identified as being produced by the species (*Nodularia spumigena*), and this proliferation has a poisonous impact identical to that of MC-LR.

### 2.5.3 Cylindrospermopsin

It is one of the toxins produced by the type (*Cylindrospermopsis mceberskii*), and it is the only alkaloid compound among the hepatotoxicants, as it shares this

characteristic with neurotoxins, and its toxic effect is not limited to the liver, as it has been discovered that it also affects the kidneys, causing tissue destruction [11].

## 2.6 Endotoxins

It refers to the lipo polysaccharide (LPS) that forms the cell wall of cyanobacteria, and it has been discovered that these chemicals are hazardous to humans. When injected into the peritoneal membranes at a dose of (1–1.2 mg/kg after 48 h), it was likewise proven to be deadly to rats [12].

## 3. Toxic effect of microcystins

Many researches have confirmed that the compounds produced by various varieties of cyanobacteria are harmful to many animals and humans, as they have been discovered to cause the death of many creatures in many parts of the world, including cattle, horses, dogs, birds, fish, and crocodiles. These toxins have a direct impact on society Zooplankton, particularly those that prefer cyanobacteria species as a major food source, such as the genus *Daphnia*, where it was discovered that low concentrations of these toxins reduce the ability of these organisms to reproduce new generations, as well as their members' growth rates. Toxic levels above a certain threshold cause death [13]. The use of water contaminated with microcystins in the dialysis process in a hospital's hemodialysis unit, which resulted in damage Acute hepatitis, confirms the seriousness of these toxins, as the worst accident recorded so far occurred in 1996, with the victim (60 patients) due to the use of water contaminated with microcystins in the dialysis process. Due to the usage of recycled water for drinking, Western culture is one of the societies most exposed to these poisons, as proven by two occurrences in Australia. Due to pollution of drinking water with these chemicals, the first victim (139 children) and a number of adults became infected, resulting in severe liver, hematuria, renal failure, and death. The high concentration of toxin in the drinking water was caused by the chemical treatment of water containing blooming algae (*Microcystis aeruginosa*) with copper sulfate  $\text{CuSO}_4$ , which is commonly employed to kill algae cells. High body temperature, skin rash, enteritis, general weakness, lack of appetite, pallor of mucous membranes, vomiting, diarrhea, liver poisoning, and death within hours or days, depending on the amount of dose given and the weight of the animal, are common signs of microcystin poisoning. The most common cause of death is an abrupt bleeding within the liver. Microcystins, according to the majority of researchers in this subject, have a stimulating influence on the growth of malignant tumors when consumed low concentrations and for long periods [14].

## 4. Hazards resulting from algal toxins

Environmental parameters such as temperature, illumination, pH, salinity, macro- and micronutrients are among the most important regulators of toxins production from blue-green algae, according to environmental studies in continuous cultures of algae. Microcystins and Anatoxin-a are maintained to a significant extent inside the cell. Because the degree of (Microcystins) harm to the environment and neighboring creatures increases as the logarithmic length of growth increases, the presence of (Microcystins) cannot be overlooked. According to certain research, the quantities of

toxins in water containing creatures that emit toxins range from (1–100 g/l) and can be higher, and as a result, (microcystins) are among the contents that pose a health risk and have an effect if the water has been ingested from change the detoxification of cyanobacteria and their cells [15].

## 5. Algae producing toxins

Algae producing toxins:



*Anabaena fertilissima.*

*Lyngbya martensiana*

*Microcystis aeruginosa*



*Microcystis flos-aquae*

*Nostoc carneum*

*Lyngbya connectens*



*Oscillatoria curviceps*

*Oscillatoria sancta*

*Oscillatoria tenuis*



*Anabaena oscillorides*

*Phormidium favosum*

*Nostoc punctiforme*



## 6. Methods for treating algal toxins

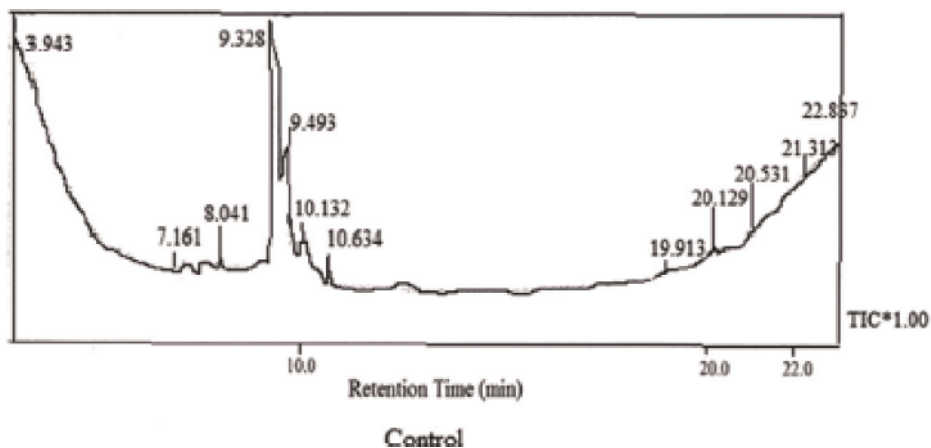
### 6.1 Treatment of algal toxins

#### 6.1.1 *potassium permanganate*

After reducing the quantity of algae that produces food enrichment (excessive growth), a potassium permanganate mixture with a concentration of 30 mg/l textured alum as coagulate was used. The concentrations of chlorophyll algal toxins per transaction were examined and compared to the standard at the end of the 72-h experiment mediated by the GC/MS device, in addition to reducing the productivity of the initial algae by reducing the concentrations of chlorophyll algal toxins per transaction. The results revealed the presence of algal toxins belonging to the groups Neurotoxins, Hepatotoxins, Pyriproxyfen, Emodin, Brevetoxins-10 (A), and Cytotoxins in the standard treatment, with a note detoxification algal 100% concentrations of 8 and 16 mg/l, respectively, textured potassium permanganate in comparison to the standard, which contained a lot of chemical compounds to algal toxins (**Figure 3**).

A result of the cessation of photovoltaic installation process stops the outer wall systems (systems enzymatic) to withdraw nutrients that enter into the composition of the algal toxin combination the non-arrival of light to stop light receptors [16], and the concentrations of 2 and 4 mg/l for the same article have some toxic compounds converted into non-toxic compounds and **Figures 4–8** describe them. Were treated toxins algal belonging to the group Neurotoxins a Besnfein Anatoxin-a, Homoanatoxin-a and the various toxins which is alkaline compounds Alkaloids with effect very quickly called and can be fatal in most cases where the cause muscle surrounding paralysis followed by a respiratory muscle paralysis, which leads to an inability to breathe then death.

These toxins, as seen in Hepatotoxins group Class Microcystin-LA, are the most common among toxins Cyanobacteria and have a severe impact, but death takes longer than nerve toxins, ranging from 5 min to a few days depending on several factors such as the weight of the animal, the type of poison, and the dosage, among others. Other forms of toxins, such as Pyriproxyfen, Emodin, and Brevetoxins-10, were shown to be effective in removing algal toxins that had emerged within the



**Figure 3.**  
GC-MASS of algal toxins within the treated standard.

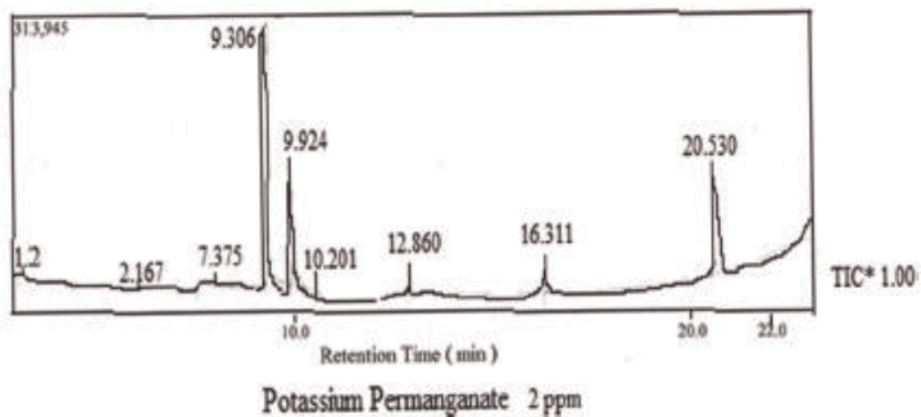


Figure 4.  
GC-MASS of algal toxins within concentration of 2 mg/l.

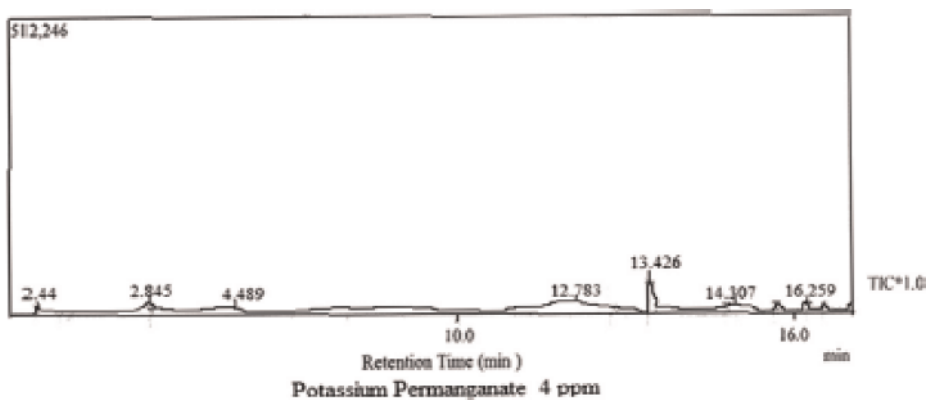


Figure 5.  
GC-MASS of algal toxins within concentration of 4 mg/l.

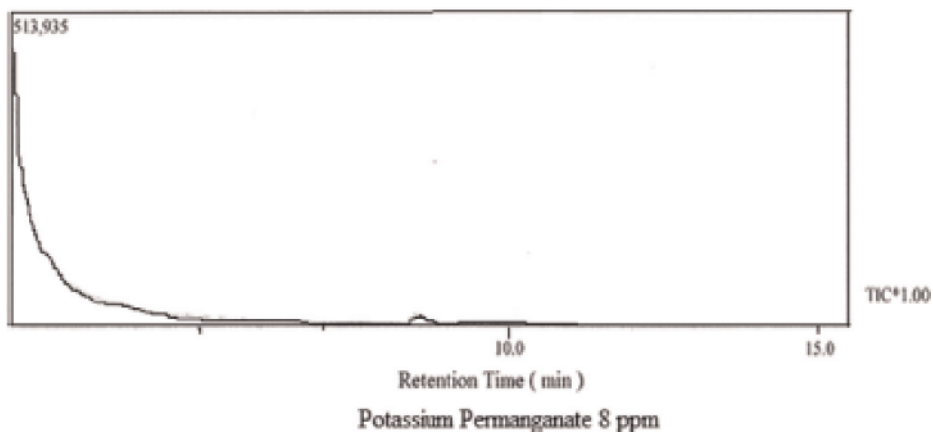
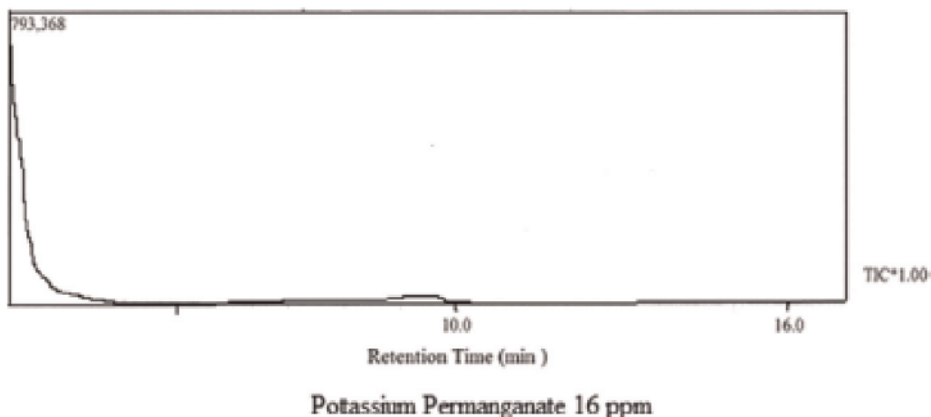
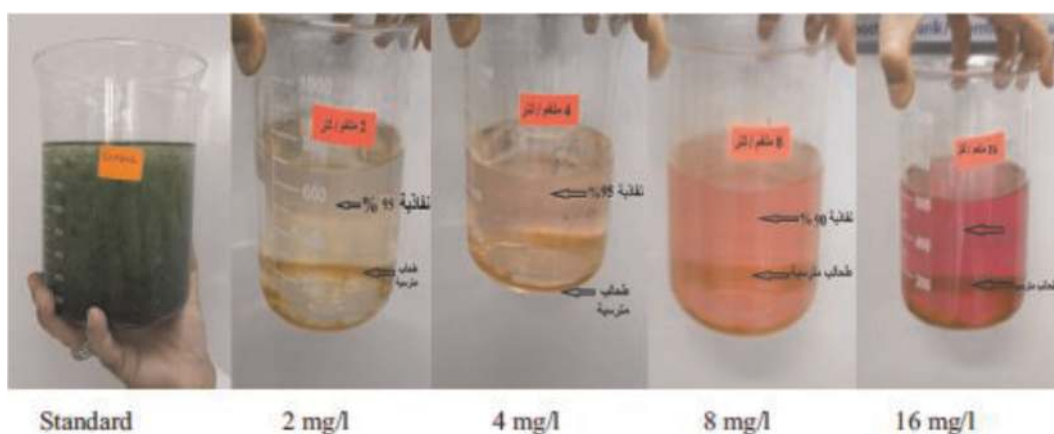


Figure 6.  
GC-MASS of algal toxins within concentration of 8 mg/l.



**Figure 7.**  
GC-MASS of algal toxins within concentration of 16 mg/l.



**Figure 8.**  
Concentrations of potassium permanganate and its impact on algae society compared to standard.

conventional treatment of 8 and 16 mg/l potassium permanganate, as shown in **Table 2**.

The same material with concentrations of 2 and 4 mg/l has been converted into non-toxic and hazardous chemicals, as indicated in **Table 2**. The current study also suggests that potassium permanganate at concentrations of 8 and 16 mg/l, respectively, could be used to treat algal cells by stopping photosynthesis and disabling all vital events without tearing the outer wall of the moss, and then deposition blocs blooms to the pelvic floor and a rise in turbidity levels in the water column, as opposed to the standard, which shows a rise in biomass value and low turbidity **Figure 8**. Furthermore, all potassium permanganate concentrations of 2, 4, 8, and 16 mg/l had no effect on the algae's outer wall. This is because to the potassium permanganate mixture's precise concentration of alum, which caused the algae's exterior wall to not tear, preserving the outer toxic blooming. It inhibits photosynthesis, resulting in a decrease in the primary productivity of chlorophyll-producing algae, solution Alum is necessary for the production of potassium permanganate and aids in the sintering, coagulation, and sedimentation processes [17]. Furthermore, potassium permanganate affects some algal toxins but not others, as it affects the toxins anatoxin-a, cylindrospermopsin, and microcystin and analyses have valued the final removal,

Algal toxins	Synthetic version of the toxin	Standard	Concentrations of potassium permanganate (mg/l)			
			2	4	8	16
1-Neurotoxins Anatoxin-a	C <sub>2</sub> H <sub>3</sub> C <sub>12</sub> NO	*	-	-	-	-
	C <sub>9</sub> H <sub>13</sub> NO <sub>2</sub>	*	-	-	-	-
	C <sub>18</sub> H <sub>27</sub> NO <sub>3</sub>	*	-	-	-	-
	C <sub>11</sub> H <sub>12</sub> N <sub>2</sub> O <sub>6</sub>	*	-	-	-	-
	C <sub>11</sub> H <sub>17</sub> N <sub>3</sub> O	*	-	-	-	-
	C <sub>10</sub> H <sub>17</sub> N <sub>3</sub> O	*	-	-	-	-
	C <sub>9</sub> H <sub>15</sub> Br <sub>2</sub> NO	*	-	-	-	-
Homoanatoxin-a	CH <sub>4</sub> N <sub>2</sub> O <sub>2</sub>	*	-	-	-	-
	C <sub>11</sub> H <sub>17</sub> NO <sub>2</sub>	*	-	-	-	-
	C <sub>13</sub> H <sub>9</sub> BrN <sub>2</sub> O <sub>3</sub>	*	-	-	-	-
2-Hepatotoxins Microcystin- LA	C <sub>3</sub> H <sub>7</sub> NO <sub>4</sub> S	*	-	-	-	-
3-Pyriproxyfen	C <sub>20</sub> H <sub>29</sub> NO <sub>3</sub>	*	-	-	-	-
4-Emodin	C <sub>15</sub> H <sub>10</sub> O <sub>5</sub>	*	-	-	-	-
5-Brevetoxins-10(A)	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	*	-	-	-	-
6- Cytotoxins	C <sub>2</sub> H <sub>2</sub> Cl <sub>3</sub> NO	*	-	-	-	-

-, absence of toxins.  
\*, The presence of toxins.

**Table 2.**

Treatment of algal toxins of different concentration of potassium permanganate with chemical formulations statement mediated by GC-MASS.

while it does not affect saxitoxin toxin, despite the fact that it is produced by algae greens blue—this is what the organization confirms [18].

### 6.1.2 Activated carbon

The use of activated carbon for the removal of a wide range of organic compounds, including numerous algal toxins, is a well-accepted treatment approach. Powdered activated carbon (PAC) and granular activated carbon (GAC) can both be used as a physical process to adsorb toxins in source water, while GAC can also be used as a biological process to degrade toxins by allowing bacteria to grow on GAC media (instead of sand or anthracite) in rapid gravity filters. The nature of the source water, particularly the sort of toxins and competing natural organic matter (NOM) constituents present, has a significant impact on the efficacy of the adsorption or biological process. Operators should consider improving reactivation and replacement frequency based on the seasonal prevalence of blue-green algae if GAC is currently being used. Because algal toxin occurrences occur on a regular or seasonal basis, the use of PAC can be beneficial because it may be introduced sporadically to the traditional treatment procedure to react to the presence of toxins in a relatively cost-effective manner.

PAC can be added before coagulation and removed in the settling tanks, or it can be added after coagulation and removed by filtering. When employing PAC, keep in mind that it must be removed by a downstream operation and discarded, as PAC is rarely reused or regenerated. When utilizing PAC, detention times must be considered to ensure that enough time is provided for adequate adsorption removal. Prior to coagulation, PAC basins are occasionally employed, but care must be taken to ensure that the PAC adsorption rate correctly accounts for any NOM compound competition for adsorption sites. For details on selection and dosing, contact your PAC supplier.

### *6.1.3 Oxidation*

Chlorination (gaseous elemental chlorine, liquid sodium hypochlorite, or calcium hypochlorite), chloramines, chlorine dioxide, potassium permanganate, and ozone are all examples of oxidation in this section. UV with hydrogen peroxide is also demonstrated. Because most oxidants will lyse the blue-green algae cells present and release their toxins, peroxidation (the administration of an oxidant at any point in the treatment process prior to filtering) is not suggested. To keep the cell structure intact and the toxins contained, blue-green algae cells should be removed during the coagulation process before adding an oxidant if at all possible (i.e., intracellular). Water systems should consider using a weaker oxidant such as potassium permanganate if pre-oxidation is required for acceptable turbidity and/or organic carbon removal.

### *6.1.4 Chlorine*

Chlorine reacts with microcystins, cylindrospermopsin, and saxitoxins to a lesser amount. Anatoxin-a does not seem to react well with chlorine. In addition, saxitoxin inactivation works best at higher pH levels, whereas microcystin inactivation works best at lower pH levels. The pH of the water and the presence of NOM affect the reactivity of chlorine with contaminants. Depending on the water quality circumstances, the contact time (CT) values necessary for the elimination of microcystins with free chlorine may be many times higher than those required for the surface water treatment rule. Chloramine and chlorine dioxide in commonly used levels have not been shown to be effective against any of the four poisons. Chloramines are effective against microcystins at very high doses and over long periods.

### *6.1.5 Ozone*

Microcystins, anatoxin-a, and cylindrospermopsin react more quickly with ozone than with other common oxidants. Saxitoxin is the one that is least affected by ozone. Only 20% of the saxitoxins present would be destroyed under equivalent settings when microcystins would be fully removed. Although hydrogen peroxide alone is ineffective in removing pollutants, ozone combined with hydrogen peroxide is significantly more powerful (**Table 3**).

	Anatoxin-a	Cylindrospermopsin	Microcystin	Saxitoxin
Chlorine	Not effective	Effective	Effective	Somewhat effective
Chloramine	Not effective	Not effective	Not effective	Inadequate information
Chlorine dioxide	Not effective	Not effective	Not effective	Inadequate information
Potassium permanganate	effective	Date ranges from not effective to possibly effective	Effective	Not effective
Ozone	Effective	Effective	Effective	Not effective
UV/advanced oxidation	Effective	Effective	Not effective	Inadequate information


**Table 3.**  
*General effectiveness of blue-green algal toxin inactivation with specific oxidants [19].*

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