comprehensive projects such as long-term monitoring, model analysis, and watershed governance can more effectively reduce the risk of harmful algal blooms (Figure 4) (Feng et al., 2024).

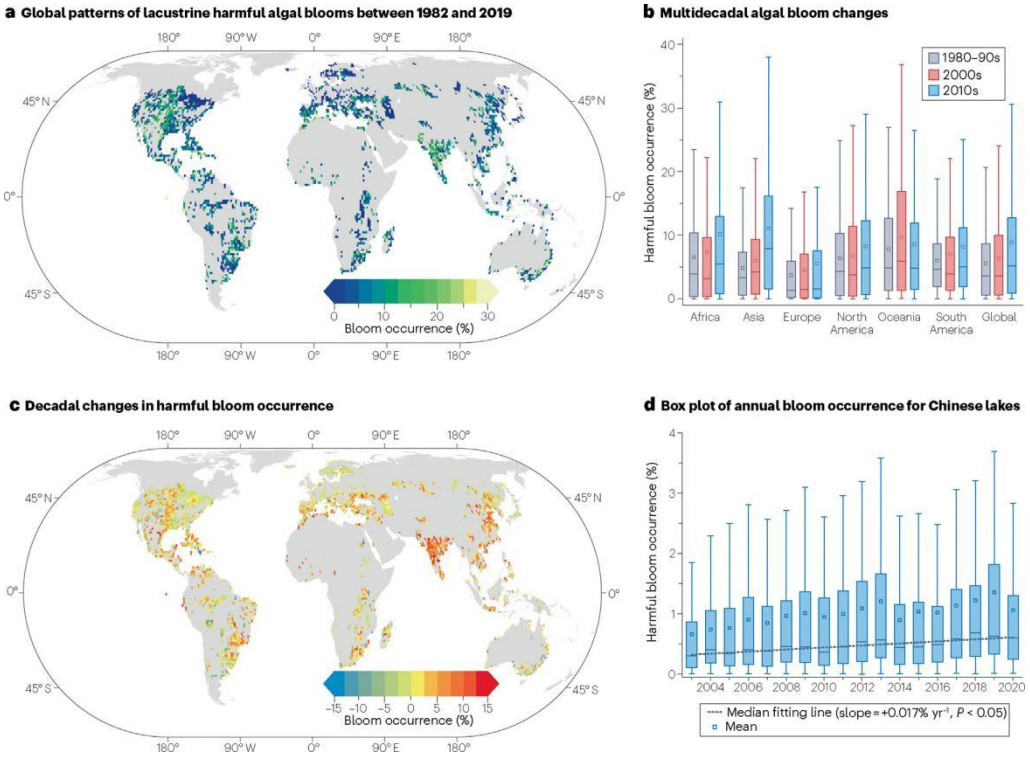

Figure 4 Global patterns and trends in harmful bloom occurrences in lakes (Adopted from Feng et al., 2024)

Image caption: a, Global occurrence patterns of harmful lacustrine algal blooms between 1982 and 2019 aggregated into 1° ×1° grid cells and expressed as a percentage of total observational bloom number over the time period. b, Box plots of harmful algal bloom (HAB) occurrence (%) separated by continent and time period; the bottom and top of the boxes are the first and third quartiles, respectively, the bar in the middle shows the median, and the whiskers show the minimum and maximum values. c, Change in harmful bloom occurrence from the 1980-90s to the 2010s expressed as the percentage change in annual bloom frequency in each location. d, Annual HAB occurrence for large, bloom-affected lakes in China, expressed as a percentage of the total number of bloom-containing pixels over the total number of cloud-free MODIS pixels within a year. The data in panels a – c were extracted from Landsat images1, and the data in panel d are from the Moderate-resolution Imaging Spectroradiometer (MODIS)20. Although most global studies show a general increase in HABs in recent decades, the trends vary by region and time period (Adopted from Feng et al., 2024)

6 Key Challenges in the Management of Harmful Algal Blooms

6.1 High management costs and technical limitations

For a long time, controlling the rampant growth of algae has been a challenging issue. It requires significant investment and often yields unsatisfactory results. Many treatment technologies have limited applicability and are difficult to be widely adopted in large lakes and oceans. For instance, physical methods such as manual water mixing and oxygen enhancement can reduce the amount of algae in certain scenarios, but they consume a lot of electricity and have cumbersome equipment, making them unsuitable for long-term use in large water bodies (Lan et al., 2024). Additionally, new technologies like nanomaterials, ultraviolet treatment, etc., can quickly kill algae, but they are costly, subject to policy and safety regulations, and have ecological risks. Therefore, they have not been widely adopted (Wang et al., 2025c).

On the other hand, advanced early warning technologies such as satellite monitoring, automatic sensors, molecular detection, and machine learning are crucial for detecting and resolving algae problems in advance. However, these systems require continuous capital investment and professional maintenance, and they need to be customized based on different water body conditions (Zahir et al., 2024). In practical applications, these technologies face problems such as insufficient funds and decentralized management responsibilities. Currently,