supply, and sometimes their toxicity becomes stronger. Intermittent nutrient input brought by heavy rain or changes in water flow can cause an algal bloom to occur suddenly if the timing is right (Huang and Liang, 2025). Moreover, phosphorus and other substances released from sediments and dead algae, even if the external nutrient sources are controlled, can allow the algal bloom to persist. This shows that algal blooms caused by eutrophication of water bodies are the result of the combined effect of nutrients introduced from outside and those circulating within the water body. That is to say, to control them, both these types of nutrients need to be controlled, and the long-term nutrient balance between land and water also needs to be managed.

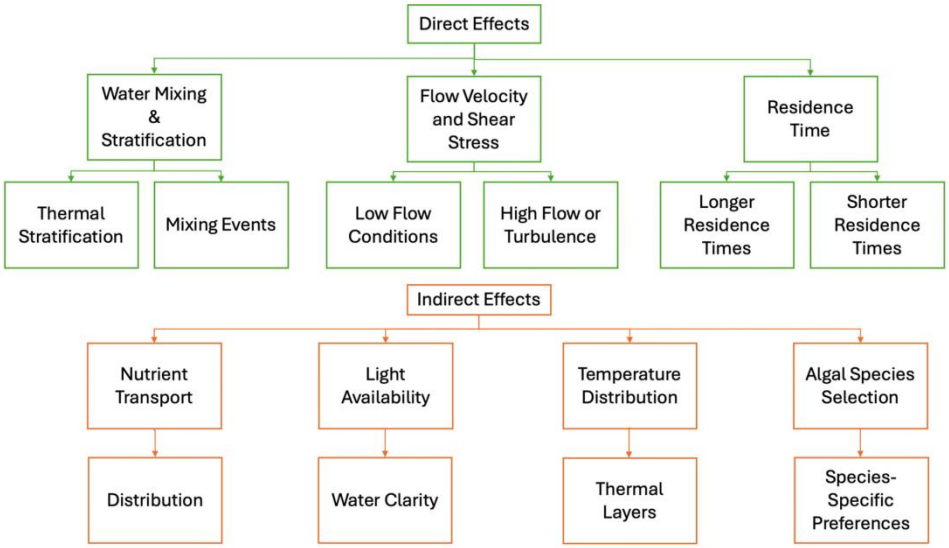

Figure 1 Flow diagram summarizing the mechanisms by which hydrodynamic conditions affect algal blooms in reservoirs, focusing on both direct and indirect effects (Adopted from Brenckman et al., 2025)

2.2 Climate change makes algal blooms more likely to occur

Climate change will cause the water temperature to rise, making the stratification of water layers more stable. At the same time, the flow conditions and the chemical environment of the water body will also change. These changes will provide more favorable conditions for harmful algae to grow, thereby increasing the possibility of algae outbreaks (Feng et al., 2024). When the water surface temperature rises, many cyanobacteria and some toxic marine plankton grow faster, having an easier advantage in competition, and their growth season will also be prolonged. Some species can even expand to regions that were previously colder and difficult to survive, such as higher latitudes or higher altitudes of water bodies. Long-term monitoring data and model studies have shown that in the case of continuous temperature rise and an increase in marine and freshwater heat waves, the range of algae outbreaks in lakes and coastal waters may expand, the duration will be longer, and the toxic risk may also increase (Lan et al., 2024; Wang et al., 2025a). In some bodies of water, the massive proliferation of algae sometimes creates a cycle: when the water surface is covered by a thick layer of algae, it actually absorbs more heat, causing the water temperature to rise even higher. As a result, the algae grow faster (Kuijpers et al., 2025).

Changes in rainfall volume, unstable water salinity, and an increase in extreme weather events all make it easier for algae to undergo large-scale outbreaks. For instance, during heavy rain or storms, more nutrients from the land are washed into lakes or estuaries; while in cases of prolonged drought or slow water flow, the water in lakes and reservoirs cannot flow freely and stays longer. Both of these situations make the already nutrient-rich water bodies more conducive to the rampant growth of algae (Feng et al., 2024; Brenckman et al., 2025). In coastal areas, the increase or decrease of incoming freshwater can affect the salinity of the sea water, and a change in salinity, in turn, can affect the growth of some harmful algae. According to some climate change research predictions, in those areas with relatively low salinity, these algae may grow even more vigorously (Shi et al., 2024). Additionally, ocean acidification, reduced oxygen levels in water, and continuous warming of water temperatures, these factors may also interact with each other to affect the growth of harmful algae, and even cause them to produce more toxins. However, the exact way these factors interact is not yet fully understood. Overall, climate change, the