Recent Developments in the Speciation and Determination of Mercury Using Various Analytical Techniques

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This paper reviews the speciation and determination of mercury by various analytical techniques such as atomic absorption spectrometry, voltammetry, inductively coupled plasma techniques, spectrophotometry, spectrofluorometry, high performance liquid chromatography, and gas chromatography. Approximately 126 research papers on the speciation and determination of mercury by various analytical techniques published in international journals since 2013 are reviewed.

1. Introduction

Mercury, which is also known as quick silver, is only the metal (Figure 1) in the modern periodic table that exists in liquid form at room temperature. The sources of mercury in the environment include the natural processes, such as breakdown of minerals in rocks and volcanic activities. The anthropogenic sources are not limited to mining and the burning of fossil fuels. Regarding the toxicity of mercury and its different species, methylmercury poisoning affects the nervous system of humans and damages the brain and kidneys [1]. Most of the mercury emitted into the environment is converted to methylmercury, which spreads to the food chain due to the bioaccumulation nature of methylmercury [2]. Owing to the toxicity nature and bioaccumulation nature of mercury, most studies in this area have focused on the determination of mercury and its species in various environmental and biological samples.

Marumoto and Imai [3] reported the determination of dissolved gaseous mercury in the seawater of Minamata Bay of Japan. This study also estimated the exchange of mercury across the air-sea interface. Panichev and Panicheva [4] reported the determination of the total mercury content in fish and sea products by thermal decomposition atomic absorption spectrometry. Fernández-Martínez et al. [5] evaluated different digestion systems for the determination of mercury with CV-AFS (cold-vapor atomic fluorescence spectrometer) in seaweeds. Pinedo-Hernández et al. [6] examined the speciation and bioavailability of mercury in sediments that had been impacted by gold mining in Colombia.

This paper presented the recent developments in this topic after a previous review published in 2013 [2]. The present study reviews the recent developments in the speciation and determination studies of mercury reported and published since 2013. For this purpose, approximately 136 research papers published were reviewed. All the analytical parameters such as limit of detection, linearity range, and interference study reported by the reviewed papers are presented in Tables 1–4 [7–133]. This extensive collection of literature and the analytical parameters of the reviewed papers established the recent developments in the determination and speciation studies of mercury using a range of analytical techniques.

2. Discussion

The toxicity and bioaccumulation nature of mercury has prompted extensive studies to determine the concentrations of mercury species in different environmental and biological samples. This paper reviewed a large number of studies on the determination and speciation of toxic metals including
mercury. The reviews regarding the determination of mercury published since 2013 are discussed hereunder.

Suvarapu et al. [2] reviewed research papers published between 2010 and 2011 regarding the speciation and determination of mercury using a variety of analytical techniques. They concluded that most researchers prefer cold-vapor atomic absorption spectrometry (CV-AAS) and atomic absorption spectrophotometry (CV-AFS) for the speciation and determination studies of mercury in various environmental samples. Suvarapu et al. [134] also reviewed research papers published in 2012 regarding the determination of mercury in various environmental samples. El-Shahawi and Al-Saidi [135] reviewed the dispersive liquid–liquid microextraction (DLLME) method for the speciation and determination of metal ions including mercury. This review concluded that the method of DLLME has the advantages of simplicity, speed, and low cost for the determination of metal ions using various analytical techniques. Ferreira et al. [136] reviewed the use of reflux systems for the sample preparation in the determination of elements, such as arsenic, antimony, cadmium, lead, and mercury. This study concluded that the use of the reflux systems is very rare in the determination of elements, such as Hg. Gao et al. [137] reviewed the application of chemical vapor generation method for the determination of metal ions, such as mercury and cadmium with ICP-MS. Sánchez et al. [138] reviewed the determination of trace elements including mercury present in petroleum products using ICP techniques. This study concluded that the electrothermal vaporization and laser ablation methods were promising for the analysis of petroleum for trace elements. Martin-Yerga et al. [139] reviewed the determination of mercury using electrochemical methods. This study discussed the advantages and disadvantages of the use of different electrodes in the determination of mercury. Chang et al. [140] reviewed the detection of heavy metals, such as cadmium, lead, and mercury in water samples using graphene based sensors. This study concluded that it is a very challenging task to detect heavy metals in water in real time due to the interference of large chemical and biological species in water. Yu and Wang [141] reviewed the determination of metal ions including mercury by atomic spectrometry by applying flow-based sample pretreatment methods. They concluded that the ICP-AES, AAS, AFS, and ICP-MS are the major detection techniques for trace metal analysis. Yin et al. [142] reviewed the speciation analysis of mercury, arsenic, and selenium using a range of analytical techniques. Gao and Huang [143] reviewed the determination of mercury(II) ions by voltammetry and concluded that stripping voltammetry is still an active field of research regarding the determination of mercury. Duarte et al. [144] reviewed disposable sensors and electrochemical sensors for the environmental monitoring of Pb, Cd, and Hg. They recommended the recycling of materials used in sensors for future studies. Recently, Ferreira et al. [145] reviewed the analytical strategies of sample preparation for the determination of mercury in food matrices.

In recent days, few research papers were published about the determination and analysis of mercury species in various environmental and biological samples and some of them are discussed hereunder. Lima et al. [146] reported an efficient method for the determination of mercury in inorganic fertilizers by using CV-AAS combined with microwave-induced plasma spectrometry. Pelcová et al. [147] reported the simultaneous determination of mercury species by LC-AFS with a low detection limit of 13–38 ng L\(^{-1}\). Chen et al. [148] reported a colorimetric method for the determination of mercury ions based on gold nanoparticles and thiocyanate acid. Fernández et al. [149] reported gold nanostructured screen-printed carbon electrodes for the determination of mercury using dispersive liquid-liquid microextraction. Fernández-Martínez et al. [5] evaluated the different digestion systems for determination of mercury in seaweeds using CV-AFS. Silva et al. [150] determined the trace amounts of mercury in alcohol vinegar samples collected from Salvador, Bahia of Brazil. Jarujamrus et al. [151] reported a colorimetric method using unmodified silver nanoparticles for the determination of mercury in water samples. A highly selective method for the determination of mercury using a glassy carbon electrode modified with nano-TiO\(_2\) and multiwalled carbon nanotubes in river and industrial wastewater was reported by Mao et al. [152].

As mentioned in our previous review [2], spectrometric techniques are used widely by many researchers for the determination of mercury over the world. Regarding the determination of mercury with various analytical instruments in the papers reviewed, more than 55% of the researchers used spectrometric instruments, such as atomic absorption spectrometry (AAS), inductively coupled plasma techniques (ICP-OES, AES, and MS), and atomic fluorescence spectrometer (AFS) (Table 1). ICP-MS technique has an advantage of low detection limits and wide range of linearity in the determination of mercury [153]. Around 20% of the researchers chose the spectrophotometer and spectrofluorometer (Table 2) for the determination and speciation of mercury. Approximately 10% of researchers in the papers reviewed used electrochemical instruments for the determination and speciation studies of mercury (Table 3). Only a few authors chose the HPLC, GC, and other techniques (Table 4) but they coupled these instruments with AAS or other instruments. Regarding the analysis of the environmental biological samples for mercury and its species, most researchers analyzed various water samples (drinking, seawater, wastewater, river, and lake waters) followed by food samples (mostly fish), human hair, and ambient air. Only a few authors determined the concentration of mercury in ambient air and atmospheric particulate matter
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD) | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|-------------------------------------------|--------|-------------------------|----------------|----------------|-----------------|-----------------|----------|
| 1         | Total Hg | CV-AAS and ICP-AES | Microwave acid digestion | $4.83 \times 10^{-8}$ M | — | Fish samples | Cadmium and lead also analyzed along with mercury | — | [7] |
| 2         | Hg(II)   | CV-AAS | Preconcentration | $1.79 \times 10^{-8}$ M | — | Water and human hair | Recovery of Hg$^{2+}$ is in the range of 95.6–104.9% in presence of Cu$^{2+}$, Co$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, Mn$^{2+}$, Br$^{2-}$, Pb$^{2+}$, Fe$^{3+}$, Cr$^{3+}$, Al$^{3+}$, Ag$^{+}$, K$^{+}$, Na$^{+}$, NH$_4^+$, Mg$^{2+}$, and Ca$^{2+}$ ions, from 750 to 2500-fold | Dithizone | [8] |
| 3         | Total Hg | CV-AAS | Ultrasound extraction | $6.98 \times 10^{-8}$ M | — | Alcohol vinegar | — | — | [9] |
| 4         | Total Hg | CV-AAS | SPE$^1$ | $4.98 \times 10^{-10}$ M | Rice, canned fish, and tea leaves | The tolerance limit for Na$^+$, K$^+$, Mg$^{2+}$, and Ca$^{2+}$ is 4000-fold, for Ba$^{2+}$ and Zn$^{2+}$ is 40-fold, for Fe$^{3+}$, Cr$^{3+}$, Co$^{2+}$, and Ni$^{2+}$ is 10-fold, and for Al$^{3+}$ is 200-fold compared to Hg$^{2+}$ | Fe$_3$O$_4$ nanoparticles | [10] |
| 5         | Hg(II)   | CV-AAS | SPE | $9.97 \times 10^{-12}$ M | Up to 500 μg L$^{-1}$ | Water samples | As, Al, Fe, Mo, and Sb are depressed the Hg signal | Carbon nanotubes | [11] |
| 6         | Total Hg | CV-AAS | Acid digestion | $3.6 \times 10^{-9}$ M | — | Marine fish | — | — | [12] |
| 7         | Total Hg | CV-AAS | Wet digestion | $3.0 \times 10^{-9}$ M | — | Green tiger shrimp | Arsenic also determined along with mercury | — | [13] |
| 8         | Total Hg | CV-AAS | Alkaline fusion digestion | $0.06$ ng g$^{-1}$ | $0.006–4000$ ng g$^{-1}$ | Phosphate rock | — | — | [14] |
| 9         | THg      | AAS | Acid digestion | $4.98 \times 10^{-12}$ M | — | Fish muscle tissues | Cadmium and lead also detected along with mercury | — | [15] |
| 10        | Hg(II)   | CV-AAS | SPE | $1.19 \times 10^{-11}$ M | $0.01–2.30$ μg L$^{-1}$ | Water samples | Fe$^{2+}$, Ca$^{2+}$, Zn$^{2+}$, Cd$^{2+}$, Co$^{2+}$, and Mn$^{2+}$ are not interfered up to 5 mg L$^{-1}$ and NH$_4^+$ and Ti$^{3+}$ are not interfered up to 1 mg L$^{-1}$ | Polymer supported ionic liquid | [16] |
| 11        | Hg(II)   | CV-AAS | SPE | $9.97 \times 10^{-13}$ M | $0.07–2.00$ μg L$^{-1}$ | Water samples | Tolerable amount of major metals is limited up to 50 μg L$^{-1}$ | Polytetrafluoroethylene | [17] |
| 12        | Total Hg | CV-AAS | Digestion | $3.98 \times 10^{-10}$ M | 2.5–10.0 μg L$^{-1}$ | Biological samples | — | Cold finger | [18] |
| 13        | Total Hg | CV-AAS | Combustion | $2.99 \times 10^{-13}$ M | — | Water and fish | Arsenic and selenium also determined along with mercury | — | [19] |
| 14        | Total Hg | AAS | Amalgamation | $0.2$ ng/g for hair and $0.02$ ng/g for blood | — | Hair and blood samples | Arsenic and selenium also determined along with mercury | — | [20] |
| 15        | Total Hg | CV-AAS (total Hg) and GC-ICPMS (MeHg) | Cold-vapor reduction with NaBH$_4$ | $5.98 \times 10^{-18}$ (total Hg) and $2.3 \times 10^{-8}$ (MeHg) | — | Blood of birds | Selenium also determined along with mercury and methylmercury | — | [21] |
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD) $^*$ | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|-------------------------------|-----------------|-----------------|---------------------|-----------------|----------|
| 16        | Total Hg and MeHg | CV-AAS (total Hg) and CV-AFS (MeHg) | Digestion | 0.03–0.1 ng/g | — | Fish, vegetables, and mushrooms | Selenium and cadmium also determined with mercury species | — | [22] |
| 17        | Hg speciation | CV-AAS (total Hg) and CV-AFS (MeHg) | Acid digestion | — | Water samples | — | — | [23] |
| 18        | Hg speciation | CV-AAS | LLME$^2$ | $1.49 \times 10^{-10}$ M (Hg$^{2+}$) and $1.8 \times 10^{-8}$ M (MeHg) | 0.5–100 ng mL$^{-1}$ | Water samples and CRMs | The recovery of Hg$^{2+}$ in presence of foreign ions is 95–105 and for MeHg is 96–106% | — | [24] |
| 19        | Total Hg | GF-AAS | Acid mineralization | $6.97 \times 10^{-15}$ M | — | Fish muscle samples | — | Copper nitrate | [25] |
| 20        | GEM | AAS | Acid digestion | — | Water samples | — | — | [26] |
| 21        | Total Hg | CV-AAS | Acid digestion | 0.0006 μg g$^{-2}$ | — | Freshwater fish samples | — | Stannous chloride | [27] |
| 22        | Total Hg | AAS (THg) and ICP-MS-HPLC-MeHg | Combustion | 0.01 ng | — | Soil samples | Interference of various heavy metals was overcome by using sample pretreatment | — | [28] |
| 23        | Hg speciation | AAS (THg) and ICP-MS-HPLC-MeHg | Hydride generation | $5.33 \times 10^{-16}$ M | 20 μg L$^{-1}$ | Fish samples | Cd, Pb, As, and Sn also measured along with Hg | — | [29] |
| 24        | THg | HG-AAS | Hydride generation | 98.4% (accuracy) | — | Irrigation water wells | Along with mercury Pb, Cd, and Al Cr also measured | — | [30] |
| 25        | THg | CV-AAS and AAS | Thermal decomposition and amalgamation | $1.34 \times 10^{-9}$ M (TD-amalgamation AAS) and $3.14 \times 10^{-10}$ M (CV-AAS) | — | Soil samples | — | — | [31] |
| 26        | Total Hg | HV-AAS and HPLC-CV-AFS | Extraction | — | — | Aqueous solutions and fish tissue | — | Multiwalled carbon nanotubes | [32] |
| 27        | Total Hg | CV-AAS (DMA) | Microwave oven digestion | — | — | Canned fish | Selenium and tin also measured along with mercury | — | [33] |
| 28        | THg | AMA (AAS) | AAS principles and without digestion process | — | — | Fish red muscle and white muscle | — | — | [34] |
| 29        | THg | AES | LIBS and SIBS | $2 \times 10^{-5}$ M (LIBS) and $9.97 \times 10^{-5}$ M (SIBS) | — | Soil samples | At 534.074 nm has less spectral interference | — | [35] |
| 30        | Hg speciation | CV-AFS | Extraction | $0.001 \times 10^{-12}$ M (Hg$^{2+}$) and $0.002 \times 10^{-12}$ M (DMHg) | — | Sea water and sediments | — | — | [36] |
| 31        | Hg speciation | CV-AFS | Extraction | $3.98 \times 10^{-13}$ M | — | Sea waters | — | — | [37] |
| 32        | Total Hg | CV-AFS | Microwave assisted digestion | — | — | Nuts | Interference of fat in nuts is removed by treatment with chloroform and methanol | — | [38] |
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD)$^a$ | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|-----------------------------|----------------|-----------------|------------------|-----------------|----------|
| 33        | Hg(II)  | AFS                                         | Fluorescence optical sensor | 9.57 $\times$ 10$^{-12}$ M | 2.27 $\times$ 10$^{-11}$ – 1.13 $\times$ 10$^{-11}$ M | Human hair, urine, and well water samples | Most of the alkali, alkaline, and transition metal ions did not interfere in the determination of Hg$^{2+}$ | N-(2-Hydroxy phenyl)-N-(2-mercapto phenyl)-o-phthalaldehyde | [39]    |
| 34        | GEM     | CV-AFS                                      | Gold amalgamation          | 0.0002 ng             | —              | Total suspended particulates | —                | QFF (quartz fiber filters) | [40]    |
| 35        | MeHg    | AAS and CV-AFS                             | Acid digestion             | 0.005 μg/g            | —              | Water, soil, sediments, and foodstuffs | —                | —               | [41]    |
| 36        | Total Hg| CV-AFS                                      | Microwave-assisted digestion | 0.5 ng g$^{-1}$       | —              | Sediments | —                | Sequential injection system | [42]    |
| 37        | Total Hg| CV-AFS                                      | Acid digestion             | 0.48 ng g$^{-1}$      | —              | Rice | Interference of other metal ions is eliminated by acid wash and kept storage of samples for 24 h | Multisyringe-flow injection analysis | [43]    |
| 38        | Hg speciation | HPLC-AFS | UV-induced atomization | 1.9 $\times$ 10$^{-7}$ (Hg$^{2+}$), 1.9 $\times$ 10$^{-8}$ (MeHg), and 2.0 $\times$ 10$^{-11}$ (EtHg) M | 1–5000 ng L$^{-1}$ | CRMs | — | — | [44]    |
| 39        | Hg(II)  | UV-AFS                                      | SPE                         | 1.49 $\times$ 10$^{-3}$ – 3.98 $\times$ 10$^{-10}$ M | 1–5000 ng L$^{-1}$ | Natural waters | 10 mg L$^{-1}$ of Fe$^{2+}$, Fe$^{3+}$, Cu$^{2+}$, Pb$^{2+}$, and As$^{3+}$ and 10 g L$^{-1}$ of Na$^+$, K$^+$, and Ca$^{2+}$ did not interfere in the determination of 100 ng L$^{-1}$ of Hg$^{2+}$ | Sodium diethyldithiocarbamate | [45]    |
| 40        | Hg(II)  | AFS                                         | Micro-SPE                   | 5.98 $\times$ 10$^{-10}$ M | Up to 5 μg L$^{-1}$ | Water samples | — | Mesosyringe platform | [46]    |
| 41        | Hg speciation | EX-AFS | —                                 | 0.5 ng g$^{-1}$ (total Hg) | —              | Waste calcines | — | — | [47]    |
| 42        | Hg speciation | CV-AFS | Extraction                       | ~0.5 pg               | —              | Atmospheric air | — | PTFE filter papers | [48]    |
| 43        | MeHg    | GC-AFS                                      | SPE                         | 12 ng g$^{-1}$       | Up to 1.5 ng mL$^{-1}$ | Biological samples | — | — | [49]    |
| 44        | Hg speciation | HPLC-AFS | Liquid-liquid microextraction | 1.54 $\times$ 10$^{-10}$ (Hg$^{2+}$), 7.42 $\times$ 10$^{-10}$ (MeHg), 1.065 $\times$ 10$^{-10}$ (EtHg), and 3.31 $\times$ 10$^{-10}$ (PhHg) M | 0.0–20 μg L$^{-1}$ | Environmental waters | No interference from other metal ions | 1-Octyl-3-methyl-1-imidazolium hexafluorophosphate | [50]    |
| 45        | MeHg    | CV-AFS                                      | Extraction                  | 0.315 ng g$^{-1}$   | —              | Petroleum | — | — | [51]    |
| 46        | GEM     | CV-AFS                                      | —                             | —                 | —              | Ambient air | — | — | [52]    |
| 47        | Hg(II)  | AFS                                         | Fluorescence               | 0.07 $\times$ 10$^{-6}$ M | 0.1–4.5 μM | Aqueous solutions | Longer excitation and emission wavelength could shield the interference | Fe$_2$O$_4$ magnetic nanoparticles | [53]    |
| 48        | Hg speciation | CV-AFS | Thermal decomposition | —                 | —              | Fish liver | Method validity is tested with CRM | — | [54]    |
| 49        | THg     | AFS                                         | —                             | <4.98 $\times$ 10$^{-11}$ M | — | Snow | — | K$_2$Cr$_2$O$_7$/SnCl$_2$ | [55]    |
| 50        | Atmospheric Hg | CV-AFS | Extraction | —             | —              | Particulate matter | — | — | [56]    |
## Table 1: Continued.

| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD) | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|--------------------------|----------------|------------------|-------------------|-----------------|-----------|
| 51        | THg     | CV-AFS                                      | Flow injection mercury system | —            | —              | Herbal products   | —                | —               | [57]      |
| 52        | Hg speciation | LC-UV-CV-AFS | Microwave digestion | $4.98 \times 10^{-12}$ (total Hg), $1.39 \times 10^{-12}$ (MeHg), and $1.99 \times 10^{-12}$ (Hg$^{2+}$) M | —              | Sea food         | Simultaneously determined both Hg(II) and MeHg | —               | [58]      |
| 53        | MeHg and total Hg | CV-AAS | Digestion | $0.088$ (MeHg) and $0.005$ (total Hg) $\mu g \cdot g^{-1}$ | —              | Hair and milk of mothers | —                | —               | [59]      |
| 54        | Hg(II)  | ICP-MS                                      | Microfluidic | $3.49 \times 10^{-10}$ M | $0.2–4.0 \mu g L^{-1}$ | Aqueous samples | —                | Gold nanoparticles | [60]      |
| 55        | Total Hg | ICP-MS                                      | Acid digestion | $0.053–0.01 \mu g g^{-1}$ | —              | Pharmaceutical ingredients | Low residual carbon content in digests is desirable to minimize some interference | —               | [61]      |
| 56        | Hg(II)  | ICP-MS                                      | Adsorption | —            | —              | Wastewaters       | —                | Multiwalled carbon nanotubes | [62]      |
| 57        | Hg(II)  | ICP-OES                                      | Extraction | $1.49 \times 10^{-10}$ M | —              | Fish samples      | Selective in presence of Na$^+$, K$^+$, Ca$^{2+}$, Cd$^{2+}$, Cr$^{3+}$, Fe$^{2+}$, Cu$^{2+}$, Co$^{2+}$, Ni$^{2+}$, Mn$^{2+}$, Cd$^{2+}$, and Pb$^{2+}$ into $1 \text{ mg} L^{-1}$ solutions of Hg(II) in pH 8 | Ion imprinted polymer | [63]      |
| 58        | Total Hg | CV-ICP-MS | Microwave digestion | $3 \text{ ng} g^{-1}$ | —              | Plants and soil   | —                | —               | [64]      |
| 59        | Total Hg | ICP-MS | Microwave assisted digestion | —            | —              | Rice              | —                | —               | [65]      |
| 60        | GEM     | CV-ICP-MS | Thermal analysis | $20 \times 10^{-15}$ g | —              | Atmospheric particulates | —                | —               | [66]      |
| 61        | Hg(II) and MeHg | HPLC-ICPMS | HF-LPME$^d$ | $5.48 \times 10^{-19}$ (Hg$^{2+}$) and $1 \times 10^{-17}$ (MeHg) M | Up to $50 \mu g L^{-1}$ | Tap, river, and estuarine waters | Simultaneously selenium also determined along with mercury | —               | [67]      |
| 62        | Hg speciation | ICP-MS | Ion exchange chromatography | $9.47 \times 10^{-15}$ (Hg$^{2+}$), $1.25 \times 10^{-10}$ (MeHg), $1.35 \times 10^{-10}$ (Hg$^{2+}$), and $7.92 \times 10^{-10}$ (PHg) M | $0.1–100 \mu g L^{-1}$ (all Hg species) | Sea water and marine fish | —                | L-Cysteine or thiourea | [68]      |
| 63        | Hg speciation | GC-ICP-MS | Preconcentration | $27$ (Hg$^{2+}$) and $12 \text{ ng} g^{-1}$ (MeHg) | —              | Human hair        | —                | —               | [69]      |
| 64        | Total Hg | MC-ICPMS | Isotope ratio analysis | $0.1–0.2$ disintegrations per minute | —              | Sediment core     | Mercury and mercury isotope compositions are determined | —               | [70]      |
| S. number | Analyte          | Analytical instrument used for the detection | Method                                      | Limit of detection (LOD)** | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|----------|-----------------|---------------------------------------------|---------------------------------------------|-----------------------------|-----------------|-------------------|-------------------|------------------|-----------|
| 65       | Hg(II) and MeHg | CVG-ICP-MS                                  | Extraction                                  | 1.7 (Hg(II)) and 2.3 ng g$^{-1}$ (MeHg) | —                | Fish samples      | —                 | —                | [71]      |
| 66       | MeHg, Hg(II),   | HPLC-CV-ICPMS                               | Extraction and separation                   | $5.98 \times 10^{-15}$ (Hg(II)), $2.17 \times 10^{-12}$ (EtHg), and $1.8 \times 10^{-8}$ (MeHg) M | —                | Plasma/serum samples | —                 | —                | [72]      |
| 67       | Total Hg        | ICP-MS                                      | Microwave assisted digestion                | —                           | —                | Freshwater fish samples | —                 | —                | [73]      |
| 68       | Total Hg        | ICP-MS                                      | Isotope dilution and UV-photochemical vapor generation | $0.5$ pg g$^{-3}$           | —                | Biological tissues | Polyatomic interference is not detectable | Formic acid | [74]      |
| 69       | Total Hg        | ICP-MS                                      | Calculation-isotope dilution                | $2 \times 10^{-15}$ M      | —                | Diploria specimens | No isobaric interference was found | —                | [75]      |
| 70       | Hg speciation   | ICP-MS                                      | Anion exchange chromatographic separation   | $3.98 \times 10^{-12}$ (Hg$^{2+}$), $1.11 \times 10^{-13}$ (MeHg), $1.26 \times 10^{-10}$ (EtHg), and $1.22 \times 10^{-10}$ (PhHg) M | —                | Fish samples       | —                 | 3-Mercapto-1-propanesulfonate | [76]      |
| 71       | Total Hg        | ICP-MS                                      | Ultrasonic slurry sampling electrothermal vaporization | 0.2 ng g$^{-3}$           | —                | Herbal samples | A.s., Cd, and Pb also determined along with Hg | 8-Hydroxyquinoline | [77]      |
| 72       | Total Hg        | ICP-MS                                      | Electrothermal vaporization                 | $5.98 \times 10^{-15}$ M   | —                | Water associated with crude oil production | By preconcentration of analyte interference is avoided | —                | [78]      |
| 73       | THg              | ICP-MS                                      | Isotope dilution equation                   | $4.98 \times 10^{-18}$ M for THg $0.0005–1.321$ mg/kg for MeHg | Arctic cod       | —                 | —                 | —                | [79]      |

*For the conversion of limit of detection values into moles per liter (M) the atomic weight of Hg is taken as 200.59 g, MeHg as 215.59 g, EtHg as 229.59 g, and PhHg as 277.59 g.

**Solid-phase extraction; **LME: liquid-liquid microextraction; **TMAH: tetramethylammonium hydroxide; **HF-LPME: hollow fiber liquid phase microextraction.

Analytical instruments: CV-AAS: cloud vapor atomic absorption spectrometer; HG-AAS: hydride generation AAS; GF-AAS: graphite furnace AAS; ICP-OES: inductively coupled plasma optical emission spectrometer; ICP-MS: ICP-mass spectrometer; ICP-AES: ICP-atomic emission spectrometer; HPLC: high performance liquid chromatography; AFS: atomic fluorescence spectrometer; AMA: automatic mercury analyzer; DMA: direct mercury analyzer.
| Number | Analyte | Analytical Instrument | Analytical Method | LOD | Linearity Range | Analyzed Samples | Interference Study | Supporting Media | Reference |
|--------|---------|-----------------------|-------------------|-----|----------------|------------------|------------------|------------------|-----------|
| 1      | Hg(II)  | Fluorescence spectrophotometer | Fluorescence | 4.0 x 10^{-9} M | 6.0 - 450 nM | Water samples | 10-fold of Pb^{2+}, Cu^{2+}, and Ag^{+} shows <7% influence on the determination of Hg^{2+} compared to reported ones | CdTe quantum dots | [80] |
| 2      | Hg(II)  | Spectrophotometer | Colorimetric | 23 x 10^{-9} M | 0.00 - 0.31 μM | Water samples | Selective in presence of Ag^{+}, Cd^{2+}, Cu^{2+}, Co^{2+}, Ni^{2+}, and Pb^{2+} | Carbon nanodots | [81] |
| 3      | Hg(II)  | Spectrophotometer | Colorimetric | 2.6 x 10^{-9} M | 0.001 - 1 μM | Water samples | Selective in presence of 20 μM Al^{3+}, Ca^{2+}, Co^{2+}, Cu^{2+}, Cd^{2+}, Fe^{3+}, Mn^{2+}, Ni^{2+}, Pb^{2+}, and Zn^{2+} | Gold nanoparticles | [82] |
| 4      | Hg(II)  | Spectrophotometer | Colorimetric | — | 0.83 - 8.6 μg/mL | Water samples | The tolerance limit of Cu^{2+}, V^{5+}, Ag^{+}, Pd^{2+}, Pt^{4+}, Au^{3+}, Fe^{2+}, Ni^{2+}, Cd^{2+}, Pb^{2+}, and Cr^{6+} is in the range of 0.11 - 0.41 μg/mL in the determination of 1.91 μg/mL of Hg^{2+} | 5-Methylthiophene-2-carboxaldehydeethylenediamine | [83] |
| 5      | Hg(II)  | Spectrofluorometer | Fluorescence | 1.73 x 10^{-9} M | 2.0 nM - 60 μM | — | Interference of major cations studied ONPCRs 1 | 5-Methylthiophene-2-carboxaldehydeethylenediamine | [84] |
| 6      | Hg(II)  | Spectrophotometer | Colorimetric | 50 x 10^{-9} M | 20 - 1000 nM | Water samples | Selective in presence of Ni^{2+}, Co^{2+}, Ca^{2+}, Cu^{2+}, Na^{+}, K^{+}, As^{3+}, Mg^{2+}, Cd^{2+}, and Fe^{2+} | Silver nanoparticles | [85] |
| 7      | Hg(II)  | UV-Vis spectrophotometer | Colorimetric | 1.35 x 10^{-6} M | — | Drinking water | Cd^{2+}, Pb^{2+}, Fe^{3+}, and Ba^{2+} do not interfere in the determination of Hg^{2+} but Mg^{2+}, Ca^{2+}, and Mn^{2+} interfere slightly | Gold nanoparticles | [86] |
| 8      | Hg(II)  | Spectrofluorometer and UV-spectrometer | Colorimetric and fluorescent sensor | 2.7 x 10^{-8} M | 0 - 1.0 x 10^{-6} M | Water samples and living cells | The fluorescent signal for Hg(II) is not influenced by the major metal ions including Fe(III), Cu(II), and Al(III) | 2,4-Dichloroquinazoline | [87] |
| 9      | Hg(II)  | Spectrophotometer | Colorimetric | 5.3 x 10^{-13} M | 1.0 x 10^{-12} - 8.6 x 10^{-4} M | Water samples and SRM | Selective in presence of Mn^{2+}, Fe^{2+}, Fe^{3+}, Ni^{2+}, Co^{2+}, Cd^{2+}, and Pb^{2+} | Chromoionophore V | [88] |
| 10     | Hg(II)  | Spectrofluorometer | Fluorescent and colorimetric | 1.0 x 10^{-9} M | — | Spiked water samples | Na^{+}, Mg^{2+}, K^{+}, Cr^{3+}, Mn^{2+}, Co^{2+}, Ni^{2+}, Fe^{3+}, Cu^{2+}, Zn^{2+}, Ag^{+}, Cd^{2+}, and Pb^{2+} did not interfere | Rhodamine B | [89] |
| 11     | Hg(II)  | Spectrofluorometer | Fluorescence | 14.2 x 10^{-9} M | 0 - 5 x 10^{-7} M | Aqueous solutions | Cd^{2+}, Cu^{2+}, and Ag^{+} do not interfere | Thioether-appended dipetide | [90] |
| 12     | Hg(II)  | Spectrofluorometer | Fluorescence | 0.5 x 10^{-9} M | 0.0005 - 0.01 μM | Lakewater samples | Zn^{2+}, Pb^{2+}, Ni^{2+}, Ca^{2+}, Mg^{2+}, Cu^{2+}, Co^{2+}, Cd^{2+}, Fe^{3+}, and Mn^{2+} did not interfere | Carbonnanotubes | [91] |
| 13     | Hg(II)  | Spectrofluorometer | Fluorescent | 1.74 - 3.83 x 10^{-6} M | — | Living cells | Minor interference from Ag^{+}, Ca^{2+}, Cd^{2+}, Co^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, K^{+}, Mg^{2+}, Mn^{2+}, Na^{+}, Ni^{2+}, Pb^{2+}, and Rb^{+} and Zn^{2+} | Pyrene | [92] |
| 14     | Hg(II)  | Spectrophotometer | Colorimetric | 0.4 x 10^{-6} M | 0.1 - 4.2 μg/mL | Water, biological, plant leaves, and soilsamples | Tolerance limit of the Cd^{2+}, Zn^{2+}, Ce^{3+}, Ce^{4+}, In^{3+}, Cr^{3+}, La^{3+}, Yb^{3+}, and Eu^{3+} is 300 μg/mL and the tolerance limit of the Co^{2+}, Cu^{2+}, Fe^{3+}, Ti^{4+}, Pb^{2+}, Ni^{2+}, and Ag^{+} is 100 μg/mL and at Hg(II) is 2.0 μg/mL | 2,4,7-Triamino-6-phenylpteridine | [93] |
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD)$^2$ | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|-------------------------------|-----------------|------------------|------------------|------------------|----------|
| 15        | Hg(II)  | Spectrofluorophotometer                      | Fluorescent | $1.0 \times 10^{-7}$ M | $2.0 \times 10^{-7}$–$3.0 \times 10^{-7}$ M | Water samples | Selective in presence of Na$^+$, K$^+$, NH$_4^+$, Ba$^{2+}$, Zn$^{2+}$, Cd$^{2+}$, Mg$^{2+}$, Ca$^{2+}$, and Ni$^{2+}$ | Conjugated polymer multilayer films | [94] |
| 16        | Hg(II)  | Spectrophotometer                            | TGFRET$^3$ | $0.49$–$0.87 \times 10^{-9}$ M | $1.0 \times 10^{-9}$–$1.0 \times 10^{-8}$ M | Water samples | Selective in presence of Mn$^{2+}$, Ba$^{2+}$, Ni$^{2+}$, Cu$^{2+}$, Ca$^{2+}$, Cd$^{2+}$, Mg$^{2+}$, Zn$^{2+}$, Al$^{3+}$, Fe$^{3+}$, and Pb$^{2+}$ | Gold nanoparticles | [95] |
| 17        | Hg(II)  | Spectrofluorometer                           | Fluorescent | $1 \times 10^{-9}$ M | $0.01$–$0.12 \mu$M | Water samples | Selective in presence of Zn$^{2+}$, Pb$^{2+}$, Ni$^{2+}$, Co$^{2+}$, Ca$^{2+}$, Cu$^{2+}$, Mg$^{2+}$, Ni$^{2+}$, Ca$^{2+}$, Al$^{3+}$, and Fe$^{3+}$ | Carbon nanodots | [96] |
| 18        | Hg(II)  | Spectrofluorometer                           | Fluorescent | $0.012 \times 10^{-6}$ M | $0.1 \mu$M | Tap and river water samples | Selective in presence of Ag$^+$, Pb$^{2+}$, Na$^+$, K$^+$, Cr$^{3+}$, Cd$^{2+}$, Ba$^{2+}$, Zn$^{2+}$, Mg$^{2+}$, Cu$^{2+}$, Ni$^{2+}$, Ca$^{2+}$, Al$^{3+}$, and Fe$^{3+}$ | Rhodamine | [97] |
| 19        | Hg(II)  | Spectrofluorometer                           | Fluorescence | $2.24 \times 10^{-9}$ M | $5.0$–$100$ nM | Drinking water | 20-fold of Ca$^{2+}$, Mg$^{2+}$, Zn$^{2+}$, Cr$^{3+}$, Pb$^{2+}$, Cd$^{2+}$, Mn$^{2+}$, Cd$^{2+}$, Fe$^{3+}$, Al$^{3+}$, and Ni$^{2+}$, 10-fold of Fe$^{3+}$, and Cu$^{2+}$, 5-fold of Cu$^{2+}$, and the same concentration of Ag$^+$ caused almost no interference | Gold nanoparticles | [98] |
| 20        | Hg(II)  | Spectrophotometer                            | Optical chemical sensor | $0.18 \times 10^{-12}$ M | $7.2 \times 10^{-13}$–$4.7 \times 10^{-4}$ M | Tap water, river water, and canned tuna fish | Interference of Cu(II) eliminated with the addition of L-histidine as a masking agent | Synthesized ionophore | [99] |
| 21        | Hg(II)  | UV-Vis spectrophotometer                     | Colorimetric sensor | $5.0 \times 10^{-6}$ M (visual), $1.0 \times 10^{-7}$ M (UV-Vis) | — | Aqueous solutions | Mg$^{2+}$, Ca$^{2+}$, Zn$^{2+}$, Cd$^{2+}$, Cr$^{3+}$, Fe$^{3+}$, Pb$^{2+}$, Ni$^{2+}$, Co$^{2+}$, and Ag$^+$ did not interfere | Dimethyl sulfoxide | [100] |
| 22        | Hg(II)  | Fluorescence spectrophotometer               | Fluorescence probe | $16 \times 10^{-9}$ M | $0.02$–$1.0 \mu$M | Aqueous solutions | Selective in the determination of Hg$^{2+}$, over other metal ions such as Fe$^{3+}$, Ca$^{2+}$, Mg$^{2+}$, Mn$^{2+}$, Cr$^{3+}$, Ni$^{2+}$, Cu$^{2+}$, Co$^{2+}$, and Pb$^{2+}$ | Gold nanoparticles | [101] |
| 23        | Hg(II)  | —                                            | Colorimetric | $1.2 \times 10^{-9}$ M | $2$–$30$ nM | Water samples | Na$^+$ (2 mM), K$^+$ (2 mM), Fe$^{3+}$, Zn$^{2+}$ and Mg$^{2+}$ (0.1 mM), Ni$^{2+}$, Co$^{2+}$, Cd$^{2+}$, Pb$^{2+}$ and Cu$^{2+}$ (50 μM), and Ag$^+$ (3.5 μM) did not interfere with the detection of Hg$^{2+}$ (25 nM) in the mentioned amounts | Rhodamine B thiolactone | [102] |

$^2$For the conversion of limit of detection values into moles per liter (M) the atomic weight of Hg is taken as 200.59 g, MeHg as 215.59 g, EtHg as 229.9 g, and PhHg as 277.59 g.

$^3$ONPCRs: oxygen-doped nitrogen-rich photoluminescent polymer carbon nanoribbons; $^2$Limit of quantification; $^3$TGFRET: time-gated fluorescence resonance energy transfer.
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD) | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|--------------------------|-----------------|----------------|------------------|------------------|-----------|
| 1         | Hg(II)  | DP-ASV                                      | Electrochemical | 4.99 × 10^{-8} M | —               | Ambient water, tap, and wastewaters | Palladium–natural phosphate–carbon paste electrode enhances the selectivity for Hg^{2+} | Natural phosphate electrodes | [103]     |
| 2         | Hg(II)  | SW-ASV                                      | Electrochemical | 0.04 × 10^{-6} M | 0.2–10.0 μM     | Foodsuffs       | Simultaneously both Cd^{2+} and Hg^{2+} are determined and 1000-fold for K^{+}, Na^{+}, Li^{+}, NH4^{+}, Ca^{2+}, Mg^{2+}, Pb^{2+}, Zn^{2+}, Cr^{2+}, Fe^{2+}, Co^{2+}, and Al^{3+} did not interfere | Carbon paste electrode | [104]     |
| 3         | Hg(II)  | Differential pulse voltammetry              | Electrochemical | 4.48 × 10^{-9} M | 0.2–10 μg L^{-1} | Spiked fish and plant samples | Cu(II), Mg(II), As(III), and Cr(II) were possible interferers | Carbon paste electrode | [104]     |
| 4         | Hg(II)  | Cyclic voltammetry                          | Electrochemical | 0.8 × 10^{-14} M | 10^{-14}–10^{-7} M | —               | Cu^{2+}, Pb^{2+}, Ni^{2+}, Zn^{2+}, Cr^{3+}, Cr^{6+}, Fe^{2+}, Fe^{3+}, Co^{2+}, and As^{3+} did not interfere | Gold atomic cluster-chitosan | [106]     |
| 5         | Hg(II)  | Voltammetric (cyclic and differential pulse) | Biosensor   | 3.93 × 10^{-12} M | 0.005–0.034 mM   | Water samples   | The working potential controlled to minimize the interference of other metal ions in test medium | PANI and PANI-co-PDTDA polymer films | [107]     |
| 6         | Hg(II)  | ASV                                          | Electrochemical | 4.98 × 10^{-9} M | 4–160 ppb       | Aquatic solutions | 400-fold mass ratio of Cu^{2+}, Mn^{2+}, Zn^{2+}, Cr^{2+}, Cr^{3+}, Fe^{2+}, Fe^{3+}, Ni^{2+}, and Co^{2+} did not interfere in the simultaneous determination of Cd^{2+}, Pb^{2+}, and Hg^{2+} | Triphenylphosphate | [109]     |
| 7         | Hg(II)  | SW-ASV                                      | Electrochemical | 9.2 × 10^{-5} M  | 0.1–150.0 nM     | Soil, gasoline, fish, tap, and wastewaters | Ag^{+} has small interference in the determination of Hg^{2+} | L3-Alternate thiacalix[4]crown | [110]     |
| 8         | Hg(II)  | Potentiometer                               | Electrochemical | 1.0 × 10^{-9} M  | 5.0 × 10^{-8}–1.0 × 10^{-2} M | —               | The selectivity coefficient of the other ions is ranging from 2.9 to 4.9 | PVC membrane | [111]     |
| 9         | Hg(II)  | Potentiometer                               | Electrochemical | 3.05 × 10^{-12} M | 1–500 nM        | Water samples   | Pb^{2+}, Th^{4+}, Cd^{2+}, Ni^{2+}, and Al^{3+} did not interfere | Gold nanoparticles | [112]     |
| 10        | Hg(II)  | DPSV                                         | Electrochemical | 1.9 × 10^{-9} M  | 40–170 μg L^{-1} | Wastewaters     | —               | Biotinyl Somatostatin-14 peptide | [113]     |
| 11        | Hg(II)  | SW-ASV                                      | Electrochemical | 1.9 × 10^{-9} M  | 40–170 μg L^{-1} | Wastewaters     | —               | Biotinyl Somatostatin-14 peptide | [114]     |
| 12        | Hg(II)  | Cyclic voltammetry                          | Electrochemical | 3 × 10^{-6} M    | 5 × 10^{-6}–1.0 × 10^{-2} M | Contaminated water | Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, Zn^{2+}, Cu^{2+}, Cr^{2+}, Fe^{3+}, and Pb^{2+} did not interfere in the determination of Hg^{2+} | Dithizone and di-n-butyl phthalate | [115]     |
| 13        | Hg(II)  | DP-ASV                                      | Electrochemical | 0.483 × 10^{-10} M | 300–700 ng mL^{-1} | —               | No interference of Cd, Ni, Zn, and Cu in 50–250, 100–1000, and 5-fold in excess, respectively | Nanocellulosic fibers | [116]     |
| 14        | Hg(II)  | —                                            | Electrochemical | 0.5 × 10^{-9} M  | 1.0 nM–1.0 μM    | —               | Zn^{2+}, Mg^{2+}, Ca^{2+}, Pb^{2+}, Cd^{2+}, Mn^{2+}, Cu^{2+}, Ni^{2+}, and Fe^{3+} did not interfere | G-quadruplex-hemin (G4-hemin) | [117]     |

*For the conversion of limit of detection values into moles per liter (M) the atomic weight of Hg is taken as 200.59 g, MeHg as 215.59 g, EtHg as 229.59 g, and PhHg as 277.59 g.

1PME: polymeric membrane electrode and CGE: coated graphite electrode.

Analytical instruments: DP-ASV: differential pulse anodic stripping voltammetry; SW-ASV: square wave anodic stripping voltammetry.
| S. number | Analyte | Analytical instrument used for the detection | Method | Limit of detection (LOD) | Linearity range | Analyzed samples | Interference study | Supporting media | Reference |
|-----------|---------|---------------------------------------------|--------|-------------------------|----------------|-----------------|------------------|-----------------|----------|
| 1         | Speciation | Continuous mercury analyzer | Thermal desorption | — | — | Solid samples (fly ash) | — | — | [118] |
| 2         | GEM | Portable mercury analyzer | — | — | — | Atmosphere | — | — | [119] |
| 3         | Hg(II) | SERS | — | $2.24 \times 10^{-12}$ M | $0.001$–$0.5$ ng mL$^{-1}$ | Drinking water samples | Selective in presence of Zn$^{2+}$, Mg$^{2+}$, Fe$^{3+}$, Cu$^{2+}$, Pb$^{2+}$, and Mn$^{2+}$ | Gold nanoparticles | [120] |
| 4         | Hg(II) | HPLC | SPE | $1.99 \times 10^{-10}$–$4.48 \times 10^{-9}$ M | $2.7$–$3.0$ μg L$^{-1}$ | Water samples | Simultaneously Ni$^{2+}$, Co$^{2+}$, and Hg$^{2+}$ are determined | Carbon nanotubes | [121] |
| 5         | Hg(II) | SERS | — | $0.1 \times 10^{-9}$ M | $0.1$–$1000$ nM | Groundwater | Ag$^+$ was also determined along with Hg$^{2+}$ and K$^+$, Cu$^{2+}$, Ag$^+$, Fe$^{3+}$, Fe$^{2+}$, NH$_4^+$, Ca$^{2+}$, Co$^{2+}$, Cd$^{2+}$, and Zn$^{2+}$ did not interfere | Oligonucleotide-functionalized magnetic silica sphere | [122] |
| 6         | Total Hg | AMA | Acid digestion | — | — | Eggs and blood of Eretmochelys imbricata | Along with mercury Cd, Cu, Zn, and Pb are also determined | — | [123] |
| 7         | Hg(II) | Luminescence spectrometer | Fluorescence | $3.0$–$9.0 \times 10^{-9}$ M | $0.05$–$1.0$ μM | Water samples | Fairly selective in presence of Ag$^+$, Fe$^{3+}$, Zn$^{2+}$, Ca$^{2+}$, Mn$^{2+}$, Mg$^{2+}$, Co$^{2+}$, Pb$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, and Cu$^{2+}$ | Silver nanoclusters | [124] |
| 8         | Hg(II) | X-ray fluorescence spectrometer | Preconcentration | $4.98 \times 10^{-12}$ M | Upto 20 mg L$^{-1}$ | Drinking water | — | Activated carbon | [125] |
| 9         | Total Hg | DMA | Acid digestion | $0.14$ ng | — | Particulate matter | Back extraction and another chemical process make the method selective for MeHg and EtHg | GF/C filters | [126] |
| 10        | MeHg and EtHg | HPLC | Chemiluminescence | $0.16$ ng g$^{-1}$ | $0.5$–$20$ ng Hg | Soil and sediment samples | Back extraction and another chemical process make the method selective for MeHg and EtHg | Emetine dithiocarbamate | [127] |
| 11        | Total Hg | CV-CCPM-OES | Microwave digestion | $2.39 \times 10^{-10}$ M | $0.27$–$55$ ng kg$^{-1}$ | Soil samples | — | — | [128] |
| 12        | Hg(II) | Chemososimeter | Fluorescence | $1.71 \times 10^{-9}$ M | $1.0 \times 10^{-1}$–$1.0 \times 10^{-6}$ M | Blood serum of mice | — | Rhodamine | [129] |
| 13        | Hg(II) | XRF | Acid digestion | $9.97 \times 10^{-9}$ M | — | Soils from industrial complex | — | — | [130] |
| 14        | Total Hg | DMA | Combustion | $0.12$ ng | $0.5$–$5$ ng | Soil and leaf samples | — | — | [131] |
| 15        | MeHg and Hg(II) | GC-MS | Matrix solid-phase dispersion | $0.06$ (MeHg) and $0.12$ (Hg(II)) μg/g | — | Tuna fish, angel shark, and guitarfish | — | — | [132] |
| 16        | GEM | Concentration-weighted trajectory model | — | — | Particulate matter | QFF | — | — | [133] |

*For the conversion of limit of detection values into moles per liter (M) the atomic weight of Hg is taken as 200.59 g, MeHg as 215.59 g, EtHg as 229.99 g, and PhHg as 277.99 g.

1SERS: surface enhanced Raman scattering; 2CV-CCPM-OES: cold-vapor capacitively coupled plasma microtorch fluorescence spectrometry.

Analytical instruments: HPLC: high performance liquid chromatography; AMA: automatic mercury analyzer; DMA: direct mercury analyzer; XRF: X-ray fluorescence.
Various measurement techniques that can be available for the determination of mercury species in ambient air were reviewed by Pandey et al. [154]. This study also concluded that most of the researchers preferred CV-AAS and CV-AFS technique for the measurement of different mercury species in ambient air. In comparison of methods, acid digestion and thermal method, for the analysis of mercury in ambient air acid digestion, is better than thermal method. By the thermal methods the values can be obtained 30% lower than the acid digestion method [155].

In the analysis of mercury species in various environmental samples, selectivity and range of linearity of the method also play a major role due to the presence of multielements in the real samples. Based on the present study, most of the spectrophotometric, spectrofluorometric, and electroanalytical methods were discussed regarding the interfering ion studies and linearity range of the method. These studies will give a clear picture about the determination of mercury species in presence of other ions which validates the methods.

Regarding the merits of the different methods for speciation and analysis of mercury, the usage of nonchromatographic methods has an advantage in terms of speed of analysis, inexpensiveness, and convenience to find the mercury in various environmental samples. But for the complete speciation studies of mercury in biological and environmental samples chromatographic methods are useful [156]. The validity of analytical methods can be enhanced with the analysis of the certified reference materials along with the real samples. In recent years, the researchers mostly preferred GC coupled with AFS or ICP-MS for the determination and speciation of mercury in natural waters [157]. In electroanalytical methods, the validity of the methods depends on various factors such as type of electrode, preconcentration, and supporting materials [139] and these methods are cost-effective, selective, and sensitive [143].

3. Conclusions

The present study revealed the recent developments in the determination and speciation studies of mercury by a range of analytical techniques. Our previous study [2] also described the challenges in the methodology for mercury determination. This review showed that most researchers focused on the determination of Hg(II) rather than speciation studies. On the other hand, the speciation studies [23, 24, 29, 36, 37, 44, 47, 50, 54, 58, 68, 69, 76, 118] accurately revealed the toxicity of mercury rather than the total mercury or single species determinations. In the papers reviewed, most researchers were aware of the interfering ions in the determination of mercury and its different forms. In the analytical method, a study of interfering ions is very important because it can predict the selectivity of the method. In future studies, it will be important to focus on speciation studies of mercury rather than a determination of the total mercury.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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