



Linear Alkylbenzene Sulphonate in Freshwater Ecosystems: Sources, Persistence, Bioaccumulation and Impacts on Fish Health – A Critical Review

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ABSTRACT

Linear alkylbenzene sulphonate (LAS) is one of the most widely used anionic surfactants and so it is used mainly in detergents for the household, cleaning, and personal care products. The massive quantity of LAS consumed makes it very often introduce into freshwater environments through different routes such as domestic sewage, industrial discharge, and urban drainage. Environmental monitoring data collected from different places show that LAS levels in surface waters are usually between 0.01 to 1.2 mg L⁻¹ and in untreated sewage systems it is much higher ranging from 5 to 20 mg L⁻¹. Although LAS is recognized as readily biodegradable under aerobic conditions, its environmental persistence in sediment and oxygen-depleted zones increases with degradation half-lives of 30-40 days. Studies on bioaccumulation performed on different types of fish have already shown the existence of bioconcentration factors in the range of 100 to 500, where variation comes mainly from the differences in the length of alkyl chains. The chronic exposure scenarios reveal that Las (Linear Alkylbenzene Sulfonates) have a negative impact on fish health through various physiological mechanisms such as damage to gill tissues, the development of oxidative stress, disturbance of the activity of enzymes, and the impairment of the reproductive system. The current paper reviews very comprehensively the whole process of exposure of freshwater fish to LAS, which includes the sources in the environment, fate processes, bioaccumulation dynamics, and toxicological consequences, especially the ecological risks linked with the continuous low-level exposure of the aquatic systems receiving wastewater inputs to the environment.

Keywords: water pollution, cuticle agent, piscine toxicity, Shrimp batter, additional environmental endurance, and seepage of wastewater.

1. Introduction

The current industrial era has seen the production of synthetic surfactants to a greater extent than ever before and their use to a larger extent as well, global manufacturing capacity now being more than 15 million tonnes per year. Among this astonishing production of anionic surfactants about 65 percent, which is the largest portion, owing to their superior cleaning efficacy, functional versatility, and cost-effectiveness in various applications. In the comprehensive range of anionic surfactants that the market offers, linear alkylbenzene sulphonate (LAS) has a particularly strong

position, as it is estimated to cover around 35–40 percent of total anionic surfactant consumption of the world. This large market share points to the essential role of LAS in the cleaning and industrial sectors of today's world.

The chemical development of linear alkylbenzene sulfonate (LAS) and its eventual widespread commercial usage took place in the 1960s, mainly due to the environmental issues caused by its chemical predecessor, branched alkylbenzene sulphonates (BAS), which had been under scrutiny for some time. BAS, with its branched-chain structure, was very difficult to biodegrade in the water and, therefore, caused continuous foam formation in rivers, lakes, and even wastewater treatment plants of many industrial countries. The environmental crisis that arose compelled both government and industry to take action, paving the way for the superior eco-friendly chemical LAS to be introduced. The structure of LAS enables microbes to effectively break it down through beta-oxidation pathways, thus marking a major advancement over the previous branched formulations.

Still, the huge amount of LAS used and its constant, unstoppable release into the water has. Lesser but significant ecological impacts are feared on freshwater ecosystems. To add to it, freshwater bodies receiving municipal wastewater discharges and industrial effluents act as sinks for LAS and other surfactant compounds. The background concentrations in rather clean, non-contaminated river systems usually remain under 0.01 mg L^{-1} , which means that the impact of humans is negligible there. On the other hand, urban and industrial areas' rivers usually show concentrations of 0.05 to 0.6 mg L^{-1} , and in some heavily affected rivers, the level may even go up to 1.2 mg L^{-1} . Even though, in most cases, environmental concentrations are significantly below acute toxicity thresholds for aquatic organisms, the continuous accumulation of scientific proof reveals that long-term exposure to environmentally relevant LAS concentrations can cause considerable sub-lethal physiological effects. The physiological effects of such exposures are particularly felt by fish populations which, due to their role in the aquatic food webs, longevity and sensitivity to water quality degradation, are the prime biological indicators of ecosystem health. Thus, comprehending the whole story of the LAS, including its sources, environmental fate, bioaccumulation behavior, and toxicological effects in freshwater systems, will be a prerequisite for effective environmental management and preservation of aquatic biodiversity.

2. Sources of LAS in Freshwater Ecosystems

2.1 Domestic Sources and Household Contributions

The largest and most important source of LAS that gets into municipal wastewater treatment and collection systems is household detergent consumption, which contributes around 60-70% of the total LAS load in the urban areas most affected by this. The high-volume and continuous input stream that residential using detergents, such as laundry detergents, and dishwashing plus general-purpose cleaners, creates is the main source of LAS. Per capita detergent consumption is very different in various geographical areas, cultural contexts, and socio-economic conditions and it usually varies from 6 to 10 kilograms per person annually in developed countries. This usage pattern corresponds to LAS levels in domestic wastewater before any treatment processes that vary between 4 and 15 mg L^{-1} .

Variability in domestic LAS concentrations over the different households indicates the difference in each household size, washing machine efficiency, consumer behavior, and product formulation preferences. A large proportion of the LAS from the households in those regions where the wastewater infrastructure is inadequate, treatment plant operation is unreliable, or systems experience mechanical failures or hydraulic overloading, may find its way into the receiving water bodies with little or no attenuation. In addition, even in well-managed treatment systems, it is rare to achieve complete removal, and the typical removal efficiencies are 90 to 99 percent, thus the residual concentrations contribute to the environmental loading.

2.2 Industrial Sources and Manufacturing Discharges

Another significant route of LAS entering freshwaters is through industrial facilities, where some manufacturing sectors are especially responsible for a disproportional high loading. The textile industry is one of the main sources of LAS in industrial effluents due to the large amounts of surfactants consumed in dyeing, washing, and finishing processes, often resulting in wastewater with LAS concentrations of over 10 mg L⁻¹. Leather tanneries using surfactants in degreasing, tanning, and finishing processes generate wastewater with a LAS concentration of 5-20 mg L⁻¹. Besides, LAS is used in the pulp and paper industry in the coating process and the food industry produces surfactant containing wastewaters due to cleaning and sanitation operations. These sources of industrial waste in total release LAS effluents in the concentration of around 1 to 25 mg L⁻¹, which varies according to the type of industrial process, operational practices, and the degree of water recycling used.

Without having the tertiary treatment technologies in place, advanced physicochemical treatment processes and comprehensive effluent management systems, about 40 percent of industrial LAS may, eventually, be discharged directly into the receiving water bodies. This discharge, in turn, raises the environmental concentration levels in the industrialized watersheds and may even lead to the formation of small areas with high contamination right next to the discharge points. The timing and consistency of industrial discharges, which are typically marked by batch releases or operational cycles, can cause occasional spikes in the groundwater LAS levels that are higher than the chronic exposure threshold levels for the sensitive aquatic species in the area, therefore, causing harm to those species.

2.3 Urban Runoff and Agricultural Sludge Application

Apart from the direct discharge of wastewater, LAS also infiltrates through extra diffuse sources into freshwater where monitoring and control are much harder. This chemical has a very strong tendency to get adsorbed onto both organic matter and mineral surfaces, which leads to a large accumulation of LAS in sewage sludge during primary and secondary treatment of wastewater. As a result, the concentrations in sewage sludge are reported to be between 1,000 and 15,000 mg kg⁻¹, which is a concentrated reservoir of LAS that has been removed from the aqueous phase.

The use of this contaminated biosolid material on agricultural fields as a soil amendment or fertilizer substitute—such practice is very common in many regions that are trying to reuse sludge beneficially—makes LAS vulnerable to the environment's multipath mobilization. When it rains, surface runoff can carry LAS-contaminated soil particles directly to rivers and lakes next to agricultural lands. Subsurface leaching through the soil strata might move dissolved LAS to the groundwater that later gets surfaced through surface water flow. These indirect agricultural sources constantly and for a long time supply the freshwater systems with LAS that could last for months or years after the initial sludge application, making it more difficult to reduce environmental concentrations by simply improving wastewater treatment.

Table 1: The Leading Sources of Light-Activated Sludge Entry into Freshwater Systems

Source Category	Contribution (%)	LAS Concentration Range	Key Characteristics
Domestic Wastewater	60–70%	4–15 mg L ⁻¹	Continuous discharge; detergent use
Industrial Effluents	20–30%	1–25 mg L ⁻¹	Variable; sector-dependent
Urban Runoff	5–10%	0.1–2 mg L ⁻¹	Storm-event dependent
Agricultural Sludge	5–10%	1,000–15,000 mg kg ⁻¹	Diffuse; long-term release

3. Environmental Persistence and Fate Processes

3.1 Biodegradation Kinetics and Environmental Half-Lives

Essentially, microbial degradation processes dictate the environmental fate of LAS, and these processes are to a great extent determined by the prevailing redox conditions, temperature regimes, and the composition and adaptation of the microbial community. In an aerobic environment, which is typical of well-operated activated sludge wastewater treatment systems, LAS is subjected to degradation by bacteria capable of using surfactants as carbon and energy sources. Biodegradation half-lives in these engineered systems are usually between 1 and 3 days, which is a clear indication of the optimized conditions such as high temperatures (20–25°C), plenty of oxygen, large microbial biomass, and populations that have already been adapted to surfactant metabolism due to the continuous exposure.

Nevertheless, there is a huge shift in the biodegradation kinetics of LAS when it is released into natural surface water environments, which are, to the microbe's-kind of-conditions, quite a hostile place for slow microbial transformation. Usually, the rivers' and lakes' indigenous microflora are not so much adapted to the degradation of surfactants, and the concentration of microbial biomass is trillions of times lower than in activated sludge, and many factors, such as seasons and day-and-night cycles, cause wide fluctuations in environmental conditions. In such natural water environments, LAS half-life prolongs to 5-10 days in summer, provided the conditions are favorable, with considerable variability coming from water temperature, dissolved oxygen, nutrient availability, pH, and the presence of inhibitory substances, among other factors. The temperature effects are of particular importance, and the degradation rates are reduced by a factor of 2 to 5 during the cold winter months that are characterized by suppressed microbial metabolic activity.

In anaerobic environments, the persistence of LAS increases significantly, especially in sediment matrices where the oxygen penetrates only a few millimeters or centimeters of the surface. In these oxygen-depleted conditions, the microbial pathways that could lead to LAS transformation are so limited that degradation takes place much slower through alternative anaerobic processes. Half-lives reported in anaerobic sediments vary from 25 to 40 days, which is an order of magnitude increase, when compared to the degradation in aerobic surface water. The prolonged persistence in sediments is of great ecological importance since about 20-30% of LAS being introduced into the water, eventually gets adsorbed on the particles and settles down to form a reservoir of contamination in the lake bottom which is, however, very quiet. This sediment-bound LAS, on the other hand, can affect the communities of sensitive benthic invertebrates, as well as be a long-term contamination source of the water column through periodic resuspension during high-flow events and gradual desorption processes.

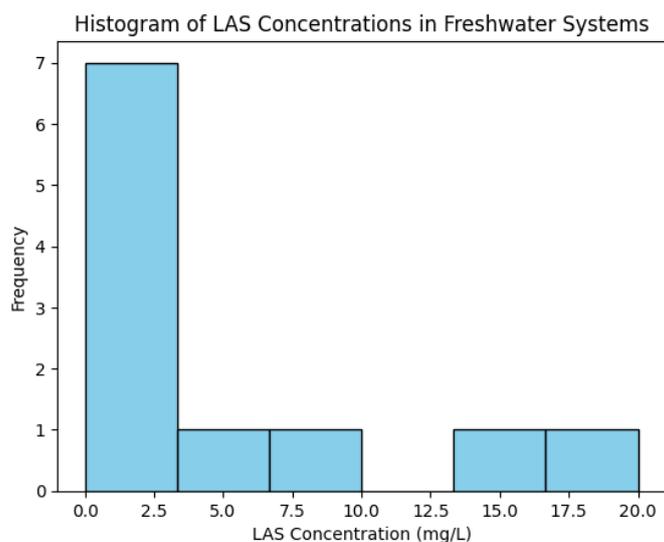
3.2 Adsorption Behavior and Environmental Partitioning

LAS is a substance that displays a moderate hydrophobic character caused by its structure similar to that of alkylbenzene, and the log K_{ow} values for it fall between 2.7 and 3.6 according to the alkyl chain length. The homologs with a longer chain will show more hydrophobicity and better partitioning to organic matter and particulate phases. The hydrophobic nature of LAS is a factor that influences its distribution and fate in the environment, determining the degree to which LAS will remain in the water and become associated with suspended particles and bottom sediments. Distribution coefficients of sediments to water (K_d), which are obtained from field and laboratory studies, usually range from 500 to 2,000 liters per kilogram, thus indicating a moderate to strong affinity for the sediment phases. Such partitioning traits promote the accumulation of the substance in the benthic zones where the LAS levels in the pore waters and sediment solids may be very high, even hundreds of times higher than those in the water column above,

thus leading to localized exposure conditions that are particularly concerning for the organisms living at the bottom because they are the most affected.

Table 2: Laser recording past physics research and development knowledge built upon these developments, and these results have been published as hopefully, rewarding the past American physics research.

Environmental Compartment	Typical LAS Concentration	Half-Life / Persistence	Key Factors
Untreated Sewage	5–20 mg L ⁻¹	N/A	Source material
Activated Sludge Systems	Variable	1–3 days	Aerobic; adapted microbes
Surface Waters (pristine)	<0.01 mg L ⁻¹	5–10 days	Temperature; oxygen
Surface Waters (urban)	0.05–0.6 mg L ⁻¹	5–10 days	Continuous loading
Heavily Impacted Waters	0.6–1.2 mg L ⁻¹	7–15 days	High loading; inhibition
Anaerobic Sediments	10–100 mg kg ⁻¹	25–40 days	Oxygen limitation
Sewage Sludge	1,000–15,000 mg kg ⁻¹	Variable	Strongly adsorbed



4. Bioaccumulation Potential in Aquatic Organisms

LAS is not - according to regulatory frameworks such as the Stockholm Convention criteria or EU REACH legislation - a highly bioaccumulative substance but rather a subject of measurable portable animals' accumulation when they are exposed to concentrations that are environmentally relevant. The bioaccumulation potential of LAS is a product of the various factors that are involved in this process, which include uptake (mainly through gill membranes and dietary ingestion), distribution to different tissue, metabolic biotransformation, and elimination through gills, kidneys and bile. The Fish bioconcentration factors (BCF), which are the ratio of tissue concentration to water concentration at steady state, typically range between 100 and 500 across various species and exposure conditions. The moderate BCF values fall below the threshold of 2,000 that is generally used to classify substances as

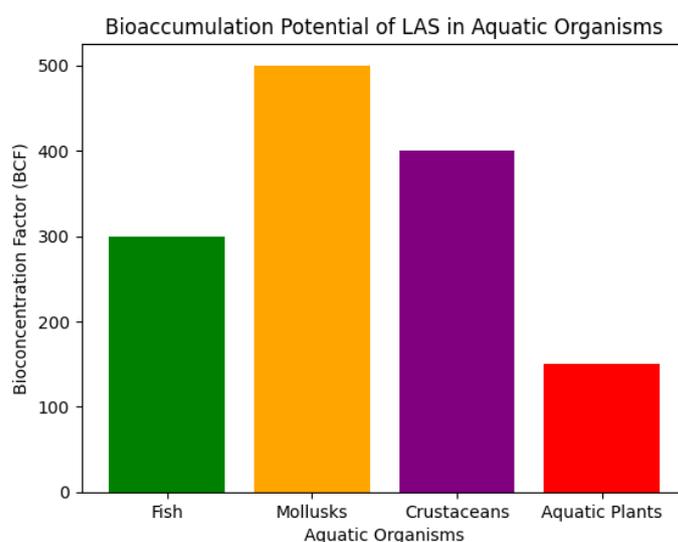
bioaccumulative, yet they are still high enough to cause tissue concentrations that may be two to three orders of magnitude higher than the surrounding water.

Invertebrate forms like mollusks (e.g., clams and mussels) and crustaceans are generally considered as having a slightly higher bioconcentration potential, since their BCF values are reported to be between 200 and 800. The higher concentrations of pollutants in the case of invertebrates might be due to the differences in the processes of life, the capacity to metabolize, and the efficiency of excretion compared with fish. The distribution of LAS in fish remains different among the various tissues. The distribution is marked by a very high concentration in gills, liver and to a lesser extent in fat, which are the primary sites for the fish's contact with dissolved LAS in water and for the metabolism and detoxification of xenobiotics, respectively. Studies of tissue concentrations in fish (exposed to 0.1 mg L⁻¹ for 21 days under laboratory conditions) report LAS levels of 2–10 mg kg⁻¹ wet weight, which correspond to bioconcentration factors of 20 to 100 within the range of values reported.

Once the fish stop being exposed to the LAS and are moved to fresh water, they get rid of those that got accumulated quite fast. The time it takes for half of the LAS to be eliminated from their bodies varies from 3 to 7 days and this is influenced by species, temperature, and their physiological condition. This short elimination half-life reveals that LAS is not the kind of chemical that would bioaccumulate to a large extent and the levels of the substance in the body are in a constant state of change according to the environmental exposure concentrations. However, in case of constant environmental exposure typical of wastewater-impacted systems, fish populations would then be able to keep their body concentration levels high, which is in turn contributing to the chronic toxicity and physiological stress.

Table 3: Bioconcentration Factor (BCF) and Tissue Distribution of LAS in Aquatic Organism

Organism Group	BCF Range	Primary Accumulation Sites	Elimination Half-Life
Fish (general)	100–500	Gills, liver, kidney	3–7 days
Mollusks	200–800	Digestive gland, gills	5–10 days
Crustaceans	150–600	Hepatopancreas, gills	4–8 days
Aquatic Plants	50–200	Root tissues, leaves	Variable



5. Impacts on Fish Health and Physiological Function

5.1 Acute Toxicity and Species Sensitivity

The acute toxicity of LAS to freshwater fish is quite different in the case of different species but all these factors which include the distribution of alkyl chain lengths, fish species, life stage, water quality parameters, and exposure duration have an impact. The standardized 96-hour median lethal concentration (LC_{50}), that is, the concentration at which 50 percent of the exposed individuals die within four days, gives a background measure of acute toxic potential. For the rainbow trout (*Oncorhynchus mykiss*), a frequently tested cold-water species, the reported 96-hour LC_{50} values vary between 2 and 5 mg L⁻¹. The common carp (*Cyprinus carpio*), a warm-water species that usually tolerates more pollution than the cold-water ones, has LC_{50} values of about 3–7 mg L⁻¹. Zebrafish (*Danio rerio*), which is becoming a popular model organism in ecotoxicological research, shows slightly higher sensitivity with 1–3 mg L⁻¹ LC_{50} values. Typically, these thresholds for acute toxicity are one to two orders of magnitude higher than the environmental concentrations that can be usually found in surface waters. This indicates that it is quite rare to have field situations where acute mortality events are solely caused by LAS exposure. Nevertheless, the life stages of juvenile and larval fishes show always higher sensitivity than adult fish, with the toxicity ratios showing that the early life stages are about 1.5 to 2 times more sensitive than adults. This difference in sensitivity, which has significant ecological repercussions, since the processes of reproduction and recruitment may be affected at the concentrations that are harmless to the adult population. Besides, the environmental presence of other stressors or co-pollutants might cause the toxic interactions to be either additive or synergistic in nature, which may lower the effective toxicity thresholds below those determined in laboratory exposures with single chemicals.

5.2 Sub-lethal and Chronic Effects on Fish Physiology

Chronic exposure to environmentally relevant LAS concentrations causes various sub-lethal effects which are of greater ecological significance than acute mortality. A lot of laboratory and field studies have shown that long-term exposure to very low concentrations of 0.05-0.1 mg L⁻¹, which is the range typically found in urban waterways, causes physiological impairments that can be detected in various organ systems. Gill tissues are one of the main targets of LAS toxicity because they are the most sensitive respiratory structures. These gills are the ones that come into direct contact with the contaminants dissolved in water and their epithelium is very thin, which is good for gas exchange but not good for preventing the entry of toxic substances.

Consistently, histopathological analyses of gill tissues from LAS-exposed fish show the presence of the following conditions: epithelial hyperplasia, which is characterized by the abnormal increase and thickening of gill epithelial cells, and lamellar fusion, where Neighboring gill lamellae link to each other through the growing of the tissue. Such changes in structure greatly limit the respiratory function because they increase the distance for the diffusion of oxygen from the water to the blood. The oxygen uptake efficiency is measured to be reduced by 20 to 35 percent in chronic LAS- exposed fish compared to the unexposed ones, thus; these fish have no option but to increase the ventilation rates to keep the tissues well oxygenated. Apart from the fact that this respiratory effort is increased, it also translates to an energetic cost that could lead to the reduction of energy available for growth, reproduction, and other life functions that are considered to be essential.

At the cellular and molecular levels, the LAS effect has different pathways causing oxidative stress. One of the pathways is the disruption of the electron transport chain in mitochondria, another is the modification of the membrane structure and function and lastly, there is the inhibition of the antioxidant systems in the cell. Biochemical tests show oxidation of lipids to the extent of 30 to 60 percent, which is a marker of membrane damage, in the liver

and gill tissues of fish that had been kept for the past two to four weeks in a solution of 0.1 mg L^{-1} LAS. The activities of the two main antioxidant enzymes, superoxide dismutase (SOD) and catalase (CAT) are concurrently lowered significantly by 25 to 40 percent. This decrease reduces the ability of the cell to kill the reactive oxygen species and to heal oxidative damage. The situation of more oxidative damage and less antioxidant defense is a fertile ground for cellular malfunction, DNA injury, and, over time, an eventuality of being classified among the cancer-causing agents due to long exposure.

5.3 Reproductive and Developmental Toxicity

One of the most notable ecological ramifications of the continual exposure to LAS that are of great concern, particularly for the fish population, is the latter's reproductive capacity and early life stage development, since the impacts here extend directly to population and recruitment sustainability. Studies with chronic exposure over reproductive cycles reveal that adult fish exposed to LAS levels of $0.02\text{--}0.05 \text{ mg L}^{-1}$, which are normally found in streams with moderate pollution, seriously suffer from reproductive problems. Fecundity, indicated by the number of eggs laid per female, is reduced by 15–30% in comparison with controls that have not been exposed. This decline in egg production denotes endocrine disruption, reduced energy allocation to reproduction caused by the increased metabolic costs of detoxification, and perhaps even direct gonadal toxicity.

Parental exposure to LAS has a negative impact on eggs and makes them unviable even when they are produced. In case of egg hatchability, which is measured as the percentage of fertilized eggs that have undergone embryonic development and turning into free-swimming larvae, it has been a significant reduction to the range of 20–40% for the young ones of parents that were exposed to LAS. Embryonic defects such as skeletal malformations, heart defects, and failure to develop the swim bladder are more regularly seen during the parental exposure to LAS. The larvae that succeed in hatching are impaired in the sense that they have to grow slower, with the length and weight of the measurement being around 25% less than the controls at the same developmental stages. This growth retardation, in turn, results in the larvae having lower chances of surviving as they are smaller and therefore more susceptible to being eaten, starving, and being affected by the environmental changes. The combined effects of reduced fertility, lower hatchability, and poor survival of larvae can greatly decrease effective recruitment in the fish populations that were exposed, thus causing the populations to decline at the level of a few generations.

Table 4: Common Freshwater Fish Species: Acute and Chronic Toxicity of LAS

Fish Species	96-h LC_{50} (mg L^{-1})	Chronic Effect Level (mg L^{-1})	Primary Effects Observed
Oncorhynchus mykiss (Rainbow trout)	2–5	0.05–0.1	Gill damage, reduced growth
Cyprinus carpio (Common carp)	3–7	0.1–0.2	Oxidative stress, enzyme changes
Danio rerio (Zebrafish)	1–3	0.02–0.05	Developmental toxicity, reduced fecundity
Pimephales promelas (Fathead minnow)	2–4	0.05–0.1	Reproductive impairment

Table 5: Sub-lethal effects of chronic LAS exposure in fishes

Biological Endpoint	Exposure Concentration	Effect Magnitude	Ecological Significance
Gill Epithelial Damage	0.05–0.1 mg L ⁻¹	Moderate to severe	Reduced respiratory efficiency
Oxygen Uptake Reduction	0.1 mg L ⁻¹	20–35% decrease	Increased metabolic cost
Lipid Peroxidation	0.1 mg L ⁻¹	30–60% increase	Cellular damage
Antioxidant Enzymes (SOD, CAT)	0.1 mg L ⁻¹	25–40% reduction	Compromised defense
Fecundity	0.02–0.05 mg L ⁻¹	15–30% reduction	Population recruitment
Egg Hatchability	0.02–0.05 mg L ⁻¹	20–40% reduction	Reproductive success
Larval Growth Rate	0.05 mg L ⁻¹	~25% reduction	Survival probability

6. Ecological Risk Assessment and Environmental Management

Ecological risk assessment is a comprehensive process that provides risk evaluation based on the prediction and impact of environmental contamination on aquatic ecosystems. For the assessment of LAS in freshwater systems, the risk quotient (RQ) approach is mainly used in the risk characterization which involves the comparison of the predicted environmental concentrations (PEC) with predicted no-effect concentrations (PNEC) based on toxicity data. The representative PEC value of 0.1 mg L⁻¹ is usually established through the monitoring data of urban streams affected by wastewater. The PNEC is found by dividing chronic toxicity endpoints by certain safety factors thus resulting in a value of about 0.02 mg L⁻¹ for safeguarding the most susceptible fish species and life stages.

The risk quotient that was calculated as PEC over PNEC gave a value of 5 for the average urban freshwater ecosystems that receive treated wastewater. Standard risk assessment guidelines indicate that RQ values of more than 1 mean there is a possible problem with the ecosystem, while RQ values of more than 5 mean that there is a great risk to the ecosystem and management intervention is required. Thus, the present study pointed out that the LAS levels in some freshwater bodies that are receiving wastewater are so high that they are almost always a cause for concern regarding the fish population, mainly because of their effects on growth, reproduction, and physiological functions through chronic exposure to the lower than lethal doses.

LAS presents a larger ecological risk than previously thought, mainly because of the factors that are usually ignored by the standard risk assessments. First and foremost, environmental exposures often comprise intricate mixtures of LAS homologs that have different alkyl chain lengths, along with various co-occurring contaminants that include other surfactants, pharmaceuticals, personal care products, and industrial chemicals. The resulting mixture effects may cause either additive or synergistic toxicity that goes beyond the individual compound assessment predictions. Secondly, seasonal changes in river flow, temperature, and the ability of wastewater to dilute create an exposure

concentration that varies over time with the lowest and summer periods for flow having peak exposures that may even exceed the thresholds for acute toxicity. Thirdly, the distribution of LAS in water bodies is not uniform, and thus, elevated concentrations of LAS in sediments can lead to the formation of localized exposure hotspots for organisms living at the bottom or for fish species that feed at the bottom.

7. Conclusion

Even though LAS is now able to biodegrade much faster than most surfactants, it is still a serious contaminant in global freshwater areas and not easily biodegradable. The widespread utilization of AS in domestic and industrial practices leads to constant dispersion of the chemical into water bodies at levels that could cause chronic toxicity to the most vulnerable fish species and life stages. Although acute death incidents are rare at usual environmental concentrations, laboratory, and field studies so far have provided evidence that sub-lethal effects like gill function impairment, oxidative stress response, and decline in reproduction are occurring at concentrations that are usually found in urban rivers receiving treated sewage water.

The environmental persistence of LAS in anaerobic sediments, moderate bioaccumulation potential in aquatic organisms, and impacts on fish physiology and reproduction documented together present a strong case for the need of improvement in wastewater treatment technologies and more rigorous regulatory monitoring. Advanced treatment processes such as membrane bioreactors, activated carbon adsorption, and advanced oxidation processes have been proved to be very effective in the elimination of LAS, but their implementation needs a big investment in the existing infrastructure. Source reduction strategies like the creation of alternative surfactants that are more rapidly biodegradable, and product formulations optimization for less environmental loading, are complementary to the ecological risk; they are just different approaches to the same solution.

There are several significant knowledge gaps that need to be addressed through further research to upgrade our understanding of the ecological impacts of LAS and to devise better management strategies. First, it is necessary to conduct long-term studies at the population level that would allow the assessment of the demographic impacts of chronic low-dose exposure throughout the life cycles of several fish generations. This would help establish the sustainability of the population by validating the inter-species transfer of effects from individual to population level. Second, field studies determining the extent of LAS exposure and its effects on wild fish populations subjected to practical mixture exposures would serve as a critical point of validation for toxicity endpoints derived from laboratory experiments. Third, the study of possible endocrine disrupting properties, behavioral effects, and fish immunity impacts are the continuing research frontiers which could possibly lead to the identification of new adverse outcome pathways not accounted for in the existing risk assessments. Fourth, the generation and authentication of biomarkers for the early detection of LAS exposure and its effect might open the door for more thorough environmental monitoring programs and timely management action to protect the already stressed freshwater ecosystems.

References

- [1]. Scott, Michael J., and Jones, Michael N. (2000). The biodegradation of surfactants in the environment. *Biochimica et Biophysica Acta (BBA) – Biomembranes*, 1508(1–2), 235–251.
- [2]. Holt, Matthew S. (2000). Sources of chemical contaminants and routes into the freshwater environment. *Food and Chemical Toxicology*, 38(1), S21–S27.
- [3]. Madsen, Torben, Boyd, Henry B., and Nylén, David. (2001). Environmental and health assessment of substances in household detergents and cosmetic detergent products. *Environmental Project No. 615*, Danish Environmental Protection Agency.

- [4]. Lewis, Michael A. (1991). Chronic and sublethal toxicities of surfactants to aquatic animals: A review and risk assessment. *Water Research*, 25(1), 101–113.
- [5]. Temmink, Henk, Klapwijk, Bert, de Kreuk, Merle, and Rulkens, Willem. (1998). Removal of surfactants in activated sludge treatment. *Water Research*, 32(10), 3071–3080.
- [6]. Mungray, Anuradha K., and Kumar, Pankaj. (2009). Fate of linear alkylbenzene sulfonates in the environment: A review. *International Biodeterioration & Biodegradation*, 63(8), 981–987.
- [7]. Tolls, Johannes, Haller, Monika, and Sijm, Dik J. T. H. M. (1999). Extraction and isolation of linear alkylbenzene sulfonates from fish tissue. *Environmental Toxicology and Chemistry*, 18(6), 1170–1177.
- [8]. Versteeg, Dennis J., and Rawlings, John M. (2003). Biodegradation and aquatic toxicity of surfactants. *Chemosphere*, 53(8), 955–964.
- [9]. Cserhádi, Tibor, Forgács, Esther, and Oros, Gyula. (2002). Biological activity and environmental impact of anionic surfactants. *Environment International*, 28(5), 337–348.
- [10]. Tatarazako, Norihisa, and Kawai, Hiroshi. (2008). Acute and chronic effects of linear alkylbenzene sulfonate on freshwater fish. *Environmental Toxicology*, 23(3), 321–328.
- [11]. Sánchez, María I., Martínez-Haro, María, Green, Andy J., and Mateo, Rafael. (2013). Accumulation and effects of surfactants in aquatic organisms. *Environmental Pollution*, 176, 21–28.
- [12]. World Health Organization. (2003). *Linear alkylbenzene sulfonates and related compounds in drinking-water: Background document for development of WHO guidelines*. World Health Organization Press.
- [13]. European Commission. (2007). *Risk assessment report: Linear alkylbenzene sulphonate (LAS)*. European Chemicals Bureau, Joint Research Centre.
- [14]. Ying, Guang-Guo. (2006). Fate, behavior and effects of surfactants and their degradation products in the environment. *Environment International*, 32(3), 417–431.
- [15]. Chen, Bin, Xie, Liang, & Zhang, Jing. (2014). Bioaccumulation and toxicity of anionic surfactants in aquatic organisms. *Ecotoxicology and Environmental Safety*, 102, 116–123.
- [16]. Kimerle, Richard A. (1989). Aquatic and terrestrial ecotoxicology of linear alkylbenzene sulfonate. *Critical Reviews in Toxicology*, 19(1), 1–46.
- [17]. Marcomini, Antonio, Zanette, Monica, & Pojana, Giulio. (2000). Fate of linear alkylbenzene sulfonates in the aquatic environment. *Marine Pollution Bulletin*, 40(8), 684–690.
- [18]. Rand, Gary M., Wells, Patrick G., & McCarty, Larry Scott. (1995). *Introduction to aquatic toxicology*. CRC Press.
- [19]. Volkering, Frits, Breure, Antonie M., & Rulkens, Willem Hendrik. (1998). Microbiological aspects of surfactant use and environmental fate. *Biodegradation*, 9(3–4), 251–268.
- [20]. Ankley, Gerald Thomas, Bennett, Richard Scott, Erickson, Russell James, Hoff, David James, Hornung, Michael Wayne, Johnson, Richard David, Mount, David Ronald, Nichols, James William, Russom, Christine Lynn, Schmieder, Paul Keith, Serrano, Juan Antonio, Tietge, Joseph Edward, & Villeneuve, Daniel Lee. (2010). Adverse outcome pathways: A conceptual framework to support ecotoxicology research. *Environmental Toxicology and Chemistry*, 29(3), 730–741.
- [21]. USEPA. (2005). *Aquatic life ambient water quality criteria for detergents*. United States Environmental Protection Agency.

- [22]. Jobling, Susan, Nolan, Matthew, Tyler, Charles Richard, Brighty, Geoff, & Sumpter, John Peter. (1998). Widespread sexual disruption in wild fish. *Environmental Science & Technology*, 32(17), 2498–2506.
- [23]. van Wezel, Annemarie P., & Opperhuizen, Antoon. (1995). Narcosis due to environmental pollutants in aquatic organisms. *Environmental Toxicology and Chemistry*, 14(1), 7–24.
- [24]. HERA Project. (2013). *Human and environmental risk assessment on ingredients of household cleaning products: LAS*. Human & Environmental Risk Assessment Initiative.
- [25]. Mackay, Donald, Shiu, Wan Ying, & Ma, Kuo-Ching. (1997). *Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals*. CRC Press.
- [26]. OECD. (2002). *Test guideline 305: Bioaccumulation in fish*. Organisation for Economic Co-operation and Development.
- [27]. Walker, Colin H., Sibly, Richard M., Hopkin, Steven P., & Peakall, David Brian. (2012). *Principles of ecotoxicology* (4th ed.). CRC Press.

Cite this Article:

Gargi Singh, "Linear Alkylbenzene Sulphonate in Freshwater Ecosystems: Sources, Persistence, Bioaccumulation and Impacts on Fish Health – A Critical Review", *International Journal of Scientific Research in Modern Science and Technology (IJSRMST)*, ISSN: 2583-7605 (Online), Volume 4, Issue 12, pp. 39-50, December 2025.

Journal URL: <https://ijrmst.com/>

DOI: <https://doi.org/10.59828/ijrmst.v4i12.403>.



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