Chapter 5

Recent Developments on Mass Spectrometry for the Analysis of Pesticides in Wastewater

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/51929

1. Introduction

The utility of pesticides plays an important role in the production of agronomy and horticulture areas. In recent years, pesticides have been widely used in increasing amount in various fields including agriculture, floriculture and horticulture. Pesticides applications are multidisciplinary involving in addition to man, behind agronomist, biologist, economist, chemists, engineers, medical practitioners and physicists. The ideal pesticide would be one which is effective against the target species and has little or no side effects on human beings, livestock, crop plants and other non-target organisms. The uses of various pesticides are increasing rapidly year by year with the growing awareness among the farmers about the utility of pesticides in maximum their benefits. Pesticides are a group of chemicals intended for preventing/destroying any pest detrimental to man or his interest during production, processing, storage, transportation and distribution of food. These are toxic substances deliberately added to environment. They are used because of toxic and biocidal to kill and harm living things. Pest control is an integral part of the development of every country because the damage done by pests is considerably high. Pesticides are not only destroy crops but also transmit diseases. Hence, the use of pesticides became necessary both in agricultural and household sectors.

In this connection, multidisciplinary nature and applications of pesticides in different fields have been described and shown in Figure 1 [1]. Pesticides are classified based on their intended target groups and depending on their chemical composition and molecular structures. In terms of intended target groups, the pesticides are classified into the following categories [2].

- Insecticides: These are helpful to destroy insects (Stomach poisons and contact poison).
- Fungicides: These are toxic to fungi and help to prevent plant diseases.
- Herbicides: These are helpful to kill weeds and other unwanted vegetation.
- Others: These includes rodenticides (against rats, mice, grass hoppers etc.,) molluscicides (against snails) and nematicides (control microscopic worms).

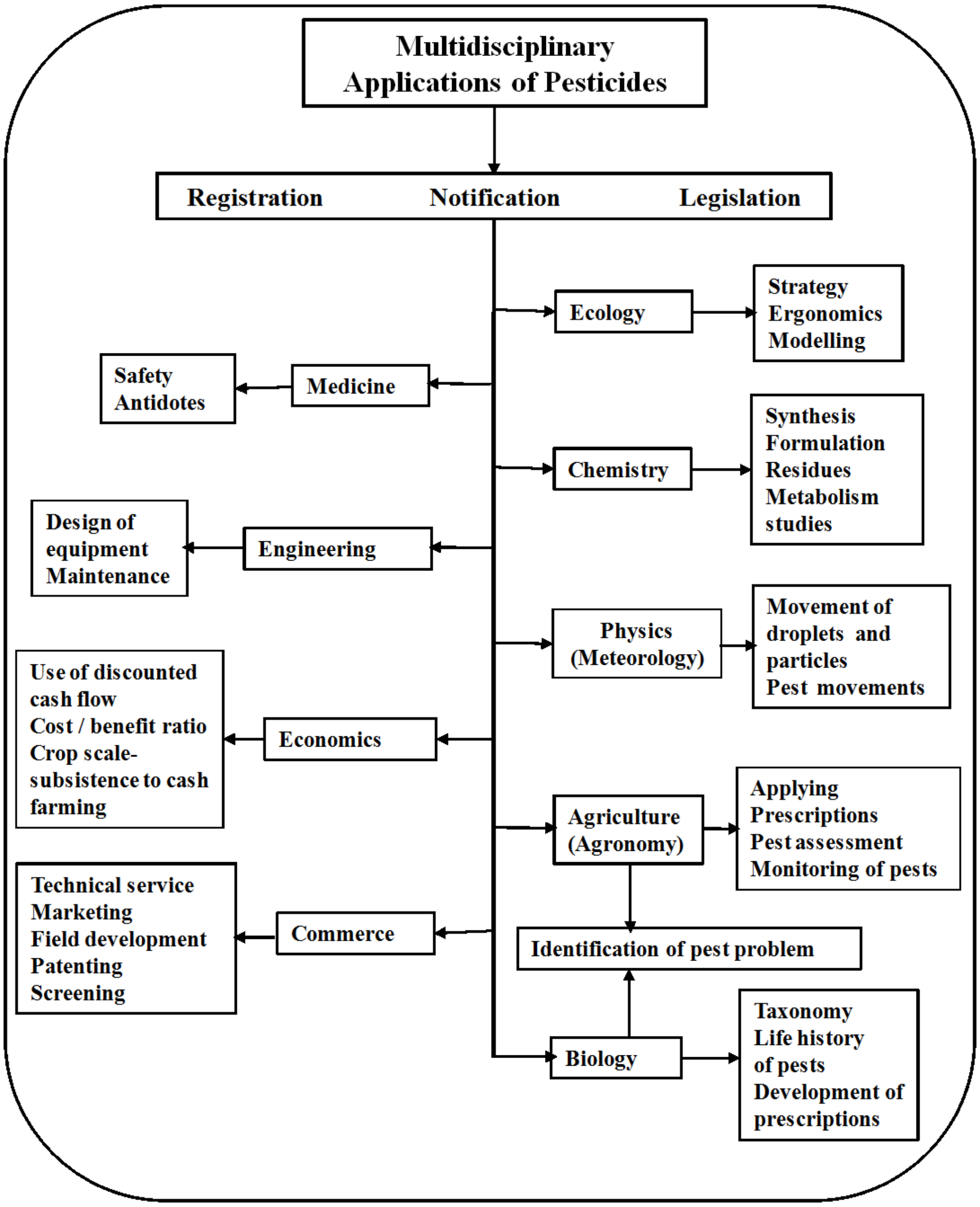

Figure 1. Pesticides applications in multidisciplinary areas.

The persistence of pesticide residues is governed by many factors such as the nature and dosage of pesticide application, its degradation with time, metabolism and conversion into various products along with their movement from one sphere to another through the pesticide cycle [3] and shown in Figure 2. Pesticide residue cycle in the environment starts right from the stage of pesticide application for pest control purposes both in indoor and outdoor. Those are contaminated every component of the environment including food material like food grains, fruits, vegetables and other crops; animal and animal products; water and aquatic animals; non-target organisms; air and soil [4].

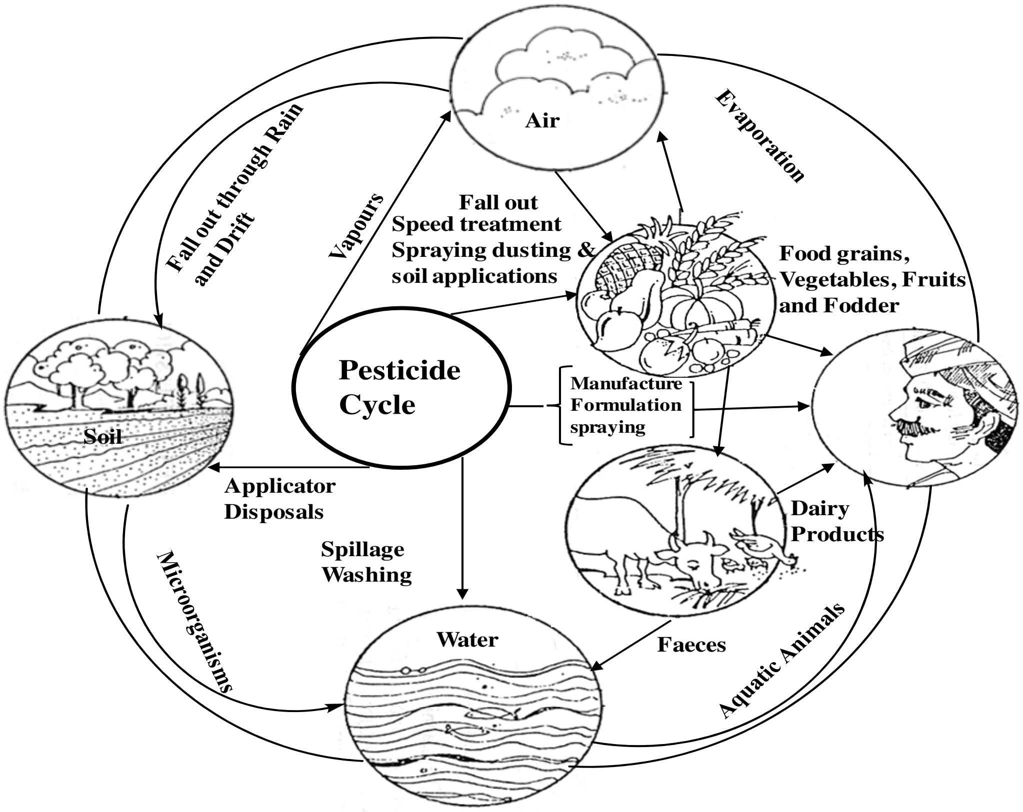

Figure 2. Pesticides cycle in environment

Comprising over 70% of the Earth's surface, water is undoubtedly the most precious natural resource that exists on our planet. Without the seemingly invaluable compound comprised of hydrogen and oxygen, life on Earth would be non-existent: it is essential for everything on our planet to grow and prosper. Although we as humans recognize this fact, we disregard it by polluting our rivers, lakes, and oceans. Subsequently, we are slowly but surely harming our planet to the point where organisms are dying at a very alarming rate. In addition to innocent organisms dying off, the drinking water has become greatly affected as is ability to use water for recreational purposes. In order to combat water pollution, we must understand the problems and become part of finding the solution.

Water pollution is referred to an addition in excess of any material or heat that is harmful to humans or animals or desirable aquatic life or otherwise causes significant departures from normal activities of various living communities in a measurement of water. As per the water commission, water is considered as polluted if it is not of sufficient quality to be suitable for variety of uses, people wish to use in the present or in the future. Water pollution according to Environmental Protection Agency (EPA) and World Health Organisation (WHO) are defined as demonstrable and recurrent breach of any physical or chemical or biological criteria of quality of water systems. Water is not a national problem but a global problem. The degree of water pollution depends on both population and living standards of a citizen in a country. As water travels through the hydrological cycle, it changes from pure salt free moisture suspended in the troposphere as clouds to the brine of the sea. Given the ecosystem disruption, the toxicity, and the biological resistance to these pesticides that many insect species have developed organochlorines have largely been replaced with organophosphates and carbamates.

In modern economies, various types of activity, including agriculture, industry and transportation produce a large amount of pesticide pollution. Soil, air and water have traditionally been used as sites for the disposal of all these wastes. Some of them may get into nearby streams, and pollute rivers, lakes and soil. The most common kinds of waste can be classified into four types: agricultural, industrial, municipal and nuclear. Most of the agricultural wastes including a wide range of organic materials (pesticides), animal wastes and timber by-products are laying long time in wastewater. Many of these, such as plant residues and livestock manure, are very beneficial if they are returned to the soil. However, improper handling and disposal may cause pollution.

Persistent Organic Pollutants (POPs) are toxic substances which are produced intentionally for various uses or created as by-products of combustion or industrial processes. They include hexachlorobenzene (HCBs), polychlorinated biphenyls (PCBs), dicholorodiphenyltrichloroethane (DDT), dioxin, furan, dieldrin, aldrin, endrin, chlordane, heptachlor, toxaphene, and mirex. Some persistent organic pollutants, such as aldrin, chlordane, DDT, HCBs, mirex, and toxaphene are used as pesticides. Others have industrial uses; PCBs, for example, were used for insulating electric transformers. POPs are characterized by their chemical properties. They are substances which are found to be toxic and that are persistent, means they break down very slowly in soil, air, and water and therefore remain in the environment for a long time. Because they persist in the environment, they can be transported long distances through wind or water before they are deposited. According to the United Nations Environment Program, these pollutants have been found on "every continent, at sites representing every major climatic zone and geographic sector throughout the world." This is true even if there is no local source for the pollutants. For example, levels of DDT have been found in the Arctic even though it has never been used there.

The international environmental treaty (the Stockholm Convention on Persistent Organic Pollutants) bans the use of eight POP pesticides immediately: HCBs, dieldrin, aldrin, endrin, chlordane, heptachlor, toxaphene, and mirex, the use of other substances identified as persistent organic pollutants are restricted. Furthermore, the treaty includes measures to provide aid to countries to eliminate the use and production of persistent organic pollutants. At present, near about 1,209 pesticides [4] and their metabolites and degradation products belonging to more than 100 chemical classes in use in food production or present in the environment. Moreover, applications of pesticides are continually expanding, hence their consumption is ever increasing and more of them are infiltrating into the environment. Recent studies have been revealed that European Union countries are consumed more than 300,000 tons of pesticides per annum on crop protection alone [6-8]. In order to determine trace amounts (very low concentrations) of pesticides and their residues in wastewater, it is necessary to follow a series of operations to accurate quantification by using mass spectrometric methods. The series of operations are (i) isolation (extraction and separation) of pesticides from sample matrix (air, water, sediment, living things, etc.), (ii) separation and purification of the pesticide residues from co-extracted, non-target chemicals (sample clean-up), (iii) sample concentration and (iv) pesticide residues identification by mass spectrometry. Therefore, we will focus on the extraction methods coupled with mass spectrometric techniques for the multi-residue pesticides analysis in wastewater.

2. Extraction methods coupled with mass spectrometric techniques

Despite the advances in analytical instrumentation, sample pre-treatment for analyte concentration and matrix removal is frequently the bottleneck in the overall analytical method and inhibits a high sample throughput. Since, sample preparation plays a vital role for the analysis of pesticide residues, and it includes interferent removal and analyte preconcentration. Generally, extraction can define the use of two immiscible phases to separate target species from one phase into the other. The separation or purification of target species involve either by extraction into organic phase, leaving undesirable substances in aqueous phase; or by extraction of unwanted substances into organic phase, leaving desirable solute in aqueous phase. Extraction is a separation process that involves the distribution of a solute between two phases is an equilibrium condition described by partition theory. Extraction efficiency of the method is calculated by the ability of solvent to extract the analyte (inorganic or organic species). This can be defined that the ratio of the concentration of the solute in each solvent at equilibrium is a constant called the distribution coefficient (K).

$$K = \frac{[\text{solute}]_{\text{Org}}}{[\text{solute}]_{\text{Aq}}} = \frac{C_{\text{Org}}}{C_{\text{Aq}}} = \frac{W_{\text{Org}} / V_{\text{Org}}}{W_{\text{Aq}} / V_{\text{Aq}}}$$

where Org and Aq refer to the organic and aqueous layers and C_{org} and C_{Aq} are the concentrations of solute in each layer at equilibrium in mass/volume (W/V).

(Note that K is independent of the actual amounts of the two solvents mixed)

To date some researchers have also published some reviews as well as book chapters in pesticide analysis in water and food by using extraction methods coupled with mass spectrometric techniques [9-15]. These monographs were mainly highlighted the types of extraction methods, extraction- and chromatographic -techniques coupled with mass spectrometric techniques for the analysis of multi-residues pesticides in water, soil and food samples. The developed extraction methods-, coupled with used ion sources and -analyzers in mass spectrometry was shown in Figure 3. However, keeping in mind the recent developments in miniaturized extraction techniques coupled with mass spectrometry for the pesticide analysis in today's world, it is hoped that there is still a strong demand for an extensive review with updated literature on recent developments in mass spectrometry for pesticide analysis in wastewater. The aim of this book chapter is to give a comprehensive overview of the recent developments in mass spectrometry for the analysis of pesticides in wastewater.

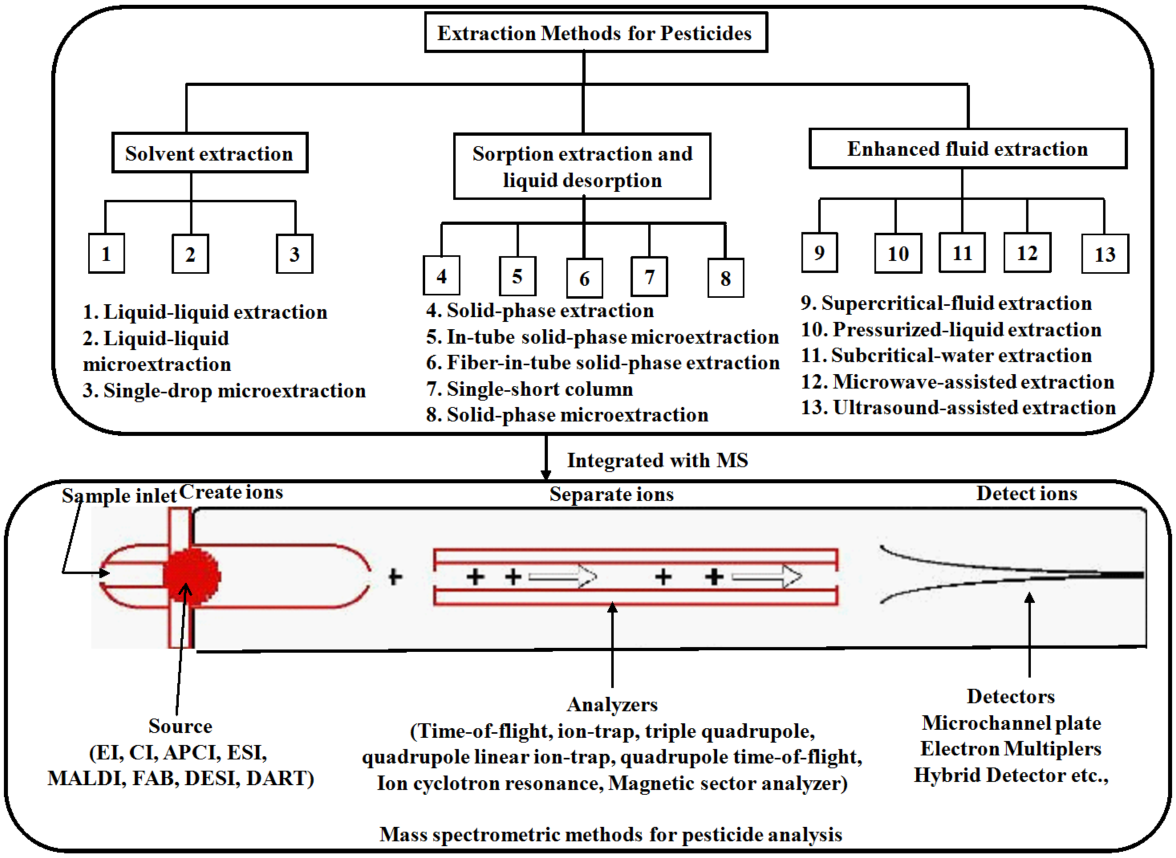

Figure 3. Extraction methods coupled with mass spectrometric techniques

Mass spectrometry coupled to chromatographic techniques (gas chromatography (GC) and liquid chromatography (LC)) is powerful tools for the identification of pesticides in wastewater. Since, these techniques allow selective and routine identification of many pesticide species in parts-per-trillion (ppt) or lower concentrations. In recent years, developments in chromatography coupled with mass spectrometric techniques have been received much attention for the efficient separation and detection of a wide variety of pesticides in wastewater analysis.

Due to the ultra-trace levels of pesticides in environmental samples (ng/L), a preconcentration step is essentially required for the pesticides in wastewater prior to their measurement. Huang's group developed high-performance liquid chromatography coupled with ESI-MS/MS for the identification of 11 chloro- and thiomethyltriazines and metolachlor and its ethanesulfonic and oxanilic acid degradates in water samples [16]. Stir bar sorptive extraction (SBSE) coupled with liquid chromatography/tandem mass spectrometry was used for the determination of pesticides in surface water [17]. Hernandez's group investigated the presence of pesticide transformation products in water by using solid-phase extraction (SPE) coupled with liquid chromatography-mass spectrometry (LC-MS) using different mass analyzers [18]. Moreover, Marin's group described online SPE coupled with LC-MS method for the quantification and confirmation of 27 pesticides including anionic, cationic and neutral species in water samples [19]. Kuster's team developed an automated on-line SPE-LC–MS/MS and LC-MS/MS techniques for the analysis of polar and semi-polar pesticides in nature and treated water samples [20-21]. Moreover, the two dominant ionization methods (EI and chemical ionization (CI)) are used for the analysis of pesticides by GC–MS. Pitarch's group described the use of negative CI mode for the detection of pesticides in water samples [22]. This negative CI mode provided better selectivity and sensitivity than the electron impact (EI) ionization. Meanwhile, several research groups have been developed SBSE methods coupled with thermal desorption low thermal gas chromatography mass spectrometry (TD-LT-GC-MS) and thermal desorption gas chromatography mass spectrometry (TD-GC-MS) techniques for the fast screening of huge number of multi-residue pesticides in water samples with limit of detections (LODs) 10 ng L^{-1} [23-25]. At the same time, SBSE coupled with automated TD-GC-MS method was used for the sensitive determination of triazines in underground waters [26]. Wang et al. developed GC-MS method for the determination of pesticides in water by solid-phase extraction (SPE) using carbon nanotubes as sorbent [27]. Derouiche's team simultaneous analyzed polychlorinated biphenyls and organochlorine pesticides in water by headspace solid-phase microextraction (HS-SPME) coupled with GC-MS [28].

Designing a fully integrated miniaturized analytical platform for multi-residue pesticides analysis in wastewater studies is a great challenge for any analytical chemist. This can be achieved by imagine of complete platform combining sample preparation, separation methods coupled to a dedicated instrument such as mass spectrometer. Recently, several SPE methods coupled with liquid chromatography – electrospray ionization (ESI) tandem mass spectrometric approaches have been described for the analysis of a wide variety of pesticides in water samples [29-36]. These methods allow efficient ionization of a wide spectrum of compounds with varying polarities and wide linear dynamic ranges. Potter and co-workers developed SPE technique combined with HPLC- atmospheric pressure chemical ionization (APCI) – MS for the analysis of multiresidue pesticides in water samples [37]. A HPLC combined with ESI MS method was described for the direct determination of 300 pesticides in water samples [38]. These approaches have been successfully described that the potentiality of mass spectrometric methods for the analysis of pesticides using various mass analyzers such as ion trap (IT), triple quadrupole (QpQ) and time-of-flight (TOF) which can facilitate to detect pesticides with more accuracy. These methods are allowed to build homemade libraries (empirical or theoretical) for the identification of pesticides. Moreover, these methods provide a promising direction towards the development of spectral libraries of pesticides by using quatrupole and TOF analyzers. These approaches were successfully provided pesticides full-scan accurate-mass spectra combined with the evidence from isotopic clusters related to the suspected peaks, which allowed the prediction of a reduced number of possible elemental compositions. The confirmation of the pesticide residues was accomplished using characteristic fragment ions with tandem mass spectrometry, which showed the same isotopic profile as the parent molecule. These advances were effectively addressed for the multiresidue determination of wide variety pesticides in water samples. In another application of these methods, exact mass and relative isotopic abundances (RIAs) information of pesticides ions can be obtained using TOF instruments, which allowed to elucidate the elemental composition of organic molecules. By using these methods, all possible elemental compositions of the precursor and product ions and their neutral losses were calculated.

Nowadays, the public has more concerns about the toxic effects of pesticides being widely used for control of insects and weeds, which leads to serious contamination of hydrosphere. Dual-pre-column-based trace enrichment combined on-line with liquid chromatography-diode-array UV and tandem mass spectrometric detection was developed for the determination of a wide polarity range of organic microcontaminants in river water [39]. Tandem MS was used for confirmation and quantification of organic microcontaminants in river water and target species were found at ng/L level. Recently, identification of micro-organic contaminants are very important in wastewater treatment plants. To this, an online HPLC–heated ESI tandem mass spectrometric method was developed and validated for the determination of basic pesticides in effluent wastewaters [40]. Mass resolution was greatly increased to minimize interference from endogenous compounds in the matrix and micro-organic contaminants were effectively detected with improved signal-to-noise ratio and better detection limits. This method was used to detect 11 basic pesticides, such as methoxytriazine, chlorotriazines, chloroacetanilides, phenylurea and carbamate pesticides. Very recently, Santana-Rodríguez's group developed a fully automated on-line SPE system combined with ultra-HPLC-MS/MS method for the detection of 27 endocrine disrupting compounds in sewage samples [41]. This method was effectively separated and detected all the species in a single chromatographic run and analyzed within 4 min. In this method, ESI positive and negative ions modes are used for the analysis of pesticides. Precursor ions included positive ions in positive ion mode ($[M+NH_4]^+$ adducts for short ethoxylated chains AP_nEOs ($n \leq 2$), and $[M+H]^+$ for 19- norethindrone, testosterone and norgestrel) and negative ions in negative ion mode ($[M-H]^-$ for raw alkylphenol (NP and OP), diethylstilbestrol, 17β-oestradiol, oestriol, 17α-ethynyloestradiol and bisphenol-A, respectively. Hernandez's developed a multiclass screening method for organic contaminants in natural and wastewater for the qualitative and sensitive identification of trace level organic compounds by SPE coupled with GC-TOF-MS [42]. This method was successfully detected a wide variety of compounds such as polyaromatic hydrocarbons, octyl/nonyl phenols, polychlorinated biphenyls, polybrominated diphenyl ethers, insecticides (organochlorines, organophosphorus, carbamates and pyrethroids), herbicides (triazines and chloroacetanilides), fungicides and several relevant metabolites. The method was effectively elucidated the possible chemical structures of pesticides by the identification of fragment ions of molecular ions. HPLC combined with ESI-MS/MS technique was used for the simultaneous determination of six selected endocrine disrupter compounds (diltiazem, progesterone, benzyl butyl phthalate, estrone, carbamazepine and acetaminophen) in wastewater samples [43]. Fernandez-Alba's group developed LC-MS/MS method for the analysis of a group of 14 organic pollutants including pharmaceuticals (analgesics/anti-inflammatories, lipid regulators and diuretics), pesticides (diuron) and disinfectants (chlorophene) in wastewater [44]. Mass analysis was performed by using a hybrid triple quadrupole-linear ion trap-mass spectrometer. MS/MS spectra of organic pollutants revealed that losses of 44 amu, assigned to $[M–H–CO_2]^-$ ions, characteristic of the presence of carboxylic acid functionalities in the pollutant molecules. Moreover, the antilipemic agent, bezafibrate, and the biologically-active clofibrate metabolite, clofibric acid were produced $[M–H]^- \rightarrow [M–H-86]^-$ as the main transition-corresponding to the loss of the methylpropanoic acid moiety $[M–H–C(CH_3)_2\ CO_2]^-$. Similarly, gemfibrozil gave product ions by the loss of the dimethylpentanoic acid group while diuron and chlorophene lost dimethylamine and chlorine, respectively.

It is well known that the treatments used at the wastewater treatment plants are not exhaustive enough to completely remove organic compounds. Therefore, the effluents of urban waters become a source of many different organic pollutants. Frenich and co-workers developed a rapid multi-residue method for the analysis of 40 herbicides (such as simazine, terbuthylazine and diuron) in waters by ultra-performance liquid chromatography (UPLC) coupled to tandem mass spectrometry [45]. Prior to LC-MS, SPE was used for the extraction of herbicides from water samples. This method describes the advantage of triple quadrupole analysers over ion trap mass spectrometers as there are no restrictions on the maximum *m*/*z* value of the product ion. Multi-residue methods are analytical methods for determination of dozens or even hundreds analytes in a single analysis. Nurmi and Pellinen developed a multiresidue method for screening of 84 pesticides in aquatic environments by using SPE-UPLC-TOF-MS [46]. Similarly, SPE-UPLC coupled with ESI MS/MS technique was developed for the validation of 28 basic/neutral pharmaceuticals (antiepileptics, antibacterial drugs, β-blockers, analgesics, lipid-regulating agents, bronchodilators, histamine-2-blockers, anti-inflammatory agents, calcium channel blockers, angiotensin-II antagonists and antidepressants) and illicit drugs in surface water [47].

The trace amounts of organic pollutants (herbicides, fungicides, insecticides, xenobiotics, endocrine disrupting agents and their corresponding transformation products in the water compartment is still of growing and demands a sensitive methods for the preservation and sustainability of the environment. Godejohann's team described the applications of SPE coupled with HPLC-ESI-MS/MS and NMR techniques for the identification of pesticides and their residues in two different wastewater treatment plants in Switzerland [48]. These results confirmed that the presence of pesticides (linuron, metazachlor, ethofumesate, isoproturon, metamitron, propazine and chloridazon desaminometamitron) and their transformation products in wastewater plant. Sauve's group described a simple on-line method for the analysis of 10 compounds including herbicides, pharmaceuticals, caffeine and some metabolites in drinking, surface and wastewater samples [49]. This technique illustrated that the use of on-line SPE coupled with LC-ESI-MS/MS. This method provides detection limits in the range of 2 to 24 ng/L for the pesticide residues, with recoveries from 87 to 110% in surface as well as wastewater samples. The same group described that the development and validation of an on-line -SPE-LC-ESI-MS/MS and –SPE-LC-ESI-TOF-MS/MS methods for the simultaneous quantitation and confirmation of 14 selected trace organic contaminants such as anti-infectives (clarithromycin, sulfamethoxazole and trimethoprim), an anticonvulsant (carbamazepine) and its transformation product 10,11-dihydrocarbamazepine, an antihypertensive (enalapril), antineoplastics (cyclophosphamide and methotrexate), herbicides (atrazine, cyanazine, and simazine) and two of their transformation products (deethylatrazine and deisopropylatrazine) and an antiseptic (triclocarban) in drinking and surface water [50]. This method allowed for the detection and confirmation of trace level organic contaminants by using LC–MS/MS in SRM mode, with a second SRM transition monitored for confirmation of each compound.

Recent years, there is an overwhelming evidence of the importance of monitoring programs of pesticide residues on environmental compartments, especially water that constitutes an essential element for animals and human beings. Fernández-Franzón's group developed SBSE coupled with LC-MS/MS with a triple quadrupole analyzer using selected reaction monitoring mode via electrospray ionization for the validation and confirmation of 16 pesticides in surface water [51]. This method was successfully validated in spiked surface water samples at limits of quantifications (LOQs), showed recoveries <62%, and LOQs were found to be 0.03 and 3.0 μg/L for diazinon and simazine, respectively. Fernandez-Alba *et al*. developed and evaluated an analytical method for a rapid automated screening and confirmation of 400 organic micro-contaminants and their quantification in water samples of different types (surface and wastewaters) using LC–electrospray quadrupole-time-of-flight mass spectrometry (LC–QTOFMS) [52]. This method provided detailed fragmentation information of micro-organic species and identified unknown compounds and/or transformation products with similar structures to those of known organic contaminants by in-source CID fragmentation. This method was effectively detected target species and LODs were found to be 2 - 5 ng/L, respectively. Benvenuto's group described that the validation and application of ultra-HPLC-MS/MS method for the quantification and confirmation of 11 compounds (atrazine, simazine, terbuthylazine, terbumeton, terbutryn and their main transformation products) in surface and wastewater samples [53]. This method was optimized full-scan MS and MS/MS spectra of parent pesticides for their identification and confirmation in wastewater. All analytes were measured in positive ionization mode presenting an abundant $[M+H]^+$, which was selected as precursor ion. These approaches were effectively and rapidly identified and confirmed by tandem mass spectrometry and provided cost-efficient separation and screening of multiple compounds in wastewater. Table 1 describes that an overview of extraction methods coupled with mass spectrometric tools for the multi-residue analysis of pesticides and their degradation products in water samples.

Number of pesticides analyzed	Technique	Sensitivity	Reference
11 pesticides	HPLC-ESI-MS/MS	LOD: 0.05[a]	[16]
16 pesticides	SBSE- HPLC-ESI-MS/MS	LOQs: 0.03-3[a]	[17]
11 pesticides	HPLC-ESI-MS/MS SPE-LC-ESIMS/MS	LODs: 2-25[b] LOQs: 50[b]	[18]
27 pesticides	Online SPE-HPLC-ESI-MS/MS	LODs: < 5[b] LOQs: 25[b]	[19]
17 pesticides	Online SPE-HPLC-ESI-MS/MS	LODs: 0.1-2.7[b] LOQs: 0.2-7.2[b]	[20]
25 pesticides	SPE- GC-MS/MS	LODs: 25-250[b] LOQs: 5-150[b]	[22]
46 pesticides	Dual SBSE-TD-LTM-GC-MS	Not reported	[23]
85 pesticides	SBSE-TD -GC-MS	LODs: <10[b]	[24]
82 pesticides	Dual SBSE-TD-LTM-GC- MS	LODs <10[b]	[25]
10 triazines	SBSE-GC-MS	LOQs: 0.7- 11.3[b]	[26]
12 pesticides	SPE-GC-MS	LODs: 0.01– 0.03[a]	[27]
15 organochlorines	HS-SPME-GC-MS	LODs: 0.4 – 26[b]	[28]
7 pesticides	SPE- HPLC-ESI-MS$_n$	LODs: 5.0-8.1[a] LOQs: 16.7-26.9[a]	[29]
14 pesticides	SPE-HPLC-ESI-MS/MS	LOQs: 0.005 - 0.048[a]	[30]
37 pesticides	SPE-ultra-high pressure-LC-ESI-MS/MS	LOQs: 0.025[a]	[31]
9 pesticides	SPE-ultra-high pressure-LC-ESI-MS/MS	LODs: 0.1 – 20[b]	[32]
31 pesticides	SPE-ultra-high pressure-LC-ESI-MS/MS	LODs: ≤ 8[b] LOQs: 50[b]	[33]
101 pesticides	SPE- HPLC-ESI -MS	Not reported	[34]
28 pesticides	SPE- HPLC-ESI-MS/MS	LOQs:0.025 - 0.050[a]	[35]
12 pesticides	SPE-HPLC-ESI-MS/MS	LODs: 0.2-88.9[b] LOQs: 0.7-296[b]	[36]
27 pesticides	SPE-HPLC-APCI(+)-MSn	LODs: 0.01-0.1[a]	[37]
300 pesticides	HPLC-ESI-MS/MS	LODs: 0.1[a]	[38]
8 polar and acidic pesticides	On-line SPE-LC-ESI-MS/MS	LODs: <1.0[b]	[39]
11 basic pesticides	On-line SPE-HPLC-ESI-MS/MS	LODs: 0.017 - 0.21[a] LOQs: 0.045 - 0.63[a]	[40]
27 pesticides	On-line SPE-ultra HPLC-ESI-MS/MS	LODs: 0.3–2.1[b]	[41]

Number of pesticides analyzed	Technique	Sensitivity	Reference
150 pesticides	SPE-GC-TOF-MS/MS	LODs: 0.02 – 1.0[a]	[42]
6 pesticides	HPLC-ESI-MS/MS	LODs: 40 – 130[a]	[43]
14 organic pollutants	HPLC-ESI-MS/MS	LODs: 0.1 – 10.0[a] LOQs: 0.1 – 10.0[a]	[44]
40 herbicides	SPE-UPLC-MS/MS	LODs: 0.002 - 0.02[a] LOQs: 0.005 -0.05[a]	[45]
84 pesticides	UPLC-TOF-MS	LODs: 0.8 – 110 pg/L LOQs: 2.6 – 360 pg/L	[46]
28-basic and neutral pharmaceuticals	SPE-UPLC-ESI-MS/MS	LODs: 0.02 – 2.0[a] LOQs: 0.2 - 10[a]	[47]
9 pesticides	SPE-HPLC-ESI-MS/MS	-	[48]
10 compounds including pesticdies	SPE-LC-ESI-MS/MS	LODs: 2.0 – 24[b]	[49]
14 pesticides	SPE-LC-ESI-MS/MS SPE-LC-ESI-TOF-MS/MS	LODs: 0.4 – 3[b]	[50]
16 pesticides	SBSE-LC-ESI-MS/MS	LODs: 0.01 – 1[a] LOQs: 0.03 – 9[a]	[51]
400 micro-organic compounds	LC–QTOFMS	LODs: 2 – 5[b]	[52]
11 pesticides	ultra-HPLC-MS/MS	LODs: 30 – 780[b]	[53]
2 pesticides	nanoEESI-MS/MS	LODs: 100 - 600[a]	[64]
5 pesticides	SPME-DCBI-MS	LODs: 1.0[a]	[65]

[a] $\mu g\ L^{-1}$; [b]$ng\ L^{-1}$.

Table 1. Over view of multi-residue pesticides analysis using chromatographic techniques coupled with various MS approaches in water samples.

Ambient ionization MS approaches are entirely different from atmospheric pressure ionization techniques, since analytes can be ionized at ambient conditions without applying ionization sources (voltage or heat), which differs from ESI, atmospheric pressure photoionization (APPI), atmospheric pressure chemical ionization (APCI), or AP-MALDI. Briefly, desorption electrospray ionization (DESI) [54] and direct analysis in real time (DART) [55] MS techniques were introduced in 2004 - 2005. These are evidently provided high-throughput applications for the efficient analysis of a wide range of analytes and adapted the underlying methodology to specific analytical needs. After these developments, various research groups have been developed different ionization methods that includes variations of the DESI theme such as desorption sonic spray ionization (DeSSI) [56], later renamed easy sonic spray ionization (EASI) [57] or extractive electrospray ionization (EESI) [58-59], desorption atmospheric pressure chemical ionization (DAPCI) [60-61] and desorption atmospheric pressure photoionization (DAPPI) [62], respectively. The main function of these techniques is analytes can be ionized without voltage or heat and transported through air into the mass analyzer via a standard API interface, which allows analytes ionization under ambient conditions. Therefore, ambient ionization methods are of great interest for the real-time monitoring of micro-organic compounds since the analytes can be easily ionized and introduced to the mass spectrometer under ambient conditions, which facilitated to eliminate the sample pretreatment process. Recently, Fernandez *et al*. reviewed 290 references those described that the application of ambient ionization mass spectrometric approaches for in-situ and direct analysis of a wide variety of molecules [63]. Even though, these approaches allowed to detect analytes without sample pretreatment, unfortunately limited number of research articles are illustrated that ambient MS tools for the analysis of pesticides in wastewater samples.

Chen's group developed a homemade novel nanoextractive electrospray ionization (nanoEESI) source has been used for in situ mass spectrometric analysis of ambient samples such as pharmaceutical compounds, and pesticides residues without sample pretreatment [64]. The ability of nanoEESI is experimentally investigated by integrating nanoEESI source with a commercial LTQ mass spectrometer for rapid analysis of various ambient samples without sample pretreatment. This method proved as a promising tool for the high-throughput and sensitive in-situ analysis of organic compounds at ambient conditions. Paraquat,β-cypermethrin and pyrethroid pesticides were analyzed by using the nanoEESI MS and peaks were obtained at *m/z* 186, 93 and 416, which correspond to the paraquat radical ions and protonated β-cypermethrin, respectively. Furthermore, signals at *m/z* 93 and 185 are correspond to the doubly charged paraquat ions and deprotonated paraquat ions. To confirm the structures of those ions, the CID was carried out and the tandem mass spectra for the ions *m/z* 186 and 416 are yielded fragmented ions at *m/z* 171 by the loss of $CH_3\bullet$ and the other ions at *m/z* 157, 145, and 131, which due to the loss of $HN=CH_2$, $CH_2=N-CH\bullet$, and $[HN-CH_2, C_2H_2]$, respectively. The ion at *m/z* 416 yielded the product ion at *m/z* 388, by the loss of CO, and the other product ions at *m/z* 191 and 226 are generated by the cleavage of C-O bond in the ester group. Meanwhile, Li's group described that the expanded direct MS analysis to pesticides solution samples by using the desorption corona beam ionization (DCBI) technique in combination with poly(dimethylsiloxane) (PDMS) as substrate solid-phase microextraction of pesticides from sample solution [65]. Pesticides were extracted by using PDMS substrate and then is transferred to MS ion source for desorption and ionization. This approach was effectively improved the detection limit for the direct analysis of five pesticides (acephate, isoprocarb, dimethoate, dichlorvos, and dicofol) in water. This DCBI technique coupled with PDMS sampling is an excellent method for the analysis of organic pesticides in solution and LODs are in the range of 1.0 μg/L. Crook's team published a series of papers on ambient ionization mass spectrometric techniques using low-temperature plasma (LTP) [66], paper spray [67] and desorption electrospray ionization [68] methods for the trace analysis of pesticides in foodstuffs. These ambient MS techniques are directly analyzed trace level agrochemicals in foodstuffs without sample pretreatment. These approaches were effectively validated and confirmed pesticides by tandem mass spectrometry (MS/MS) at analytes concentration < pg level. These methods are little or literally not required sample pre-separation, preparation, or derivatization and the analytes mass spectra are most often acquired directly at ambient conditions (open atmosphere, real world and natural environment). Therefore, ambient MS is still a very juvenile field for the analysis of multi-residue pesticides in wastewater samples; however it has already experienced explosive growth in terms of many new variants, hybridization, combinations, and applications for other samples.

3. Final remarks

This chapter has explored the analysis of multi-residue pesticides and their degradation products in wastewater by using different MS approaches over the last few years. Sensitivity of MS methods was enhanced by several ways such as sample pre-concentration, integration of chromatographic techniques and changing MS analyzers. These extraction and chromatographic techniques coupled with MS approaches have brought the promise of simple, validation, high-throughput qualitative and quantitative analysis of trace amounts of multi-residue pesticides in wastewater. These approaches have been demonstrated that effective pesticides analyses were achieved by the integration of chromatographic techniques with different MS platforms, which lead to a higher analysis throughput without compromising separation efficiency and sensitivity. In parallel to the development of multi-residue pesticides analysis MS-based workflows, the newly developed ‘’ambient ionization’’ techniques (DART and DESI) hold some promise for the direct pesticide residue screening in foodstuffs. Since, these have well ability to inherently operate without chromatographic separation (LC and GC), and sometimes with no sample pre-treatment, are their main attractions but their utility for quantitative analysis in wastewater has not been sufficiently explored. Therefore, new perspectives are to be certainly opened in the near future for trace-multi-residue pesticides monitoring by hyphenation of miniaturized ambient ionization MS systems with various analyzers and detection systems for the qualitative and quantitative determinations of multi-residue pesticides and their degradation products in wastewater.

Acknowledgments

The authors wish to thank the National Science Council of Taiwan (NSC 99-2113-M-007-004-MY3) for financial support. We also thank Mr. Ganga Raju (Doctoral Degree Program in Marine Biotechnology, National Sun Yat - Sen University) and Mr. Hani Nasser Abdelhamid (Department of Chemistry, National Sun Yat-Sen University) for their assistance in searching for literature reprints for this work.

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