Asian Journal of Chemistry; *Vol. 35, No. 11 (2023), 2579-2594*

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2023.28333

REVIEW

Analytical Approaches for the Detection of Heavy Metals and Agrochemicals in the Environment Samples and their Recent Technologies

SANJAY KUMAR BHARDWAJ[1], TARUN KUMAR PATLE[2,*], ANJU JHA[1,*] and ALKA PATLE[1]

[1]Department of Chemistry, Government Nagarjuna Post Graduate College of Science, Raipur-492001, India
[2]Department of Chemistry, Pt. Sundarlal Sharma (Open) University Chhattisgarh, Bilaspur-495009, India

*Corresponding authors: E-mail: tarunpatle1990@gmail.com; dr.anjujharesearchpaper123@gmail.com

Received: 19 July 2023; *Accepted*: 27 August 2023; *Published online*: 31 October 2023; AJC-21413

At part per billion (ppb) concentrations, heavy metals and pesticides both pose a significant health risk. Over-ingestion of pesticides and heavy metals in the environment may cause various diseases and effects on human life. So, a systematic analysis for detecting and removing pesticides and heavy metals from the environment is required. This review provides a comprehensive study of the several analytical methodologies employed in the quantification of heavy metal ions and agrochemicals in environmental samples. Furthermore, the detrimental impacts of these substances on both human health and plant life are also discussed. Moreover, a concise overview of the latest developments in the design of nanomaterial-based sensors, specifically focusing on colorimetric and electroanalytical approaches. These sensors are utilized for the detection and analysis of heavy metals and pesticides. In addition, the information garnered from the study will improved the capability to detect and remove contaminants from environmental samples.

Keywords: Heavy metals, Agrochemicals, Nanoparticals, Analytical assay.

INTRODUCTION

Soil and water are the integral components of environment, playing a crucial role in the sustaining of living organisms by facilitating food production and supporting essential eco-systems. The biodiversity of the environment is comprized of several organisms, which provide antibiotics for better human health and the habitat of the organism is truly dependent upon the quality of soil for better growing media [1,2]. Both the soil and the water are mostly composed of inorganic and organic substances, respectively [3]. The presence of heavy metals in water and soil on their requirement and body system tolerance results a situation of toxicity. The developmental movement at the global level in past two decades has resulted in enormous industrial growth and increased consumers, this in turn further resulted in the accumulation of piles of organic and inorganic waste materials and biodegradability limits, besides geographical/neutral imbalance; ultimately polluting soil and water at source [4]. The environment is contaminated by heavy metals due to several factor such as human activities, industrial pollution sources like tanneries, chemical plants, wood preservation, electroplating industry, mining activities, *etc*. [5].

Heavy metals like lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), nickel (Ni), chromium (Cr), stannum (Sn), copper (Cu), vanadium (V), zinc (Zn), *etc*. are toxic in nature. The progress of the worldwide economy increases the contamination of heavy metals into the environmental components has gradually increased, consequential in the weakening of the environment [6-12]. Heavy metals easily pass in the food chain from the soil pollutant to it prefects the environment and living organisms [13]. The weathering process of some natural materials is parental source of heavy metals in the environmental components, which are trace (< 1000 mg/kg) and almost non-toxic. Now a days, the human activities slowly increases into environment affecting the geochemical sequence of heavy metals, most soil and water of rural and urban areas may be contaminated by higher concengtration of single or more of the heavy metals is enough to origin dangers to human health as well as other species [14]. Historically, agriculture was the first major human influence on the environmental components.

The macro- and micro-nutrients are required for the growth and completion of the lifecycle of plants. If agricultural soil are lacking in the essential metals for crops growth, can be abounding by adding them into the soil or spraying directly into the crops leaves [15-20]. The fertilizers containing sufficient amount of N, P and K are regularly added to soil during farming for proper growth and development of crops. The fertilizers containing the essential elements for healthy crop growth can also have a trace amount of unwanted heavy metals such as Cd, Pb, *etc*., which concentration is gradually increased into environmental components due to regular uses of fertilizer. The non-essential metals have no any physiological evidence to crops, these metals are toxic in nature, unintensially inter into environment by using certain phosphatic fertilizers for farming by human [21].

In past, various pesticides were used heavily in food crops and plants contained significant amounts of metals, the United Kingdom approved only 10% of chemicals that contain Zn, Pb, Hg, Mn or Cu were used as pesticides. The mixture of copper sulphate and copper oxychloride called bordeaux were used as fungicide sprayer which contains majorly copper [22,23]. Arsenic and lead-containing pesticides were used to control pests in fruits [24], additionally, the concentration of Cu and Cr gradually increases due to extensive usage of pesticides [25]. The several biosolids generated from poultry, cattle and pig farming cause to the growth of Hg, Zn, Pb, As, Mo and Cd into the environmental components [26]. In the poultry industry, the health products especially meals of poultry contains mixture of metal ion such as As, Cu and Zn, therefore, the byproducts of this industry can also enhance the concentration level of metal ion in the soil and other environmental compenents [27].

Impact on humans and plants: The study of diseases caused by soil contamination on human is a complex endeavor that attracts less attention to it, but according to the WHO listing, some soil pollutants *e.g.* Cd, Pb, Hg, Ni, Cu, As, pesticides and other chemicals show a great impact on human health [28-34]. Table-1 provides the possible sources of heavy metals and their effect of plants and humans.

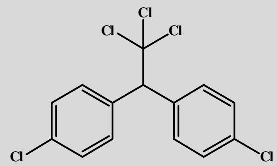
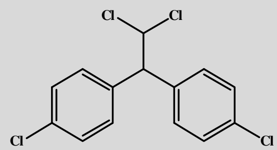
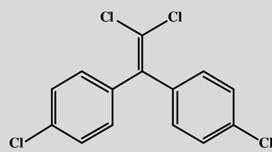
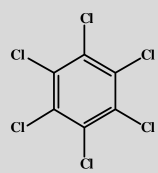
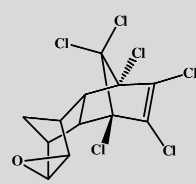
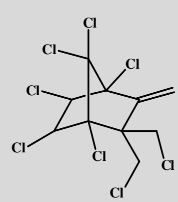
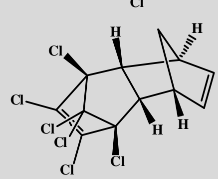
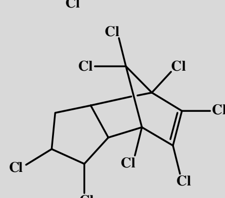
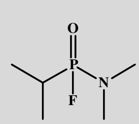
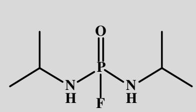
Pesticides are designed in that way to kill only the pests but their mechanism of action is still non-specific to one plant species. A report from WHO revealed that each year more than one lacs human beings are suffered from severe diseases caused by interaction with pesticides with a noticeable death rate [51]. When human being get exposer with amount of pesticides presnt in food materials can cause tumor, sugar, respiratory illnesses, neurological ailments, asthma, allergies, reproductive syndromes, hormone disturbance, oxidative stress and hypersensitivity [52,53]. Table-2 represent a comparise form of different classes of pesticides, structures and effect on humans and pests.

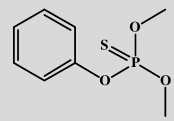
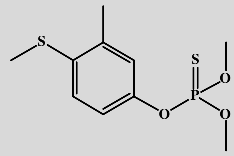
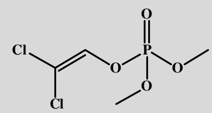
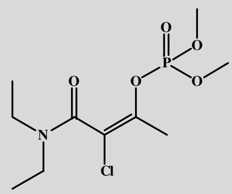
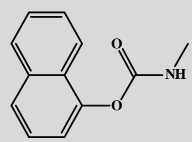
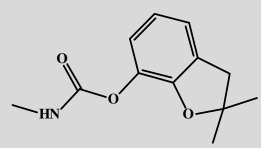
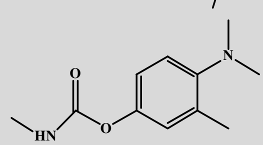
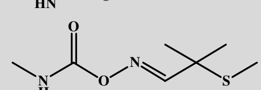
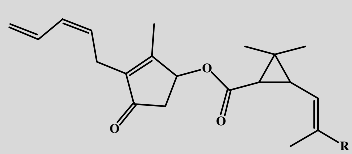
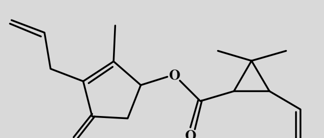
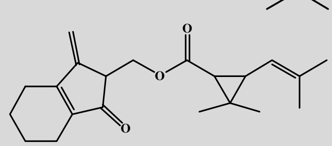
Detection and remediation of heavy metals and pesticides: Worldwide, about 8-9% of total disease is attributed by the minor molecules to pathogenic concentration of environmental contaminants. So, for the better environment and health the estimation of toxins is necessary [74,75]. For past few years, several techniques and equipment are being used for the detection of heavy metals and pesticides such as spectrophotometry [76,77], polarography [78], chromatography [79,80], FTIR-

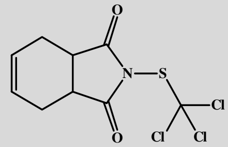
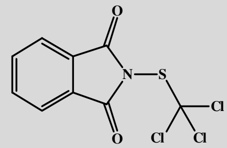
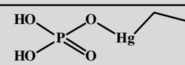
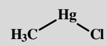
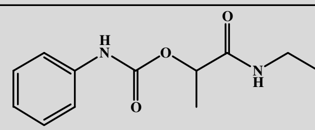
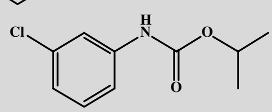
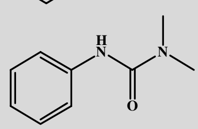
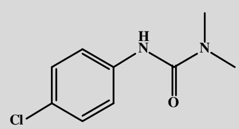
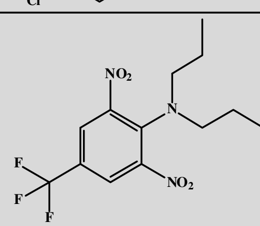
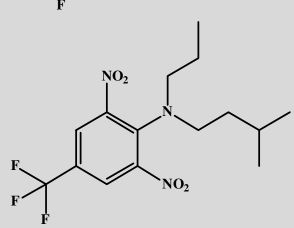
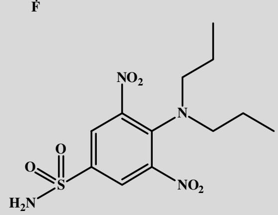
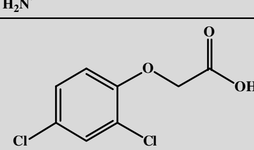
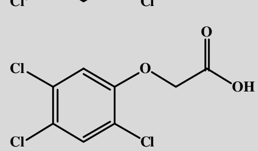
TABLE-1
SUMMARY OF POSSIBLE SOURCES OF HEAVY METALS AND THEIR EFFECT ON PLANTS AND HUMANS

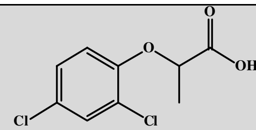
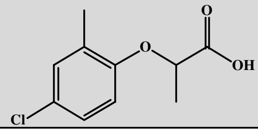
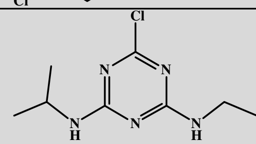
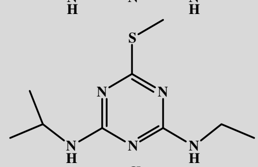
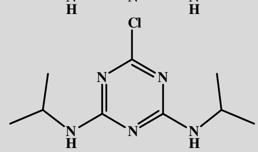
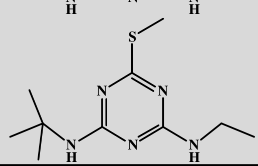
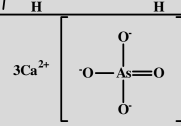
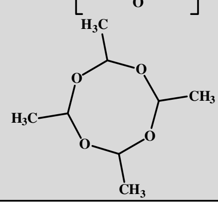
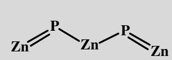
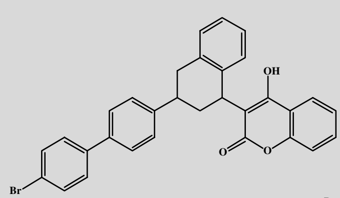
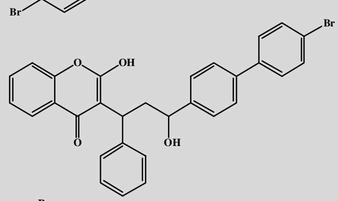
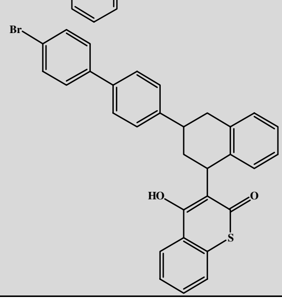
Heavy metals	Possible sources	Toxic effects on plants	Toxic effects on human health	Ref.
Cd	Electrodes, plastics, ceramics, glasses, polymers, steel, fertilizers, mining, smelting and refining	Increase oxidative stress, slowing photosynthesis and metabolism, affect root growth and seed germination, affect plant germination	Toxic effects on human health such as liver, kidney and bone density, cancer, cardiovascular disease and diabetic nephropathy.	[35-37]
Pb	Mining, smelting, gasoline, municipal sewage, paints	Affect overall growth and development, chlorosis, affects root growth, affect cell permiabilty, inhibited enzymatic activity and reduce mineral nutrition.	Central nervous sytem damage, hyperactivity, infertility, anorexia, high blood pressure, rensl damage, alzheimer disease	[38-40]
Hg	Coal, soda and wood industry, volcano outbreaks	Inhibiting electron transport causing damage of mitochondria, inhance oxidative stress, effect the cell permiabilty	Deafness, blindess, dizziness, dementia, infertility, gastric, kidney problem, memory loss, sclerosis, dysphasia	[41,42]
As	Minig, wood, battery, coal, petroleum, refineries industire, volcanoes	–	Brain damage, cardiovascular and respiratory disorders, conjunctivitis, dermatitis, skin cancer	[43,44]
Cu	Mining, electroplating biosolids, refining and smelting	Affect the cell membrane, cause oxidative stress, seed germination, affects root growth, DNA damage	Anemia, abdominal pain, diarrhea, liver damage, kidney damage, headache, nausea, metabolic disorders, vomiting	[45,46]
Ni	Forest fire, weathering, landfill, volcanic eruptions, steel, automobile, alloy, batteries, surgical instrument industries	Reduce plant growth, reduce photosynthetic activity, oxidative stress, affects on enzymatic and metabolic activity	Heart disease, dizziness, lung pain, skin disease, cancer, respiratory effects, headache, nausea, kidney damage	[47,48]
Cr	Electroplating industry, sludge, solid waste, tanneries	Affects on metabolic and enzymatic function, affects photosynthesis, affects physiological process, damage chloroplast, inhibit electron transport	Lungs related disease, diarrhea, headache, skin disease, emphysema, headache, itching, renal damage, liver damage, lung cancer, nausea and vomiting.	[49,50]

TABLE-2
SUMMARY OF DIFFERENT CLASS OF PESTICIDES, THEIR STRUCTURES, EFFECT ON HUMAN AND PEST

Class of pesticide	Chemical class of pesticide	Name of pesticide	Structure of pesticide	Effect on human	Effect on pest	Ref.
Insecticide	Organo-chlorines	Dichlorodi-phenyltrichloro-ethane (DDT)		Vomiting, tremors or shakiness, seizures and highly carcinogenic	Damaging nerve cells of insects	[54-56]
Insecticide	Organo-chlorines	Dichlorodi-phenyldichloro-ethane (DDD)		Cancer of the adrenal gland		
Insecticide	Organo-chlorines	Dichlorodi-phenyldichloro-ethylene (DDE)		Negative effect on serum and adipose tissue		
Insecticide	Organo-chlorine	Benzene hexachloride (BHC)		Seizures, ataxia, confusion and other central nervous system dysfunction.		
Insecticide	Organo-chlorines	Endrin		Convulsions, jerking of legs and arms, twitching facial muscles, sudden collapse, or even death		
Insecticide	Organo-chlorines	Toxaphene		Affect the central nervous system, liver and kidneys		
Insecticide	Organo-chlorines	Isodrin		Affect the nervous system, liver, kidneys and skin		
Insecticide	Organo-chlorines	Chlordane		Gastrointestinal distress and neurological symptoms, such as tremors and convulsions		
Insecticide	Organo-phosphates	Dimefox		Highly toxic Possible brain and central nervous system toxicant	Affect the central nervous system of insects causing them to death	[54,57-59]
Insecticide	Organo-phosphates	Mipafox		Neurotoxicity and paralysis		

Insecticide	Organo-phosphates	Methyl parathion		Aintness, blurry vision, chest pain, diaphoresis, vomiting and nausea, diarrhea, muscle pain, convulsions, comma and death		
Insecticide	Organo-phosphates	Fenthion		Nausea, headache, vomiting, faintness, muscular faintness, sleepiness, weariness, anxiety		
Insecticide	Organo-phosphates	Dichlorovas		Diarrhea, blurred vision		
Insecticide	Organo-phosphates	Phosphamidon		Toxic effect on lungs, neurons, myocardial *etc.*		
Insecticide	Carbamates	Carbaryl		Blurred vision respirator disorder	Damage the central nerous system of insects as Organo-phosphates	[60,61]
Insecticide	Carbamates	Carbofuran		Hypertens ion vision defect, respiratory disorder		
Insecticide	Carbamates	Aminocarb		Affect the nervous system and lungs		
Insecticide	Carbamates	Aldicarb		Nausea, sweating, vomiting, headache		
Insecticide	Pyrethroids	Pyrethrin		The ringing of the ears, nausea, tingling of fingers and breathing problems and other nervous system problems	This pecticide break down easily with light and affect the growth of lice and other household pests	[62,63]
Insecticide	Pyrethroids	Allethrin		Abdominal pain, dizziness, fatigue, palpitation, tightness in the chest and blurring of vision.		
Insecticide	Pyrethroids	Tetramethrin		Muscular pain, dizziness, nausea, fatigue, excessive salivation, muscle faintness, vomiting		

Fungicide	Phthalimides	Captan		Respiratory ailment	–	[64]
Fungicide	Phthalimides	Folpet		Upper and lower respiratory irritation		
Fungicide	Miscellaneous	Ethylmercuric phosphate		Neurological and psychiatric.	–	[65]
Fungicide	Miscellaneous	Methylmercury chloride		Affect the nervous system, dysarthria, ataxia, paraesthesia's		
Herbicide	Carbanilates	Carbetamide		Hypoglycaemia, anorexia	–	[66,67]
Herbicide	Carbanilates	Chlorpropham		Kidney and liver failure		
Herbicide	Carbanilates	Fenuron		Reproductive and development effects		
Herbicide	Carbanilates	Monuron		Moderately toxic to humans and a suspected carcinogen		
Herbicide	Toluidines	Trifluralin		Acute oral toxicity and dermal irritation, skin illnesses, lung problems and eye irritation	Increases the virulence of rust that attacks flax plants	[68]
Herbicide	Toluidines	Benefin (benfuralin)		Skin, eye and respiratory irritations		
Herbicide	Toluidines	Oryzalin		Carcinogen, skin sensitization		
Herbicide	Phenoxy alkonates	2,4-Dichloro-phenoxyacetic acid		Tachypnea, tachycardia, vomiting, leukocytosis, liver and kidney	–	[69]
Herbicide	Phenoxy alkonates	2,4,5-Trichloro-phenoxyacetic acid		Nausea, renal injury, dizziness, headache, body pain, mytonia, hypotension, hepatic injur		

Herbicide	Phenoxy alkonates	Dichloroprop		Reproductive disorder		
Herbicide	Phenoxy alkonates	Mecoprop		Low blood pressure, rooling		
Herbicide	Triazines	Atrazine		Kidney failure, congestive heart failure	–	[70,71]
Herbicide	Triazines	Ametryn		Liver damage and heart failure		
Herbicide	Triazines	Propazine		Reproductive toxicity, potential endocrine effects, mutagenicity, anemia		
Herbicide	Triazines	Terbutryn		Fate in humans and animals, carcinogenic effects		
Molluscicides	Miscellaneous	Calcium arsenate		Skin dmage	–	[72]
Molluscicides	Miscellaneous	Metaldehyde		Neurotoxin and exposure result in vomiting, tremors, seizures and death.		
Rodenticide	Miscellaneous	Zinc phosphide		Liver and kidney failure, convulsion, delirium and coma may also occur.	Used as spray to control pests	[73]
Rodenticide	Miscellaneous	Brodifaco		Unexplained bleeding		
Rodenticide	Miscellaneous	Bromadiolone		Nose bleeds, bleeding gums, bloody urine, black tarry stools.		
Rodenticide	Miscellaneous	Difethialone		Ecchymoses, petechiae, frank-hemorrhage, pale mucous membranes, weakness, coughing.		

spectroscopy [81], gas chromatography-mass spectroscopy (GC-MS) [82-84], X-ray photoelectron spectroscopy (XPS) [83], inductively coupled plasma mass spectrometry (ICP-MS), HPLC, LC-MS [84,85], immunoassays [86], biorecognition elements [87], electrochemical detection [88], omics technologies [89], capillary electrophoresis [90], surface-enhanced Raman spectroscopy (SERS) [91] have been used for this drive. The advantages of these analytical instrument is its sensitivity, reproducibility and reliability, but also have several drawbacks like costly, time taking, difficult sample preparation and on site detection. Therefore, these drawbacks get attention towards the development of rapid and simple analytical approcahses for analysis of trace level of pesticides in the environment and food [92].

Removal of soil pollutants like xenobiotic compounds, pecticides and metal ions is a worldwide problem because pollutants have a adverse effect on the living organisms, plants, ecosystems, agriculture, *etc*. [93]. So, the remediation and detection of pollutant is very essential [94]. In the contemporary era, there has been significant progress in the field of environmental restoration. There are five strategies, which are applicable for the removal of toxins from the environmental samples, *e.g.* (i) by separation, extraction and desorption methods; (ii) by phase separation, hydrocyclones, froth flotation and jig techniques; (iii) by thermal/chemical destruction; (iv) by biodegradation techniques; and (v) by biological mobilization or absorption [95].

Some of the remediation techniques are also used for the clean-up of soil such as isolation and containment, pyrometallurgical separation, chemical treatment, biochemical process, biosurfactant technology, mechanical separation, permeable treatment wall, electrokinetic remediation, phytoremediation, *in situ* remediations, soil washing, phytoextraction, leaching [96-100].

Nanoparticles as sensing probe: Nanoparticles are the particle with size ranges between 1-100 nm having with different shapes depending upon several factors including synthesis methods [101,102]. Several sensing approchaes were developed based on different nanomaterials like silver, gold, carbon, graphene, *etc*. [103]. Recently, the chemical free synthesis of nanoparticles is preferred due to its cheap, safe and ecofriendly nature [104]. The issue of heavy metals and pesticides has emerged as a significant and crucial concern for researchers to address, moreover, this problem has substantial implications for social development. Recently, researchers and scientist focussing on some methodologies to moniter the environmental toxins [105]. But, the methods developed were expensive and very complex for analysis of environmental pollutant, hense nanoscinece based methodology is now employed instead of these expensive techniques [106,107]. Nanosensors have several advantageous properties as compared to other traditional sensors with high precesion, accuracy, sensitivity, selectivity, stability, *etc*. [108].

Colorimetric sensor: This sensor is one of the most used sensing method for analysis of environmental samples such as water, soil, vegetables, *etc*. [109-113]. The basic mechanism of this method is the colour alteration after introduction of analyte to the prepared nanoparicles as a sensing probe. The surface plasma coupling of nanoparticles and refractive index of media can affect the colour changes and aggregation process of nanoparticles. The aggregation of nanoparticles after the addition of anlyte is a basic step and aggregation cause colour changes in colorimetric based sensing probes [114]. The nanopartiles based sensor is growing method for the analysis of environmental samples due to its several advantages like high accuracy, sensitivity, selectivity, precise and stable [115,116]. In recent times, the monitoring of environmental contaminants has been accomplished through the utilization of portable, cost-effective paper-based sensing approaches [117]. Maximum paper bridge device exploited the noble metallic nanoparticle that cost colouration have exchange with the contact of the pollutent on the paper sensor. The colour changed paper based sensor is further analyzed by different softaware such as ImageJ, which read the colour intensity developed on the paper sensor [118].

Colorimetric detection of pesticides: In the field of agricultural productivity, a wide array of agrochemicals, which often encompass substances such as pesticides and fertilizers, are frequently employed. Some part of these pesticide increases the pollution of the environment by leaching into the soil and water. Furthermore, when such chemicals get contact with humans by direct or indirect than it will affect the skin, lungs and other part of body. Hence, it is important to introduce an analytical method for sensitive and selective monitoring of pesticides [119]. Several colorimetric sensors have been reported for the identification of agrochemicals, wherein nanoparticles, enzymes, aptamers and other entities are employed in conjunction with heavy metals [120-125]. Kaur *et al.* [126] proposed a azo-coupling reaction mechanism for low limit detection (15 ppm) of carbryl pesticide. Alex *et al.* [127] developed 3D microfluidic paper-based analytical devices was fast for the estimation of paraoxon-ethyl pesticide by using cellulosic paper, since their surface contains negatively charged carboxyl group, which develops the robust electrostatic interaction with acetylcholine esterase (AChE). Hence, the value of the limit of detection is reduced in 3D microfluidic paper-based analytical devices.

Silver nanoparticles stabilized by tyrosine was synthesized by Weerathunge *et al*. [128], which have strong peroxidase-mimicing activity and this property is applied for the analysis of chlorpyrifos pesticides. Graphene quantum dots with gold nanoparticles (GQDs-AuNPs) as 3D paper was designed by several researchers [129-132] for monitoring the chlorpyrifos organophosphate pesticide with low limit of detection. This study revealed that the morphology of developed nanomaterials for colorimetric estimation can alter the limit of detection. The synthesized GQDs-AuNPs was uniform size and shape wround 12 nm was suitable for trace level detection of pesticide. So, these results are in good agreement with a previous report additionally some other reports as summeried in Table-3.

Colorimetric detection of heavy metals: Currently, metal ions such as Hg^{2+}, Ni^{2+}, Co^{2+}, Cd^{2+}, Cu^{2+}, Pb^{2+}, Al^{3+}, Fe^{3+}, As^{3+}, and Cr^{3+} have become persistent pollutants in water, soil and many environmental constituents on the global scale [152-156].

TABLE-3
LINEAR RANGE AND LOD OF COLORIMETRIC DETECTION OF SOME PESTICIDES

Nanomaterial	Pesticides	Linear range (mol/L)	LOD (mol/L)	Ref.
IL@CoFe$_2$O$_4$NPs@MWCNTs	Fenitrothion	$2 \times 10^{-8} – 1.6 \times 10^{-4}$	1.35×10^{-8}	[133]
AuNPs/FcDr/rGO/GCE	Dichlorvos	$4.3 \times 10^{-7} – 2.1 \times 10^{-4}$	2.1×10^{-7}	[134]
NiO NPs	Carbofuran	$5 \times 10^{-6} – 3.05 \times 10^{-4}$	5×10^{-7}	[135]
GSH-Lac-AgNPs	Thiram	$1 \times 10^{-8} – 3 \times 10^{-6}$	3.0×10^{-9}	[136]
AgNPs-PHMB, AgNPs-PVP and AgNPs-BH$_4^-$	Thiram	$1 \times 10^{-7} – 1 \times 10^{-4}$	3.6×10^{-8}	[137]
AuNPs	Prothioconazole	3.8×10^{-9} to 5.8×10^{-8}	0.0011	[138]
Cu@AgNPs	Phenthoate	$1.56 \times 10^{-7}$to 4.68×10^{-6}	4.68×10^{-8}	[139]
AgNP-BNCPs	4-Amino thiophenol and methomyl	1×10^{-7} to 1×10^{-3}	3.6×10^{-7}	[140]
CQDs-AgNPs	Carbaryl	9.9×10^{-10} to 9.9×10^{-8}	0.0 to 7.45×10^{-8}	[141]
AuNPs	Triazophos, parathion and chlorpyrifos	3.19×10^{-11} to 6.3×10^{-8} 1.7×10^{-10} to 1.71×10^{-7} 1.4×10^{-9} to 2.85×10^{-6}	2.23×10^{-11} 3.08×10^{-11} 2.4×10^{-10}	[142]
AuNPs	Parathion-methyl, triazophos and phosmet	3×10^{-9} and 1×10^{-8}	0.026 ng cm^{-2}, 0.031 ng cm^{-2} and 0.032 ng cm^{-2}	[143]
AuNPs	Carbendazim	2.2×10^{-9} to 5.0×10^{-7}	2.2×10^{-9}	[144]
AuNP-SPCE	Imidacloprid	5.0×10^{-11} to 1×10^{-8}	2.2×10^{-11}	[145]
Citrate-Au NPs	Acephate, phenthoate, profenofos, acetamiprid, chlorothalonil, cartap	$1 \times 10^{-5} – 9 \times 10^{-5}$ $1 \times 10^{-8} – 1.5 \times 10^{-6}$ $1 \times 10^{-6} – 2 \times 10^{-4}$ $1 \times 10^{-9} – 1.5 \times 10^{-7}$ $1 \times 10^{-6} – 1 \times 10^{-3}$ $5 \times 10^{-8} – 1.5 \times 10^{-6}$	3.46×10^{-7} 3.0×10^{-9} 6.0×10^{-7} 6.24×10^{-10} 3.75×10^{-7} 1.7×10^{-8}	[146]
Imida-AgNPs	Paraquat	$2 \times 10^{-5} – 1.8 \times 10^{-4}$	6.27×10^{-6}	[147]
NFC/Au@AgNP	Thiram and paraquat	4.1×10^{-8}	2.9×10^{-7} and 1.7×10^{-7}	[148]
PSi–Pd NPs	Imidacloprid	–	1×10^{-9}	[149]
Ag@Au NPs	Profenofos, acetamiprid, carbendazim	–	5.6×10^{-12} 2.06×10^{-11} 3.19×10^{-11}	[150]
AuNPs	Dichlorvos, trichlorfon and paraoxon	–	1.4×10^{-5} 3.7×10^{-5} 2.6×10^{-5}	[151]

The identification and remediation of the heavy metals ion contamination are of significant importance. In recent times, considerable efforts have been focused to develope an on-site detection sensor for monitoring such contaminations [157]. These sensor have tremendous better analytical properties such as precise, accurate, low cost, rapid, on site, portable, *etc.* [158].

Recently, nanoscience and nanotechnology have developed, which has led to the emergence of new applications for nanomaterials. Technologies for ultrasensitive detection and imaging have also developed in the analytical sciences. Gold and silver based nanoparticles with colorimetric sensors are currently gaining increasing attention. As these nanoparticles have strong absorption of LSPR band associated to interparticle distance, colorimetric sensing methods provide the advantages of rapid, sensitive, cheap and smooth operatable [159,160].

A smartphone integrated portable colorimetric assay was developed by Motalebizadeh *et al.* [161] for the detection of As^{2+} using polydimethylsiloxane microfluidic kit. Moreover, an extract of mango-flower can be used as colorimetric sensor for monitoring of arsenic ions [162]. These two colorimetric sensors have higher LOD 2.98×10^{-6} mol/L, 2.66×10^{-6} mol/L, respectively. In another method, Boruah *et al.* [163] developed glucose-functionalized gold nanoparticles as colorimetric approach towards detection of As^{3+} using with LOD 7.07×10^{-9} mol/L. The main region for good LOD is a strong chemical bond between hydroxyl(-OH) and arsenic ion (As^{3+}).

For cadmium ions, a smartphone integrated colorimetric fluorescent paper strip was also developed by Wang *et al.* [164] for the quantitative estimation of Cd having a limit of detection of 3.33×10^{-8} mol/L. Sung & Wu [165] reported the colorimetric estimation of Cd(II) ions in lake water sample by using functionalized gold nanoparticles with a lower limit of detection.

Saenchoopa *et al.* [166] synthesized silver nanoparticles stabilized by γ-aminobutyric acid for the calorimetric detection of Hg^{2+} in the water sample having limit of detection is 2.37×10^{-6} mol/L and this value is higher compared to reported other nanomaterials. Graphene oxide/gold nanoparticles (GO/AuNPs) was synthesized by Tan *et al.* [167] for the detection of Hg^{2+} *via* with a lower limit of detection 3.8×10^{-10} mol/L. The Hg^{2+} have a property to sturdily binds with amino group of oligonucleotide to form T–Hg–T complex and the reaction solution from GO/AuNPs-T–Hg–T complex still shows sturdy absorption at 655 nm [167]. So far, the colorimetric sensor has been used for the detection of heavy metals contamination, additionally the analytical parameters of these sensors are summarized in Table-4.

Electrochemical analysis: Electrochemical sensor belongs to the largest family of sensor, this consist with a transducer element known as electrode. An electrode is non-affected by internal solution due to protected by a selective membrane, which act as separating membrane between electrode and ionic solution [185-187]. Electrochemical sensors have a broad area from clinical treatments to food technology, it is a magnificient technique for real time and accurate measurement of different analytes [188]. The basic mechanism behind electrochemical sensing of any analyte is based on interaction between the electrode and the analyte, which generate an electric signals, this signals will further measure as qualitative as well as quantitative electric signals [189]. Several applications have been already reported for the electrochemical sensing probes like monitoring of the environmental pollutants, pharmaceutical, clinical diagnosis, *etc*. [190-193]. This technique have several analytical properties like rapid, reliable, effective sensing probe for monitoring the environmental pollutants [194]. The electroanalytical application is more powerful with modified electrode by nanoparticles, the properties like its sensitivity, high surface to volume ratio, rapidity, stability were increased [195].

Electrochemical detection of pesticides: The agricultural industry extensively employs various types of pesticides in order to maximize profits and achieve desired outcomes. Consequently, trace amounts of pesticides can be detected in the environmental components. So, the monitoring of pesticides by some developed nanosensor is important to reduce their toxicity for all living organisms [196,197]. Mogha *et al.* [198] reported AChE biosensor which was based on the reduction of graphene by ZrO^{2-} used for the estimation of chlorpyrifos with a high limit of detection 1×10^{-7} µM. Different types of nanomaterials such as Au@MWCNTs/GCE, CuO NWs–SWCNTs hybrid nanocomposite, nano-MIP-CP electrode for the detection of dichlorvos, malathion, diazion are successfully accomplished [199]. Kamyabi *et al.* [200] developed an ultrasensitive electrochemiluminescence platform that is based on ZnONPs/Ni-foam in the occurrence of $K_2S_2O_8$ as the robust co-reactant for detection of chlorpyrifos with a lower limit of detection *i.e.* of 9.5×10^{-16} µM. Several other colorimetric sensors have been used for the detection of other kind of pesticides with their analytical parameters are summarized in Table-5.

Electrochemical detection of heavy metals: The electrochemical method is one of most affective, rapid, portable, selective, cost -affective technique for simultaneous measurement of metal ion from the environmental samples [221-224]. Recently, new techniques such as screen printed electrodes, which are flexible, portable and disposable in nature are widely used as electrochemical detection of heavy metal ions [225]. Several Nowadays, the researchers and scientist developed a range of nanomaterials effectively been fabricated on papers by direct deposition or through screen printing [226]. For example, the magnetic nanoparticles like Fe_3O_4 fabricated by AuNPs was also helpful for monitoring of these heavy metal ions [227]. Similarly, glutathione coated magnetic nanoparticles (GSH@Fe_3O_4) for the electroanalytical measurement of heavy metals ions such as Pb^{2+} and Cd^{2+} ions with good lower detection limits 0.182 µg L^{-1} and 0.172 µgL^{-1}, respectively has been reported [228]. Recently, Fe_3O_4@Au-cystamine-thymine acetic acid based on the screen-printed electrode for the detection of arsenic (As^{2+}) and mercury (Hg^{2+}) ions are too reported [229].

TABLE-4
LINEAR RANGE AND LOD OF COLORIMETRIC DETECTION OF SOME HEAVY METALS

Nanomaterial	Heavy metal	Linear range (mol/L)	LOD (mol/L)	Ref.
GSH-AuNPs	Cd^{2+}	Maximum contamination level of 4.45×10^{-8}	1.88×10^{-8}	[168]
GNSs	Pb^{2+}	$0 – 1 \times 10^{-3}$	1.5×10^{-12}	[169]
AuNPs/Glu	As^{3+}	$2.6 \times 10^{-7} – 6.67 \times 10^{-6}$	7.4×10^{-8}	[170]
AuNPs/Glu	Pb^{2+}	$9.6 \times 10^{-8} – 4.82 \times 10^{-6}$	3.7×10^{-8}	[170]
(Ag@rGO)	Cr^{4+}	$1 \times 10^{-7} – 2.52 \times 10^{-5}$	3.1×10^{-8}	[171]
AgNPs LSPR	Pb^{2+}	$2.4 \times 10^{-9} – 4.8 \times 10^{-8}$	0.64 ± 0.04 µg/L	[172]
TiO_2 NPs	Cu^{2+}	1×10^{-8} to 1.25×10^{-5}	2.51×10^{-9}	[173]
NDTM-AuNPs	Pb^{2+}	$0 – 3.0 \times 10^{-8}$	3.5×10^{-7}	[174]
AuNPs	Cd^{2+}	$2.0 \times 10^{-7} – 1.70 \times 10^{-6}$	1.0×10^{-7}	[175]
Au-NPs-PVA-Cy	Cu^{2+}	9.74×10^{-8} to 3.27×10^{-6}	2.1×10^{-8}	[176]
Au@Ag NPs	Hg^{2+}	–	1.0×10^{-10}	[177]
AuNPs	Co^{2+}	0.05 to 1.6×10^{-5}	4.0×10^{-10}	[178]
AuNPs@MB	As^{3+}	1.3×10^{-8} to 4×10^{-7} and 4×10^{-7} to 1.3×10^{-6}	2.40×10^{-9}	[179]
AuNPs-(EK)3	Ni^{2+}	$5 \times 10^{-6} – 5.0 \times 10^{-5}$	4.8×10^{-6}	[180]
Chl-AgNPs	Hg^{2+}	1×10^{-7} to 2×10^{-4}	2.7×10^{-6}	[181]
AgCu-BNPs	Hg^{2+}	$1 \times 10^{-9} – 1 \times 10^{-4}$	9.0×10^{-9}	[182]
Molybdenum oxide nanomaterial-based three-input logic gate	Sn^{2+}	$1 \times 10^{-6} – 1.4 \times 10^{-4}$	2.75×10^{-8}	[183]
AgNPs	As^{3+}	1.3×10^{-8}	1.33×10^{-8}	[184]

TABLE-5
LINEAR RANGE AND LOD VALUES FOR THE DETECTION OF SOME PESTICIDES

Nanomaterial	Pesticides	Linear range (mol/L)	LOD (mol/L)	Ref.
AuNP-SPCE	Imidacloprid	$5 \times 10^{-11} – 1 \times 10^{-8}$	2.2×10^{-11}	[201]
screen-printed carbon electrodes(SPCE)	Imidacloprid	$5 \times 10^{-11} – 1 \times 10^{-8}$	2.4×10^{-1}	[202]
h-CNT-μPs/Nafion/GCEs	Parathion	$3 \times 10^{-7} – 2 \times 10^{-5}$	9.2×10^{-8}	[203]
Carbon electrode modified with platinum doped silica	Chlorpyrifos-methyl	$1.2 \times 10^{-9} – 6.2 \times 10^{-8}$	7.0×10^{-11}	[204]
Nd-UiO-66@MWCNT	Paraoxon	$7 \times 10^{-10} – 1 \times 10^{-7}$, $1 \times 10^{-9} – 1.2 \times 10^{-7}$	4.0×10^{-11}	[205]
SWCNT-ZnPc hybrid material	Methyl parathion, deltamethrin, chlorpyrifos and Spinosad	$2.45 \times 10^{-9} – 4.0 \times 10^{-8}$	1.49×10^{-9}	[206]
ELP-OPH/BSA/TiO_2NFs/c-MWCNTs	Parathion	Up to 3.64×10^{-5}	1.0×10^{-8}	[207]
ZnO NPs/SPCE	Chlortoluron	$1 \times 10^{-9} – 1 \times 10^{-7}$	4.7×10^{-10}	[208]
Au-SPEs	Paraoxon	Up to 1.4×10^{-4}	7.26×10^{-6}	[209]
PCz/CRGO	Imidacloprid	$3 \times 10^{-5} – 2 \times 10^{-4}$	4.4×10^{-7}	[210]
MIP/GN modified glassy carbon electrode	Imidacloprid	$5 \times 10^{-7} – 1.5 \times 10^{-5}$	1×10^{-7}	[211]
Nanosilver Nafion®/nanoTiO_2 Nafion® modified glassy carbon electrode	Imidacloprid	$1 \times 10^{-6} – 5 \times 10^{-6}$	9.3×10^{-7}	[212]
AG/Au-NPs	Hydrazine	Up to 9.36×10^{-4}	5.7×10^{-10}	[213]
AuNPs/GO-SPCE	Carbofuran	$1 \times 10^{-6} – 2.50 \times 10^{-4}$	2.2×10^{-7}	[214]
Gd_2S_3/RGO	Carbofuran	$1 \times 10^{-9} –1.38 \times 10^{-3}$	1.28×10^{-8}	[215]
3DG-Au/GCE	Carbaryl	$4 \times 10^{-9} – 3 \times 10^{-7}$	1.2×10^{-9}	[216]
Au NPs/Mo_2C/Mo_2N	chlorpyrifos	0 to 1.14×10^{-6}	1.0×10^{-10}	[217]
ZrP/GO	fenitrothion	$8 \times 10^{-9} – 2.6 \times 10^{-5}$	1.0×10^{-9}	[218]
g–C_3N_4–CTAB/CPE	Amino-triazole and linuron	$3 \times 10^{-7} – 4.5 \times 10^{-5}$	6.4×10^{-8}	[219]
GO@Ce-doped TiO_2 NPs	Methyl parathion	$2 \times 10^{-9} – 4.83 \times 10^{-5}$	1.6×10^{-9}	[220]

TABLE-6
ANALYTICAL PERFORMANCE OF SOME ELECTROCHEMICAL SENSOR FOR THE DETECTION OF HEAVY METALS

Nanomaterials	Heavy metals	Linear range (mol/L)	LOD (mol/L)	Ref.
Fe_3O_4@Au NPs/MGCE	Ag^+	$1.17 \times 10^{-7} – 1.77 \times 10^{-5}$	59×10^{-9}	[230]
MCPE/Fe_3O_4/DA/DTPA	Cu^{2+}	$5.0 \times 10^{-9} – 1.0 \times 10^{-4}$	2.1×10^{-9}	[231]
MCPE/Fe_3O_4/DA/DTPA	Pb^{2+}	$1.0 \times 10^{-9} – 5.0 \times 10^{-8}$ and $5.0 \times 10^{-7} – 1.0 \times 10^{-3}$	8.2×10^{-9}	[231]
$MnFe_2O_4$/Au/GCE	As^{3+}	–	44.9×10^{-9}	[232]
Fe_3O_4@TiO_2@NG@Au@ETBD/GCE	Pb^{2+}	$4 \times 10^{-13} – 2 \times 10^{-8}$	7.5×10^{-13}	[233]
Bi/Fe_2O_3/Gr	Zn^{2+}	$1.5 \times 10^{-8} – 1.5 \times 10^{-6}$	1.68×10^{-9}	[234]
RGO-Fe_3O_4/SPE	As^{3+}	$2.6 \times 10^{-8} – 4.0 \times 10^{-6}$	1.3×10^{-9}	[235]
Fe_3O_4@Au	Ag^+	$1.0 \times 10^{-8} – 1.5 \times 10^{-7}$	3.4×10^{-9}	[236]
$MnFe_2O_4$/GO/GCE	Pb^{2+}	$2.0 \times 10^{-7} – 1.1 \times 10^{-6}$	0.08×10^{-6}	[237]
GSH@Fe_3O_4/MGCE	Pb^{2+}	$2.4 \times 10^{-9} – 4.82 \times 10^{-7}$	8.78×10^{-10}	[228]
GSH@Fe_3O_4/MGCE	Cd^{2+}	$4.4 \times 10^{-9} – 8.89 \times 10^{-7}$	1.5×10^{-9}	[228]
Fe_3O_4@PANI/MGCE	Cd^{2+}	$1 \times 10^{-9} – 9 \times 10^{-4}$	0.3×10^{-9}	[238]
MWCNT-Fe_3O_4/eggshell-CPE	Cd^{2+}	$2.66 \times 10^{-11} – 2.22 \times 10^{-9}$	2.1×10^{-1}	[239]
Bi_2O_3/Fe_2O_3@GO/GPE	Cd^{2+}	$5.5 \times 10^{-11} – 1.03 \times 10^{-8}$	9.56×10^{-13}	[240]
Au/ZIF67	Hg^+	$4.9 \times 10^{-9} – 1.24 \times 10^{-7}$	2.49×10^{-10}	[241]
GO-Fe_3O_4-PAMAM/GCE	Pb^{2+}	$1.9 \times 10^{-9} – 5.79 \times 10^{-7}$	6.2×10^{-10}	[242]
Fe_3O_4/MWCNTs/LSG/CS/GCE	Cd^{2+}	$8.8 \times 10^{-9} – 1.779 \times 10^{-6}$	6.9×10^{-10}	[243]
Fe_3O_4/F-MWCNTs/NF/GCE	Cu^{2+}	$5.0 \times 10^{-7} – 3.0 \times 10^{-5}$	0.02×10^{-9}	[244]
Fe_3O_4/F-MWCNTs/NF/GCE	Hg^{2+}	$5.0 \times 10^{-7} – 2.0 \times 10^{-5}$	0.05×10^{-9}	[244]
Au NPs/Fe_3O_4/GCE	As^{3+}	$1.33 \times 10^{-10} – 1.33 \times 10^{-8}$	4.90×10^{-12}	[245]

Table-6 shows the analytical performance of some electrochemical sensors for the detection of heavy metals.

Conclusion

The current study aims to report the potential origins of harmful heavy metals and pesticides, as well as their adverse effects on human health and plant life. The present study reveals that the levels of potentially toxic heavy metals and pesticides in ambient samples exhibit a significant elevation, demanding regular monitoring and assessment. In these circumstances, the different nanomaterials based analytical approaches are developed. This study explores various methodologies for detecting and mitigating the presence of certain heavy metals and pesticides in diverse samples. This work presents a comprehensive overview of the latest advancements in the field of nanomaterial based simple colorimetric and paper-based colorimetric chemical sensors. This overview might prove useful to researchers working on the nanomaterial-based chemical sensors for the detection of a wide range of analytes.

CONFLICT OF INTEREST

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

REFERENCES

1. M. Jiang, L. He, N.K. Niazi, H. Wang, W. Gustave, M. Vithanage, K. Geng, H. Shang, X. Zhang and Z. Wang, *Biochar*, **5**, 2 (2023); https://doi.org/10.1007/s42773-022-00201-x
2. S. Fatichi, D. Or, R. Walko, H. Vereecken, M.H. Young, T.A. Ghezzehei, T. Hengl, S. Kollet, N. Agam and R. Avissar, *Nat. Commun.*, **11**, 522 (2020); https://doi.org/10.1038/s41467-020-14411-z
3. G. Song and M.H. Hayes, *Adv. Agron.*, **177**, 169 (2023); https://doi.org/10.1016/bs.agron.2022.10.002
4. Y. Li, E. Padoan and F. Ajmone-Marsan, *Ecotoxicol. Environ. Saf.*, **209**, 111806 (2021); https://doi.org/10.1016/j.ecoenv.2020.111806
5. A. Patle, R. Kurrey, M.K. Deb, T.K. Patle, D. Sinha and K. Shrivas, *J. Indian Chem. Soc.*, **99**, 100545 (2022); https://doi.org/10.1016/j.jics.2022.100545
6. O. Akoto, S. Yakubu, L.A. Ofori, N. Bortey-sam, N.O. Boadi, J. Horgah and L.N. Sackey, *Heliyon*, **9**, e12661 (2023); https://doi.org/10.1016/j.heliyon.2022.e12661
7. S. Sharma, A.K. Nagpal and I. Kaur, *Food Chem.*, **255**, 15 (2018); https://doi.org/10.1016/j.foodchem.2018.02.037
8. Y. Fan, T. Zhu, M. Li, J. He and R. Huang, *J. Healthc. Eng.*, **2017**, 4124302 (2017); https://doi.org/10.1155/2017/4124302
9. A.G. Santos, G.O. da Rocha and J.B. de Andrade, *Sci. Rep.*, **9**, 1 (2019); https://doi.org/10.1038/s41598-018-37186-2
10. Y. Lin, Y. Ye, Y. Hu and H. Shi, *Ecotoxicol. Environ. Saf.*, **180**, 557 (2019); https://doi.org/10.1016/j.ecoenv.2019.05.057
11. G. Singh, N. Patel, T. Jindal and M.R. Ranjan, *Bull. Environ. Contam. Toxicol.*, **107**, 931 (2021); https://doi.org/10.1007/s00128-021-03349-7
12. M. Uchimiya, D. Bannon, H. Nakanishi, M.B. McBride, M.A. Williams and T. Yoshihara, *J. Agric. Food Chem.*, **68**, 12856 (2020); https://doi.org/10.1021/acs.jafc.0c00183
13. X. Luo, C. Wu, Y. Lin, W. Li, M. Deng, J. Tan and S. Xue, *J. Environ. Sci.*, **125**, 662 (2023); https://doi.org/10.1016/j.jes.2022.01.029
14. Z. Rahman and V.P. Singh, *Environ. Monit. Assess.*, **191**, 419 (2019); https://doi.org/10.1007/s10661-019-7528-7
15. S.S. Dhaliwal, R.K. Naresh, A. Mandal, M.K. Walia, R.K. Gupta, R. Singh and M.K. Dhaliwal, *J. Plant Nutr.*, **42**, 2873 (2019); https://doi.org/10.1080/01904167.2019.1659337
16. Z. Ai, J. Zhang, H. Liu, C. Liang, S. Xue and G. Liu, *Environ. Sci. Pollut. Res. Int.*, **27**, 20160 (2020); https://doi.org/10.1007/s11356-020-08570-1
17. N. Dogra, R. Yadav, M. Kaur, A. Adhikary, W. Ramakrishna and S. Kumar, *Physiol. Mol. Biol. Plants*, **25**, 1251 (2019); https://doi.org/10.1007/s12298-019-00661-9
18. R.S. Ahmed, M.E. Abuarab, M.M. Ibrahim, M. Baioumy and A. Mokhtar, *Chemosphere*, **318**, 137872 (2023); https://doi.org/10.1016/j.chemosphere.2023.137872
19. P. Mazumder, M. Khwairakpam and A.S. Kalamdhad, *Total Environ. Res. Themes*, **5**, 100025 (2023); https://doi.org/10.1016/j.totert.2023.100025
20. M.L. Bornø, D.S. Müller-Stöver and F. Liu, *J. Plant Nutr. Soil Sci.*, **182**, 149 (2019); https://doi.org/10.1002/jpln.201800228
21. S. Boudjabi and H. Chenchouni, *Heliyon*, **9**, e14615 (2023); https://doi.org/10.1016/j.heliyon.2023.e14615
22. L.M.G. dos Santos, C. Barata-Silva, S.A.V. Neto, C.D. Magalhães, R.A. Pereira, J. Malheiros, A.L.O. da Silva and S. do Couto Jacob, *J. Food Compos. Anal.*, **119**, 105272 (2023); https://doi.org/10.1016/j.jfca.2023.105272
23. L. Tamm, B. Thuerig, S. Apostolov, H. Blogg, E. Borgo, P.E. Corneo, S. Fittje, M. de Palma, A. Donko, C. Experton, É.A. Marín, Á.M. Pérez, I. Pertot, A. Rasmussen, H. Steinshamn, A. Vetemaa, H. Willer and J. Herforth-Rahmé, Agronomy, **12**, 673 (2022); https://doi.org/10.3390/agronomy12030673
24. H.I. Jeong, J.E. Han, B.C. Shin, S.B. Jang, J.H. Won, K.H. Kim and S.H. Sung, *Int. J. Environ. Res. Public Health*, **19**, 8523 (2022); https://doi.org/10.3390/ijerph19148523
25. M.A. Rodrigo, E. Puche, N. Carabal, S. Armenta, F.A. Esteve-Turrillas, J. Jiménez and F. Juan, *Environ. Sci. Pollut. Res. Int.*, **29**, 79478 (2022); https://doi.org/10.1007/s11356-022-21365-w
26. Y. Li, H. Liu, J. He, X. Shen, K. Zhao and Y. Wang, *Biol. Trace Elem. Res.*, **200**, 2750 (2022); https://doi.org/10.1007/s12011-021-02901-0
27. M. Hejna, E. Onelli, A. Moscatelli, M. Bellotto, C. Cristiani, N. Stroppa and L. Rossi, *Int. J. Environ. Res. Public Health*, **18**, 2239 (2021); https://doi.org/10.3390/ijerph18052239
28. R.A. Wuana and F.E. Okieimen, *Int. Schol. Res. Notices*, **2011**, 402647 (2011); https://doi.org/10.5402/2011/402647
29. S. Selvam, K. Jesuraja, P.D. Roy, S. Venkatramanan, R. Khan, S. Shukla, D. Manimaran and P. Muthukumar, *Chemosphere*, **298**, 134027 (2022); https://doi.org/10.1016/j.chemosphere.2022.134027
30. I. Diarra and S. Prasad, *Appl. Spectrosc. Rev.*, **56**, 27 (2021); https://doi.org/10.1080/05704928.2020.1719130
31. A. Rashid, B.J. Schutte, A. Ulery, M.K. Deyholos, S. Sanogo, E.A. Lehnhoff and L. Beck, *Agronomy*, **13**, 1521 (2023); https://doi.org/10.3390/agronomy13061521
32. R. Lounas, H. Kasmi, S. Chernai, N. Amarni, L. Ghebriout and B. Hamdi, *Environ. Sci. Pollut. Res. Int.*, **2021**, 30732 (2021); https://doi.org/10.1007/s11356-021-12864-3
33. X. Xu, S. Nie, H. Ding and F.F. Hou, *Nat. Rev. Nephrol.*, **14**, 313 (2018); https://doi.org/10.1038/nrneph.2018.11
34. S. Sellami, O. Zeghouan, F. Dhahri, L. Mechi, Y. Moussaoui and B. Kebabi, *Environ. Monit. Assess.*, **194**, 126 (2022); https://doi.org/10.1007/s10661-022-09781-4
35. D. Chen, D. Chen, R. Xue, J. Long, X. Lin, Y. Lin, L. Jia, R. Zeng and Y. Song, *J. Hazard. Mater.*, **367**, 447 (2019); https://doi.org/10.1016/j.jhazmat.2018.12.111
36. N. Gujre, L. Rangan and S. Mitra, *Chemosphere*, **271**, 129573 (2021); https://doi.org/10.1016/j.chemosphere.2021.129573
37. J. Shi, P. Du, H. Luo, H. Wu, Y. Zhang, J. Chen, M. Wu, G. Xu and H. Gao, *J. Environ. Manage.*, **310**, 114509 (2022); https://doi.org/10.1016/j.jenvman.2022.114509
38. S.M. Shaheen, V. Antoniadis, E. Kwon, H. Song, S.L. Wang, Z.Y. Hseu and J. Rinklebe, *Environ. Pollut.*, **262**, 114312 (2020); https://doi.org/10.1016/j.envpol.2020.114312
39. T. Peng, D. O'Connor, B. Zhao, Y. Jin, Y. Zhang, L. Tian, N. Zheng, X. Li and D. Hou, *Environ. Pollut.*, **245**, 363 (2019); https://doi.org/10.1016/j.envpol.2018.11.011
40. R. Albernaz-Gonçalves, G. Olmos-Antillón and M.J. Hötzel, *Animals*, **12**, 216 (2022); https://doi.org/10.3390/ani12020216
41. S. Carrasco-Gil, C. Ortega-Villasante, J. Sobrino-Plata, Á. Barón-Sola, R. Millán and L.E. Hernández, *Plant Stress*, **7**, 100131 (2023); https://doi.org/10.1016/j.stress.2023.100131
42. S. Rojas-Hucks, I.A. Rodriguez-Jorquera, J. Nimpstch, P. Bahamonde, J.A. Benavides, G. Chiang, J. Pulgar and C.J. Galbán-Malagón, *Toxics*, **10**, 735 (2022); https://doi.org/10.3390/toxics10120735
43. E. Shaji, M. Santosh, K.V. Sarath, P. Prakash, V. Deepchand and B.V. Divya, *Geosci. Front.*, **12**, 101079 (2021); https://doi.org/10.1016/j.gsf.2020.08.015
44. N.J. Raju, *Environ. Res.*, **203**, 111782 (2022); https://doi.org/10.1016/j.envres.2021.111782

45. Z. Shabbir, A. Sardar, A. Shabbir, G. Abbas, S. Shamshad, S. Khalid, Natasha, G. Murtaza, C. Dumat and M. Shahid, *Chemosphere*, **259**, 127436 (2020); https://doi.org/10.1016/j.chemosphere.2020.127436
46. M. Bost, S. Houdart, M. Oberli, E. Kalonji, J.F. Huneau and I. Margaritis, *J. Trace Elem. Med. Biol.*, **35**, 107 (2016); https://doi.org/10.1016/j.jtemb.2016.02.006
47. G. Genchi, A. Carocci, G. Lauria, M.S. Sinicropi and A. Catalano, *Int. J. Environ. Res. Public Health*, **17**, 679 (2020); https://doi.org/10.3390/ijerph17030679
48. M.U. Hassan, M.U. Chattha, I. Khan, M.B. Chattha, M. Aamer, M. Nawaz, A. Ali, M.A.U. Khan and T.A. Khan, *Environ. Sci. Pollut. Res. Int.*, **26**, 12673 (2019); https://doi.org/10.1007/s11356-019-04892-x
49. S. Prasad, K.K. Yadav, S. Kumar, N. Gupta, M.M. Cabral-Pinto, S. Rezania, N. Radwan and J. Alam, *J. Environ. Manage.*, **285**, 112174 (2021); https://doi.org/10.1016/j.jenvman.2021.112174
50. S. Mishra, S. Chen, G.D. Saratale, R.G. Saratale, L.F. Romanholo Ferreira, M. Bilal and R.N. Bharagava, *J. Water Process Eng.*, **39**, 101748 (2021); https://doi.org/10.1016/j.jwpe.2020.101748
51. M.A. Hassaan and A. El Nemr, *Egypt. J. Aquat. Res.*, **46**, 207 (2020); https://doi.org/10.1016/j.ejar.2020.08.007
52. K.H. Kim, E. Kabir and S.A. Jahan, *Sci. Total Environ.*, **575**, 525 (2017); https://doi.org/10.1016/j.scitotenv.2016.09.009
53. L. Rani, K. Thapa, N. Kanojia, N. Sharma, S. Singh, A.S. Grewal, A.L. Srivastav and J. Kaushal, *J. Clean. Prod.*, **283**, 124657 (2021); https://doi.org/10.1016/j.jclepro.2020.124657
54. J.Á. Hernández-Mariano, M.C. Baltazar-Reyes, E. Salazar-Martínez and L.A. Cupul-Uicab, *Int. J. Hyg. Environ. Health*, **239**, 113865 (2022); https://doi.org/10.1016/j.ijheh.2021.113865
55. Y. Sheng, M. Benmati, S. Guendouzi, H. Benmati, Y. Yuan, J. Song, C. Xia and M. Berkani, *Chemosphere*, **308**, 136183 (2022); https://doi.org/10.1016/j.chemosphere.2022.136183
56. O.T. Ore, A.O. Adeola, A.A. Bayode, D.T. Adedipe and P.N. Nomngongo, *Environ. Chem. Ecotoxicol*., **5**, 9 (2022); https://doi.org/10.1016/j.enceco.2022.10.004
57. M.A. van den Dries, S. Lamballais, H. El Marroun, A. Pronk, S. Spaan, K.K. Ferguson, M.P. Longnecker, H. Tiemeier and M. Guxens, *Environ. Res.*, **191**, 110047 (2020); https://doi.org/10.1016/j.envres.2020.110047
58. M. Kara, and E. Öztas, Reproductive Toxicity of Insecticides, In: Animal Reproduction in Veterinary Medicine, IntechOpen (2020).
59. A.B. Mirgorodskaya, R.A. Kushnazarova, D.M. Kuznetsov, A.A. Tyryshkina and L.Y. Zakharova, *Kinet. Catal.*, **63**, 261 (2022); https://doi.org/10.1134/S0023158422030065
60. M.C. Leung and J.N. Meyer, *Reprod. Toxicol.*, **89**, 83 (2019); https://doi.org/10.1016/j.reprotox.2019.07.007
61. M. Zhong, Q. Zhai, R. Zhang, H. Yin, J. Li, Z. Ma, L. Fang, C. Zhang and Y. Li, *Toxicol. Ind. Health*, **37**, 229 (2021); https://doi.org/10.1177/07482337211000979
62. S. Tuck, A. Furey, S. Crooks and M. Danaher, *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess.*, **35**, 911 (2018); https://doi.org/10.1080/19440049.2017.1420919
63. J. Ruzicková, H. Raclavska, M. Safár, M. Kucbel, K. Raclavský, A. Grobelak, B. Svédová and D. Juchelkova, *Fuel*, **293**, 120452 (2021); https://doi.org/10.1016/j.fuel.2021.120452
64. M.M. Abuowarda, M.A. Haleem, M. Elsayed, H. Farag and S. Magdy, *Int. J. Vet. Sci.*, **9**, 175 (2020); https://doi.org/10.37422/IJVS/20.022
65. J.B. Weber, Properties and Behavior of Pesticides in Soil, In: Mechanisms of Pesticide Movement into Groundwater, CRC Press, pp. 15-42 (2018).
66. R.R. Karri, G. Ravindran and M.H. Dehghani, Soft Computing Techniques in Solid Waste and Wastewater Management, Elsevier, edn. 1, pp. 3-33 (2021).
67. M. Li, Y. Gao, W. Yang, C. Zhang, Y. Fang, C. Wang, S. Song and Q. Pan, *Inorg. Chem.*, **61**, 9801 (2022); https://doi.org/10.1021/acs.inorgchem.2c01332
68. R. Sinha, R. Jindal and C. Faggio, *Appl. Sci.*, **11**, 3507 (2021); https://doi.org/10.3390/app11083507
69. A.P.J. Lindsey, S. Murugan and R.E. Renitta, *Biocatal. Agric. Biotechnol.*, **23**, 101468 (2020); https://doi.org/10.1016/j.bcab.2019.101468
70. N.E. Korres, Herbicide Effects on Humans: Exposure, Short and Long-term Effects and Occupational Hygiene, In: Weed Control: Sustainability, Hazards, and Risks in Cropping Systems Worldwide, edn. 2, Chap. 2, pp.14-32, CRC Press (2019).
71. I.K. Abd Ali, T.A. Ibrahim, A.D. Farhan and M.N. Abbas, *J. Pharm. Sci. Res.*, **10**, 1418 (2018).
72. Y. Abobakr, A.F. Gad, H.S. Abou Elnasr, G.M. Abdelgalil, H.I. Hussein and S. Selim, *Pest Manag. Sci.*, **77**, 3208 (2021); https://doi.org/10.1002/ps.6359
73. J. Singh and A. Mirza, Natural Bioactive Products in Sustainable Agriculture Springer, Singapore, pp. 235-257 (2020).
74. L. Schweitzer and J. Noblet, Water Contamination and Pollution, In: Green Chemistry, Elsevier, pp. 261-290 (2018).
75. R. Fuller, P.J. Landrigan, K. Balakrishnan, G. Bathan, S. Bose-O'Reilly, M. Brauer, J. Caravanos, T. Chiles, A. Cohen, L. Corra and M. Cropper, *Lancet Planet. Health*, **6**, e535 (2022); https://doi.org/10.1016/S2542-5196(22)00090-0
76. T.T.T. Tran, D.M. Nguyen, A.Q. Dao, V.T. Le and Y. Vasseghian, *Chemosphere*, **297**, 134116 (2022); https://doi.org/10.1016/j.chemosphere.2022.134116
77. M.A. Farajzadeh, M. Sattari Dabbagh and A. Yadeghari, *J. Sep. Sci.*, **40**, 2253 (2017); https://doi.org/10.1002/jssc.201700052
78. Z. Liang, A.M. Abdelshafy, Z. Luo, T. Belwal, X. Lin, Y. Xu, L. Wang, M. Yang, M. Qi, Y. Dong and L. Li, *Food Chem.*, **384**, 132494 (2022); https://doi.org/10.1016/j.foodchem.2022.132494
79. X. Xu, Y. Guo, X. Wang, W. Li, P. Qi, Z. Wang, X. Wang, S. Gunasekaran and Q. Wang, *Sens. Actuators B Chem.*, **260**, 339 (2018); https://doi.org/10.1016/j.snb.2018.01.075
80. P.A. Souza Tette, L. Rocha Guidi, M.B. de Abreu Glória and C. Fernandes, *Talanta*, **149**, 124 (2016); https://doi.org/10.1016/j.talanta.2015.11.045
81. R. Gurbanov, A.G. Gozen and F. Severcan, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **189**, 282 (2018); https://doi.org/10.1016/j.saa.2017.08.038
82. M. Nishita, S.-Y. Park, T. Nishio, K. Kamizaki, Z.C. Wang, K. Tamada, T. Takumi, R. Hashimoto, H. Otani, G.J. Pazour, V.W. Hsu and Y. Minami, *Sci. Rep.*, **7**, 1 (2017); https://doi.org/10.1038/s41598-016-0028-x
83. K.S. Kantharaj, G.J. Gowda, A. El-Denglawey, N. Ramprasad, A.T. Kozakov, A.V. Nikolsky, S. Kubrin, A. Gowda, V.J. Angadi, B.M. Raafat and M. Dongol, *J. Mater. Sci. Mater. Electron.*, **33**, 14178 (2022); https://doi.org/10.1007/s10854-022-08347-x
84. N.S. Shaban, K.A. Abdou and N.E.H.Y. Hassan, *Beni. Suef Univ. J. Basic Appl. Sci.*, **5**, 102 (2016); https://doi.org/10.1016/j.bjbas.2015.10.001
85. S.H. Kim, T.T.T. Thoa and M.B. Gu, *Curr. Opin. Environ. Sci. Health*, **10**, 9 (2019); https://doi.org/10.1016/j.coesh.2019.09.003
86. M.D.L. Jara, L.A.C. Alvarez, M.C. Guimarães, P.W.P. Antunes and J.P. de Oliveira, *Environ. Sci. Pollut. Res. Int.*, **29**, 46487 (2022); https://doi.org/10.1007/s11356-022-20426-4
87. J. Kaur and P.K. Singh, *Phys. Chem. Chem. Phys.*, **22**, 15105 (2020); https://doi.org/10.1039/D0CP01647K
88. R. Gui, H. Jin, H. Guo and Z. Wang, *Biosens. Bioelectron.*, **100**, 56 (2018); https://doi.org/10.1016/j.bios.2017.08.058
89. M.S. Goh, S.D. Lam, Y. Yang, M. Naqiuddin, S.N.K. Addis, W.T.L. Yong, V. Luang-In, C. Sonne and N.L. Ma, *J. Hazard. Mater.*, **420**, 126624 (2021); https://doi.org/10.1016/j.jhazmat.2021.126624
90. P.L. Chang, M.M. Hsieh and T.C. Chiu, *Int. J. Environ. Res. Public Health*, **13**, 409 (2016); https://doi.org/10.3390/ijerph13040409
91. O. Guselnikova, P. Postnikov, R. Elashnikov, E. Miliutina, V. Svorcik and O. Lyutakov, *Anal. Chim. Acta*, **1068**, 70 (2019); https://doi.org/10.1016/j.aca.2019.03.058
92. R. Singh, P. Thakur, A. Thakur, H. Kumar, P. Chawla, J. V. Rohit, R. Kaushik and N. Kumar, *Int. J. Environ. Anal. Chem.*, **101**, 3006 (2021); https://doi.org/10.1080/03067319.2020.1715382

93. R.K. Mohapatra, H. Srichandan, S. Mishra and P.K. Parhi, Native Soil Bacteria: Potential Agent for Bioremediation, In: Soil Microenvironment for Bioremediation and Polymer Production, Wiley, Chap. 2, pp. 17-34 (2019); https://doi.org/10.1002/9781119592129.ch2
94. L. Chen, K. Nakamura and T. Hama, *J. Environ. Manage.*, **332**, 117362 (2023); https://doi.org/10.1016/j.jenvman.2023.117362
95. H.T. Tran, C. Lin, H.G. Hoang, X.T. Bui, V.G. Le and C.T. Vu, *J. Hazard. Mater.*, **421**, 126767 (2022); https://doi.org/10.1016/j.jhazmat.2021.126767
96. W. Hu, Y. Niu, H. Zhu, K. Dong, D. Wang and F. Liu, *Chemosphere*, **282**, 131092 (2021); https://doi.org/10.1016/j.chemosphere.2021.131092
97. D. O'Connor, T. Peng, J. Zhang, D.C. Tsang, D.S. Alessi, Z. Shen, N.S. Bolan and D. Hou, *Sci. Total Environ.*, **619-620**, 815 (2018); https://doi.org/10.1016/j.scitotenv.2017.11.132
98. X. Yang, L. Liu, W. Tan, C. Liu, Z. Dang and G. Qiu, *Environ. Pollut.*, **264**, 114745 (2020); https://doi.org/10.1016/j.envpol.2020.114745
99. C. Cameselle and S. Gouveia, *J. Hazard. Mater.*, **361**, 95 (2019); https://doi.org/10.1016/j.jhazmat.2018.08.062
100. C. Li, K. Zhou, W. Qin, C. Tian, M. Qi, X. Yan and W. Han, *Soil Sediment Contam.*, **28**, 380 (2019); https://doi.org/10.1080/15320383.2019.1592108
101. S.A.M.Ealia, and M.P.Saravanakumar, *IOP Conf. Ser.: Mater. Sci. Eng.*, **263**, 032019 (2017); https://doi.org/10.1088/1757-899X/263/3/032019
102. P. Punia, M.K. Bharti, S. Chalia, R. Dhar, B. Ravelo, P. Thakur and A. Thakur, *Ceram. Int.*, **47**, 1526 (2021); https://doi.org/10.1016/j.ceramint.2020.09.050
103. K. Wieszczycka, K. Staszak, M.J. WoŸniak-Budych, J. Litowczenko, B.M. Maciejewska and S. Jurga, *Coord. Chem. Rev.*, **436**, 213846 (2021); https://doi.org/10.1016/j.ccr.2021.213846
104. S.S. Salem and A. Fouda, *Biol. Trace Elem. Res.*, **199**, 344 (2021); https://doi.org/10.1007/s12011-020-02138-3
105. L. Madianos, E. Skotadis, G. Tsekenis, L. Patsiouras, M. Tsigkourakos and D. Tsoukalas, *Microelectron. Eng.*, **189**, 39 (2018); https://doi.org/10.1016/j.mee.2017.12.016
106. R. Singh, N. Kumar, R. Mehra, H. Kumar and V.P. Singh, *Trends Environ. Anal. Chem.*, **26**, e00086 (2020); https://doi.org/10.1016/j.teac.2020.e00086
107. M. Xie, F. Zhao, Y. Zhang, Y. Xiong and S. Han, *Food Control*, **131**, 108399 (2022); https://doi.org/10.1016/j.foodcont.2021.108399
108. E. Omanovic-Miklièanina and M. Maksimovic, *Bull. Chem. Technol. Bosnia Herzegovina*, **47**, 59 (2016).
109. F. Amin, Y. Iqbal and G. Korotcenkov, Handbook of II-VI Semiconductor Based Sensors and Radiation Detectors: Vol. 3: Sensors, Biosensors and Radiation Detectors, pp. 361-391 (2023).
110. G. Alberti, C. Zanoni, L.R. Magnaghi and R. Biesuz, *Int. J. Environ. Res. Public Health*, **17**, 8331 (2020); https://doi.org/10.3390/ijerph17228331
111. S.W. Lv, N. Zhao, J.M. Liu, F.E. Yang, C.Y. Li and S. Wang, *ACS Appl. Mater. Interfaces*, **13**, 25044 (2021); https://doi.org/10.1021/acsami.1c06705
112. M. Griep, B. DeVore-Wedding, J. Woodard, and H. Miller, Lab Manual for Connecting Chemistry to the Tribal Community (2018).
113. R. Sivakumar and N.Y. Lee, *Chemosphere*, **275**, 130096 (2021); https://doi.org/10.1016/j.chemosphere.2021.130096
114. A. Ravindran, P. Chandran and S.S. Khan, *Colloids Surf. B Biointerfaces*, **105**, 342 (2013); https://doi.org/10.1016/j.colsurfb.2012.07.036
115. K. Jiang and A.O. Pinchuk, Noble Metal Nanomaterials: Synthetic Routes, Fundamental Properties, and Promising Applications, In: Solid State Physics; Elsevier: Oxford, UK, pp. 131–211 (2015).
116. P. Rebelo, E. Costa-Rama, I. Seguro, J.G. Pacheco, H.P. Nouws, M.N.D. Cordeiro and C. Delerue-Matos, *Biosens. Bioelectron.*, **172**, 112719 (2021); https://doi.org/10.1016/j.bios.2020.112719
117. Y.-Q. Li and L. Feng, *Chin. J. Anal. Chem.*, **48**, 1448 (2020); https://doi.org/10.1016/S1872-2040(20)60057-3
118. S. Patel, R. Jamunkar, D. Sinha, Monisha, T.K. Patle, T. Kant, K. Dewangan and K. Shrivas, *Trends Environ. Anal. Chem.*, **31**, e00136 (2021); https://doi.org/10.1016/j.teac.2021.e00136
119. Q.T. Hua, H. Shibata, Y. Hiruta and D. Citterio, *Anal. Sci.*, **35**, 393 (2018); https://doi.org/10.2116/analsci.18P435
120. I.S. Che Sulaiman, B.W. Chieng, M.J. Osman, K.K. Ong, J.I.A. Rashid, W.M.Z. Wan Yunus, S.A.M. Noor, N.A.M. Kasim, N.A. Halim and A. Mohamad, *Mikrochim. Acta*, **187**, 131 (2020); https://doi.org/10.1007/s00604-019-3893-8
121. R. Umapathi, S. Sonwal, M.J. Lee, G. Mohana Rani, E.-S. Lee, T.-J. Jeon, S.-M. Kang, M.-H. Oh and Y.S. Huh, *Coord. Chem. Rev.*, **446**, 214061 (2021); https://doi.org/10.1016/j.ccr.2021.214061
122. G. Ma, J. Cao, G. Hu, L. Zhu, H. Chen, X. Zhang, J. Liu, J. Ji, X. Liu and C. Lu, *Analyst*, **146**, 4576 (2021); https://doi.org/10.1039/D1AN00621E
123. J. Zheng, H. Zhang, J. Qu, Q. Zhu and X. Chen, *Anal. Methods*, **5**, 917 (2013); https://doi.org/10.1039/C2AY26391B
124. J. Xie, H. Pang, R. Sun, T. Wang, X. Meng and Z. Zhou, *Micromachines*, **12**, 290 (2021); https://doi.org/10.3390/mi12030290
125. Y.H. Chien, C.H. Su, C.C. Hu, K.H. Yeh and W.C. Lin, *Langmuir*, **38**, 838 (2022); https://doi.org/10.1021/acs.langmuir.1c02901
126. N. Kaur, A. Khunger, S.L. Wallen, A. Kaushik, G.R. Chaudhary and R.S. Varma, *Curr. Opin. Green Sustain. Chem.*, **30**, 100488 (2021); https://doi.org/10.1016/j.cogsc.2021.100488
127. A.V. Alex and A. Mukherjee, *Microchem. J.*, **161**, 105779 (2021); https://doi.org/10.1016/j.microc.2020.105779
128. P. Weerathunge, B.K. Behera, S. Zihara, M. Singh, S.N. Prasad, S. Hashmi, P.R.D. Mariathomas, V. Bansal and R. Ramanathan, *Anal. Chim. Acta*, **1083**, 157 (2019); https://doi.org/10.1016/j.aca.2019.07.066
129. W. Chungchai, M. Amatatongchai, R. Meelapsom, K. Seebunrueng, S. Suparsorn and P. Jarujamrus, *Int. J. Environ. Anal. Chem.*, **100**, 1160 (2020); https://doi.org/10.1080/03067319.2019.1650921
130. H. Bhardwaj, M.K. Pandey, Rajesh and G. Sumana, *Mikrochim. Acta*, **186**, 592 (2019); https://doi.org/10.1007/s00604-019-3701-5
131. P. Sawetwong, S. Chairam, P. Jarujamrus and M. Amatatongchai, *Talanta*, **225**, 122077 (2021); https://doi.org/10.1016/j.talanta.2020.122077
132. M.D. Fernández-Ramos, A.L. Ogunneye, N.A.A. Babarinde, M.M. Erenas and L.F. Capitán-Vallvey, *Talanta*, **218**, 121108 (2020); https://doi.org/10.1016/j.talanta.2020.121108
133. J.C. Kilele, R. Chokkareddy and G.G. Redhi, *Microchem. J.*, **164**, 106012 (2021); https://doi.org/10.1016/j.microc.2021.106012
134. L. Yan, X. Yan, H. Li, X. Zhang, M. Wang, S. Fu, G. Zhang, C. Qian, H. Yang, J. Han and F. Xiao, *Microchem. J.*, **157**, 105016 (2020); https://doi.org/10.1016/j.microc.2020.105016
135. H. Baksh, J.A. Buledi, N.H. Khand, A.R. Solangi, A. Mallah, S.T. Sherazi and M.I. Abro, *Monatsh. Chem.*, **151**, 1689 (2020); https://doi.org/10.1007/s00706-020-02704-4
136. V. Dhavle, M.R. Kateshiya, T.J. Park and S.K. Kailasa, *J. Electron. Mater.*, **50**, 3676 (2021); https://doi.org/10.1007/s11664-021-08875-y
137. V.-T. Hoang, N.X. Dinh, N.L. Nhat Trang, N.T. Khi, N.V. Quy, P.A. Tuan, D.Q. Tri, L.H. Thang, T.Q. Huy and A.-T. Le, *Mater. Res. Bull.*, **139**, 111278 (2021); https://doi.org/10.1016/j.materresbull.2021.111278
138. Y. Zhou, C. Li, R. Liu, Z. Chen, L. Li, W. Li, Y. He and L. Yuan, *ACS Biomater. Sci. Eng.*, **6**, 2805 (2020); https://doi.org/10.1021/acsbiomaterials.0c00208
139. K. Shrivas, Monisha, S. Patel, S.S. Thakur and R. Shankar, *Lab Chip*, **20**, 3996 (2020); https://doi.org/10.1039/D0LC00515K

140. A. Parnsubsakul, U. Ngoensawat, T. Wutikhun, C. Sapcharoenkun, T. Sukmanee, P. Pienpinijtham and S. Ekgasit, *Carbohydr. Polym.*, **235**, 115956 (2020); https://doi.org/10.1016/j.carbpol.2020.115956
141. Y. Chen, X. Qin, C. Yuan, R. Shi and Y. Wang, *Dyes Pigments*, **181**, 108529 (2020); https://doi.org/10.1016/j.dyepig.2020.108529
142. C. Zhang, Z. Jiang, M. Jin, P. Du, G. Chen, X. Cui, Y. Zhang, G. Qin, F. Yan, A.M. Abd El-Aty, A. Hacimüftüoglu and J. Wang, *Food Chem.*, **326**, 126813 (2020); https://doi.org/10.1016/j.foodchem.2020.126813
143. D. Huang, J. Zhao, M. Wang and S. Zhu, *Food Control*, **108**, 106835 (2020); https://doi.org/10.1016/j.foodcont.2019.106835
144. S. Wang, L. Su, L. Wang, D. Zhang, G. Shen and Y. Ma, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **228**, 117809 (2020); https://doi.org/10.1016/j.saa.2019.117809
145. B. Pérez-Fernández, J.V. Mercader, A. Abad-Fuentes, B.I. Checa-Orrego, A. Costa-García and A. Escosura-Muñiz, *Talanta*, **209**, 120465 (2020); https://doi.org/10.1016/j.talanta.2019.120465
146. S. Tai, Q. Pan, X. Chen, C. Peng, C. Zhang and Z. Wang, *Sens. Actuators B Chem.*, **378**, 133130 (2023); https://doi.org/10.1016/j.snb.2022.133130
147. S. Ali, M.R. Shah, S. Hussain, S. Khan, A. Latif, M. Ahmad and M. Ali, *J. Cluster Sci.*, **33**, 413 (2021); https://doi.org/10.1007/s10876-021-01978-w
148. S. Asgari, L. Sun, J. Lin, Z. Weng, G. Wu, Y. Zhang and M. Lin, *Mikrochim. Acta*, **187**, 390 (2020); https://doi.org/10.1007/s00604-020-04358-9
149. A.M. Al-Syadi, M. Faisal, F.A. Harraz, M. Jalalah and M. Alsaiari, *Sci. Rep.*, **11**, 9174 (2021); https://doi.org/10.1038/s41598-021-88326-0
150. Y. Lu, Y. Tan, Y. Xiao, Z. Li, E. Sheng and Z. Dai, *Talanta*, **234**, 122585 (2021); https://doi.org/10.1016/j.talanta.2021.122585
151. H. Yu, M. Wang, J. Cao, Y. She, Y. Zhu, J. Ye, A.M. Abd El-Aty, A. Hacimüftüoglu, J. Wang and S. Lao, *Food Chem.*, **364**, 130326 (2021); https://doi.org/10.1016/j.foodchem.2021.130326
152. J. Briffa, E Sinagra and R. Blundell, *Heliyon*, **6**, e04691 (2020); https://doi.org/10.1016/j.heliyon.2020.e04691
153. P.B. Tchounwou, C.G. Yedjou, A.K. Patlolla and D.J. Sutton, *EXS*, **101**, 133 (2012); https://doi.org/10.1007/978-3-7643-8340-4_6
154. A.H.M.S.I.M. Jamal, Y.A. Tarek, M.A.B. Siddique, M.A.A. Shaikh, S.C. Debnath, M.R. Uddin, S. Ahmed, M.A. Akbor, M.A. Al-Mansur, A.R.M.T. Islam, R. Khan, M. Moniruzzaman and S. Sultana, *Heliyon*, **9**, e13027 (2023); https://doi.org/10.1016/j.heliyon.2023.e13027
155. A.Q. Alorabi, M. Abdelbaset and S.A. Zabin, *Chemosensors*, **8**, 1 (2019); https://doi.org/10.3390/chemosensors8010001
156. A. Alengebawy, S.T. Abdelkhalek, S.R. Qureshi and M.Q. Wang, *Toxics*, **9**, 42 (2021); https://doi.org/10.3390/toxics9030042
157. M. Naseri, M. Mohammadniaei, K. Ghosh, S. Sarkar, R. Sankar, S. Pal, S. Mukherjee, E. Ansari Dezfouli, A. Halder, J. Qiao, N. Bhattacharyya and Y. Sun, *Electroanalysis*, **35**, e202200114 (2023); https://doi.org/10.1002/elan.202200114
158. V.S. Ajay Piriya, P. Joseph, S.C.G. Kiruba Daniel, S. Lakshmanan, T. Kinoshita and S. Muthusamy, *Mater. Sci. Eng. C*, **78**, 1231 (2017); https://doi.org/10.1016/j.msec.2017.05.018
159. S. Jabariyan and M.A. Zanjanchi, *Appl. Phys., A Mater. Sci. Process.*, **125**, 872 (2019); https://doi.org/10.1007/s00339-019-3167-7
160. H. Sohrabi, A. Khataee, S. Ghasemzadeh, M.R. Majidi and Y. Orooji, *Trends Environ. Anal. Chem.*, **31**, e00139 (2021); https://doi.org/10.1016/j.teac.2021.e00139
161. A. Motalebizadeh, H. Bagheri, S. Asiaei, N. Fekrat and A. Afkhami, *RSC Adv.*, **8**, 27091 (2018); https://doi.org/10.1039/C8RA04006K
162. H. Kolya, T. Kuila, N.H. Kim and J.H. Lee, *Appl. Surf. Sci.*, **513**, 145760 (2020); https://doi.org/10.1016/j.apsusc.2020.145760
163. B.S. Boruah, R. Biswas and P. Deb, *Opt. Laser Technol.*, **111**, 825 (2019); https://doi.org/10.1016/j.optlastec.2018.09.023
164. H. Wang, L. Da, L. Yang, S. Chu, F. Yang, S. Yu and C. Jiang, *J. Hazard. Mater.*, **392**, 122506 (2020); https://doi.org/10.1016/j.jhazmat.2020.122506
165. Y.M. Sung and S.P. Wu, *Sens. Actuators B Chem.*, **201**, 86 (2014); https://doi.org/10.1016/j.snb.2014.04.069
166. A. Saenchoopa, W. Boonta, C. Talodthaisong, O. Srichaiyapol, R. Patramanon and S. Kulchat, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **251**, 119433 (2021); https://doi.org/10.1016/j.saa.2021.119433
167. D. Tan, Y. He, X. Xing, Y. Zhao, H. Tang and D. Pang, *Talanta*, **113**, 26 (2013); https://doi.org/10.1016/j.talanta.2013.03.055
168. H.H. Cho, J.H. Heo, D.H. Jung, S.H. Kim, S.J. Suh, K.H. Han and J.H. Lee, *Biochip J.*, **17**, 263 (2021); https://doi.org/10.1007/s13206-023-00101-7
169. S. Wang, X. Huang, Q. An, R. Zhou, W. Xu, D. Xu, Q. Lin and X. Cao, *Anal. Chim. Acta*, **1160**, 338380 (2021); https://doi.org/10.1016/j.aca.2021.338380
170. B. Sahu, R. Kurrey, M.K. Deb, K. Shrivas, I. Karbhal and B.R. Khalkho, *RSC Adv.*, **11**, 20769 (2021); https://doi.org/10.1039/D1RA02929K
171. P.N. Minh, V.-T. Hoang, N.X. Dinh, O. Van Hoang, N. Van Cuong, D. Thi Bich Hop, T.Q. Tuan, N.T. Khi, T.Q. Huy and A.-T. Le, *New J. Chem.*, **44**, 7611 (2020); https://doi.org/10.1039/D0NJ00947D
172. R. Roto, B. Mellisani, A. Kuncaka, M. Mudasir and A. Suratman, *Chemosensors*, **7**, 28 (2019); https://doi.org/10.3390/chemosensors7030028
173. Z. Ghasemi and A. Mohammadi, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **239**, 118554 (2020); https://doi.org/10.1016/j.saa.2020.118554
174. S. Megarajan, K.R. Kanth and V. Anbazhagan, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **239**, 118485 (2020); https://doi.org/10.1016/j.saa.2020.118485
175. Y. Xue, H. Zhao, Z. Wu, X. Li, Y. He and Z. Yuan, *Analyst*, **136**, 3725 (2011); https://doi.org/10.1039/C1AN15238F
176. F. Amourizi, K. Dashtian and M. Ghaedi, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **230**, 118026 (2020); https://doi.org/10.1016/j.saa.2020.118026
177. J. Wang, J. Wu, Y. Zhang, X. Zhou, Z. Hu, X. Liao, B. Sheng, K. Yuan, X. Wu, H. Cai, H. Zhou and P. Sun, *Sens. Actuators B Chem.*, **330**, 129364 (2021); https://doi.org/10.1016/j.snb.2020.129364
178. C. Karami and M.A. Taher, *Plasmonics*, **13**, 1315 (2018); https://doi.org/10.1007/s11468-017-0635-9
179. E. Wi and Y. Kim, *J. Ind. Eng. Chem.*, **124**, 481 (2023); https://doi.org/10.1016/j.jiec.2023.05.003
180. A. Parnsubsakul, S. Oaew and W. Surareungchai, *Nanoscale*, **10**, 5466 (2018); https://doi.org/10.1039/C7NR07998B
181. D.D. Yilmaz, D.A. Demirezen and H. Mihçiokur, *Surf. Interfaces*, **22**, 100840 (2021); https://doi.org/10.1016/j.surfin.2020.100840
182. J. Pang, R. Xie, S. Chua, Y. Zou, M. Tang, F. Zhang and F. Chai, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **261**, 120035 (2021); https://doi.org/10.1016/j.saa.2021.120035
183. G.M. Sangaonkar, M.P. Desai, T.D. Dongale and K.D. Pawar, *Sci. Rep.*, **10**, 2037 (2020); https://doi.org/10.1038/s41598-020-58844-4
184. B.S. Boruah, N.K. Daimari and R. Biswas, *Results Phys.*, **12**, 2061 (2019); https://doi.org/10.1016/j.rinp.2019.02.044
185. C. Wardak, K. Morawska and K. Pietrzak, *Materials*, **16**, 5779 (2023); https://doi.org/10.3390/ma16175779

186. Y. Lyu, S. Gan, Y. Bao, L. Zhong, J. Xu, W. Wang, Z. Liu, Y. Ma, G. Yang and L. Niu, *Membranes*, **10**, 128 (2020); https://doi.org/10.3390/membranes10060128
187. J. Kojima, K. Uchiyama and Y. Yoshida, *Sens. Actuators B: Chemical*, **347**, 130625 (2021); https://doi.org/10.1016/j.snb.2021.130625
188. C. Bliem, E. Piccinini, W. Knoll and O. Azzaroni, Methods in Enzymology, Academic Press, vol. 609, pp. 23-46 (2018).
189. B. Mostafiz, S.A. Bigdeli, K. Banan, H. Afsharara, D. Hatamabadi, P. Mousavi, C.M. Hussain, R. Keçili and F. Ghorbani-Bidkorbeh, *Trends Environ. Anal. Chem.*, **32**, e00144 (2021); https://doi.org/10.1016/j.teac.2021.e00144
190. Q. Tian, J. Xu, Y. Zuo, Y. Li, J. Zhang, Y. Zhou, X. Duan, L. Lu, H. Jia, Q. Xu and Y. Yu, *J. Electroanal. Chem.*, **837**, 1 (2019); https://doi.org/10.1016/j.jelechem.2019.01.055
191. S. Tajik, H. Beitollahi, F.G. Nejad, Z. Dourandish, M.A. Khalilzadeh, H.W. Jang, R.A. Venditti, R.S. Varma and M. Shokouhimehr, *Ind. Eng. Chem. Res.*, **60**, 1112 (2021); https://doi.org/10.1021/acs.iecr.0c04952
192. S. Tajik, H. Beitollahi, F. Garkani Nejad, I. Sheikhshoaie, A.S. Nugraha, H.W. Jang, Y. Yamauchi and M. Shokouhimehr, *J. Mater. Chem. A Mater. Energy Sustain.*, **9**, 8195 (2021); https://doi.org/10.1039/D0TA08344E
193. C. Li, A. Begum and J. Xue, *Water Environ. Res.*, **92**, 1770 (2020); https://doi.org/10.1002/wer.1431
194. Y. Yang, W. Yan, C. Guo, J. Zhang, L. Yu, G. Zhang, X. Wang, G. Fang and D. Sun, *Anal. Chim. Acta*, **1106**, 1 (2020); https://doi.org/10.1016/j.aca.2020.01.044
195. S. Tajik, Y. Orooji, Z. Ghazanfari, F. Karimi, H. Beitollahi, R.S. Varma, H.W. Jang and M. Shokouhimehr, *J. Food Meas. Charact.*, **15**, 3837 (2021); https://doi.org/10.1007/s11694-021-00955-1
196. V.P. Kalyabina, E.N. Esimbekova, K.V. Kopylova and V.A. Kratasyuk, *Toxicol. Rep.*, **8**, 1179 (2021); https://doi.org/10.1016/j.toxrep.2021.06.004
197. J. da Silva Sousa, H.O. do Nascimento, H. de Oliveira-Gomes and R.F. do Nascimento, *Microchem. J.*, **168**, 106359 (2021); https://doi.org/10.1016/j.microc.2021.106359
198. N.K. Mogha, V. Sahu, M. Sharma, R.K. Sharma and D.T. Masram, *Mater. Des.*, **111**, 312 (2016); https://doi.org/10.1016/j.matdes.2016.09.019
199. K.A. Abd-Elsalam, M.M. Ramadan and M.K. Hassanien, Nanocarbon-based Sensors for Pesticide Detection: Recent Trends, In: Carbon Nanomaterials for Agri-Food and Environmental Applications, Elsevier, Chap. 18, pp. 401-428 (2020); https://doi.org/10.1016/B978-0-12-819786-8.00018-9
200. M.A. Kamyabi and M. Moharramnezhad, *J. Electroanal. Chem.*, **865**, 114120 (2020); https://doi.org/10.1016/j.jelechem.2020.114120
201. S. Babazadeh, P.A. Moghaddam, S. Keshipour and K. Mollazade, *Sci. Rep.*, **10**, 14327 (2020); https://doi.org/10.1038/s41598-020-71349-4
202. B. Pérez-Fernández, J.V. Mercader, A. de la Escosura-Muñiz, B.I. Checa-Orrego and A. Costa-García, *Analyst*, **144**, 2936 (2019); https://doi.org/10.1039/C9AN00176J
203. J. Yao, Z. Liu, M. Jin, Y. Zou, J. Chen, P. Xie, X. Wang, E.M. Akinoglu, G. Zhou and L. Shui, *Sens. Actuators B Chem.*, **321**, 128517 (2020); https://doi.org/10.1016/j.snb.2020.128517
204. W. Wei, X. Zong, X. Wang, L. Yin, Y. Pu and S. Liu, *Food Chem.*, **135**, 888 (2012); https://doi.org/10.1016/j.foodchem.2012.06.037
205. H. Khoshsafar, N. Karimian, T.A. Nguyen, A. Khanmohammadi, H. Fakhri, A. Hajian and H. Bagheri, *Chemosphere*, **292**, 133440 (2021); https://doi.org/10.1016/j.chemosphere.2021.133440
206. B. Köksoy, D. Akyüz, A. Senocak, M. Durmus and E. Demirbas, *Food Chem. Toxicol.*, **147**, 111886 (2021); https://doi.org/10.1016/j.fct.2020.111886
207. J. Bao, C. Hou, Q. Dong, X. Ma, J. Chen, D. Huo, M. Yang, K.H.A.E. Galil, W. Chen and Y. Lei, *Biosens. Bioelectron.*, **85**, 935 (2016); https://doi.org/10.1016/j.bios.2016.05.094
208. M. Haddaoui and N. Raouafi, *Sens. Actuators B Chem.*, **219**, 171 (2015); https://doi.org/10.1016/j.snb.2015.05.023
209. F. Arduini, S. Guidone, A. Amine, G. Palleschi and D. Moscone, *Sens. Actuators B Chem.*, **179**, 201 (2013); https://doi.org/10.1016/j.snb.2012.10.016
210. W. Lei, Q. Wu, W. Si, Z. Gu, Y. Zhang, J. Deng and Q. Hao, *Sens. Actuators B Chem.*, **183**, 102 (2013); https://doi.org/10.1016/j.snb.2013.03.118
211. M. Zhang, H.T. Zhao, T.J. Xie, X. Yang, A.J. Dong, H. Zhang, J. Wang and Z.Y. Wang, *Sens. Actuators B Chem.*, **252**, 991 (2017); https://doi.org/10.1016/j.snb.2017.04.159
212. A. Kumaravel and M. Chandrasekaran, *Sens. Actuators B Chem.*, **158**, 319 (2011); https://doi.org/10.1016/j.snb.2011.06.028
213. C. Karuppiah, S. Palanisamy, S.M. Chen, S.K. Ramaraj and P. Periakaruppan, *Electrochim. Acta*, **139**, 157 (2014); https://doi.org/10.1016/j.electacta.2014.06.158
214. A. Jirasirichote, E. Punrat, A. Suea-Ngam, O. Chailapakul and S. Chuanuwatanakul, *Talanta*, **175**, 331 (2017); https://doi.org/10.1016/j.talanta.2017.07.050
215. V. Mariyappan, M. Keerthi and S.M. Chen, *J. Agric. Food Chem.*, **69**, 2679 (2021); https://doi.org/10.1021/acs.jafc.0c07522
216. T. Rahmani, H. Bagheri, M. Behbahani, A. Hajian and A. Afkhami, *Food Anal. Methods*, **11**, 3005 (2018); https://doi.org/10.1007/s12161-018-1280-4
217. H. Khosropour, B. Rezaei, H.A. Alinajafi and A.A. Ensafi, *Mikrochim. Acta*, **188**, 1 (2021); https://doi.org/10.1007/s00604-020-04655-3
218. T. Kokulnathan, T.J. Wang, N. Duraisamy, E.A. Kumar and A. Ni-Sung, *J. Hazard. Mater.*, **412**, 125257 (2021); https://doi.org/10.1016/j.jhazmat.2021.125257
219. D. Ilager, N.P. Shetti, K.R. Reddy, S.M. Tuwar and T.M. Aminabhavi, *Environ. Res.*, **204**, 111856 (2022); https://doi.org/10.1016/j.envres.2021.111856
220. R. Nehru, Y.F. Hsu, S.F. Wang, C.D. Dong, M. Govindasamy, M.A. Habila and N. AlMasoud, *Mikrochim. Acta*, **188**, 216 (2021); https://doi.org/10.1007/s00604-021-04847-5
221. Q. Ding, C. Li, H. Wang, C. Xu and H. Kuang, *Chem. Commun.*, **57**, 7215 (2021); https://doi.org/10.1039/D1CC00983D
222. Q. Wu, H.-M. Bi and X.-J. Han, *Chin. J. Anal. Chem.*, **49**, 330 (2021); https://doi.org/10.1016/S1872-2040(21)60083-X
223. A. Qureashi, A.H. Pandith, A. Bashir, T. Manzoor, L.A. Malik and F.A. Sheikh, *Surf. Interfaces*, **23**, 101004 (2021); https://doi.org/10.1016/j.surfin.2021.101004
224. A. Numan, A.A. Gill, S. Rafique, M. Guduri, Y. Zhan, B. Maddiboyina, L. Li, S. Singh and N. Nguyen Dang, *J. Hazard. Mater.*, **409**, 124493 (2021); https://doi.org/10.1016/j.jhazmat.2020.124493
225. K. Torres-Rivero, A. Florido and J. Bastos-Arrieta, *Sensors*, **21**, 2596 (2021); https://doi.org/10.3390/s21082596
226. Y. Shao, Y. Dong, L. Bin, L. Fan, L. Wang, X. Yuan, D. Li, X. Liu and S. Zhao, *Microchem. J.*, **170**, 106726 (2021); https://doi.org/10.1016/j.microc.2021.106726
227. M. Sedki, G. Zhao, S. Ma, D. Jassby and A. Mulchandani, *Sensors*, **21**, 883 (2021); https://doi.org/10.3390/s21030883
228. M. Baghayeri, A. Amiri, B. Maleki, Z. Alizadeh and O. Reiser, *Sens. Actuators B Chem.*, **273**, 1442 (2018); https://doi.org/10.1016/j.snb.2018.07.063
229. P. Butmee, J. Mala, C. Damphathik, K. Kunpatee, G. Tumcharern, M. Kerr, E. Mehmeti, G. Raber, K. Kalcher and A. Samphao, *Talanta*, **221**, 121669 (2021); https://doi.org/10.1016/j.talanta.2020.121669
230. H. Yang, X. Liu, R. Fei and Y. Hu, *Talanta*, **116**, 548 (2013); https://doi.org/10.1016/j.talanta.2013.07.041
231. M. Bagherzadeh, M.M. Pirmoradian and F. Riahi, *Electrochim. Acta*, **115**, 573 (2014); https://doi.org/10.1016/j.electacta.2013.11.012

232. S. Zhou, X. Han, H. Fan and Y. Liu, *Sensors*, **16**, 935 (2016); https://doi.org/10.3390/s16060935
233. F.M. Liu, Y. Zhang, W. Yin, C.J. Hou, D.Q. Huo, B. He, L.L. Qian and H.B. Fa, *Sens. Actuators B Chem.*, **242**, 889 (2017); https://doi.org/10.1016/j.snb.2016.09.167
234. S. Lee, J. Oh, D. Kim and Y. Piao, *Talanta*, **160**, 528 (2016); https://doi.org/10.1016/j.talanta.2016.07.034
235. A.B. Chimezie, R. Hajian, N.A. Yusof, P.M. Woi and N. Shams, *J. Electroanal. Chem.*, **796**, 33 (2017); https://doi.org/10.1016/j.jelechem.2017.04.061
236. P. Miao, Y. Tang and L. Wang, *ACS Appl. Mater. Interfaces*, **9**, 3940 (2017); https://doi.org/10.1021/acsami.6b14247
237. S.F. Zhou, X.J. Han, H.L. Fan, J. Huang and Y.Q. Liu, *J. Alloys Compd.*, **747**, 447 (2018); https://doi.org/10.1016/j.jallcom.2018.03.037
238. Y. Kong, T. Wu, D. Wu, Y. Zhang, Y. Wang, B. Du and Q. Wei, *Anal. Methods*, **10**, 4784 (2018); https://doi.org/10.1039/C8AY01245H
239. S. Mohammadi, M.A. Taher, H. Beitollahi and M. Naghizadeh, *Environ. Nanotechnol. Monit. Manag.*, **12**, 100241 (2019); https://doi.org/10.1016/j.enmm.2019.100241
240. T.R. Das and P.K. Sharma, *Microchem. J.*, **147**, 1203 (2019); https://doi.org/10.1016/j.microc.2019.04.001
241. Y. Liu, R. Weerasooriya and X. Chen, *J. Hazard. Mater.*, **431**, 128608 (2022); https://doi.org/10.1016/j.jhazmat.2022.128608
242. M. Baghayeri, H. Alinezhad, M. Fayazi, M. Tarahomi, R. Ghanei-Motlagh and B. Maleki, *Electrochim. Acta*, **312**, 80 (2019); https://doi.org/10.1016/j.electacta.2019.04.180
243. Z. Xu, X. Fan, Q. Ma, B. Tang, Z. Lu, J. Zhang, G. Mo, J. Ye and J. Ye, *Mater. Chem. Phys.*, **238**, 121877 (2019); https://doi.org/10.1016/j.matchemphys.2019.121877
244. W. Wu, M. Jia, Z. Zhang, X. Chen, Q. Zhang, W. Zhang, P. Li and L. Chen, *Ecotoxicol. Environ. Saf.*, **175**, 243 (2019); https://doi.org/10.1016/j.ecoenv.2019.03.037
245. H. Cui, W. Yang, X. Li, H. Zhao and Z. Yuan, *Anal. Methods*, **4**, 4176 (2012); https://doi.org/10.1039/c2ay25913c