

Review Article

Sensors Applied for the Detection of Pesticides and Heavy Metals in Freshwaters

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Water is essential for every life living on the planet. However, we are facing a more serious situation such as water pollution since the industrial revolution. Fortunately, many efforts have been done to alleviate/restore water quality in freshwaters. Numerous sensors have been developed to monitor the dynamic change of water quality for ecological, early warning, and protection reasons. In the present review, we briefly introduced the pollution status of two major pollutants, i.e., pesticides and heavy metals, in freshwaters worldwide. Then, we collected data on the sensors applied to detect the two categories of pollutants in freshwaters. Special focuses were given on the sensitivity of sensors indicated by the limit of detection (LOD), sensor types, and applied waterbodies. Our results showed that most of the sensors can be applied for stream and river water. The average LOD was 72.53 ± 12.69 ng/ml ($n = 180$) for all pesticides, which is significantly higher than that for heavy metals (65.36 ± 47.51 ng/ml, $n = 117$). However, the LODs of a considerable part of pesticides and heavy metal sensors were higher than the criterion maximum concentration for aquatic life or the maximum contaminant limit concentration for drinking water. For pesticide sensors, the average LODs did not differ among insecticides (63.83 ± 17.42 ng/ml, $n = 87$), herbicides (98.06 ± 23.39 ng/ml, $n = 71$), and fungicides (24.60 ± 14.41 ng/ml, $n = 22$). The LODs that differed among sensor types with biosensors had the highest sensitivity, while electrochemical optical and biooptical sensors showed the lowest sensitivity. The sensitivity of heavy metal sensors varied among heavy metals and sensor types. Most of the sensors were targeted on lead, cadmium, mercury, and copper using electrochemical methods. These results imply that future development of pesticides and heavy metal sensors should (1) enhance the sensitivity to meet the requirements for the protection of aquatic ecosystems and human health and (2) cover more diverse pesticides and heavy metals especially those toxic pollutants that are widely used and frequently been detected in freshwaters (e.g., glyphosate, fungicides, zinc, chromium, and arsenic).

