Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them: Envisioning a chemical-safe world

Annexes to Chapter 4.3 – Adverse environmental effects of pesticide use

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### Annex 4.3-1 Recent reviews of pesticide concentrations in surface water bodies and their risks to aquatic life

Included are reviews published between 2010 and 2020

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<th>Region (coverage)</th>
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<th>Extent of review</th>
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</table>
| Global            | 2012 – 2019 (publication)        | Not specified   | No specified | – Most detected herbicides in surface water were atrazine and its metabolites, metolachlor  
                  |                     |                |            | – Most detected insecticide was chlorpyrifos  
                  |                     |                |            | – Most detected fungicides were carbendazim, tebuconazole | De Souza et al. 2020 |
| Global (73 countries) | 1960 – 2011                     | 838 studies with 11,300 measured concentrations | 28 insecticides | – in 97% of the cases, no insecticides were measured in the samples  
                  |                     |                |            | – 52% of measured insecticide concentrations exceeded regulatory thresholds from the USA and/or the EU, and on 69% of the sampled sites  
                  |                     |                |            | – Median concentrations of neonicotinoids exceeded those of organochlorines and organophosphates by a factor of about 3, and of pyrethroids by a factor 10  
                  |                     |                |            | – Most insecticide concentration monitoring data for surface waters were available from North America, Asia and Europe  
                  |                     |                |            | – No monitoring of surface water exposure by insecticides exist for about 90% of high-intensity agricultural areas of the world  
                  |                     |                |            | – Highest insecticide concentrations were detected in Africa, Asia and South America | Stehle & Schulz 2015  
                  |                     |                |            |                     | Stehle et al. 2018 |
| Global (11 countries)  | 2010 – 2016 (publication)        | 31 studies      | Neonicotinoids | – Geometric mean for average concentrations = 0.13 μg/L  
                  |                     |                |            | – Geometric mean for peak concentrations = 0.63 μg/L  
                  |                     |                |            | – 74% of measured average concentrations exceeded ecological thresholds  
                  |                     |                |            | – 81% of measured peak concentrations exceeded ecological thresholds  
                  |                     |                |            | – Average neonicotinoid residues in surface waters increased over past 15 years | Morrissey et al. (2015)  
                  |                     |                |            |                     | Sánchez-Bayo et al. (2016) |
| Global (15 countries)  | 1986 – 2017 (publication)        | 176 papers      | Pyrethroids | – Pyrethroid concentrations in surface water worldwide ranged from not detected to 13,000 μg/L  
                  |                     |                |            | – High concentrations of pyrethroids are found across all global regions; no geographical hot spots  
<pre><code>              |                     |                |            | – No risk assessment conducted | Tang et al. 2018 |
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| Europe (34 countries) | 2007 – 2017 | Monitoring data from the Waterbase – Water Quality Database | 180 pesticides | – Assessed were the exceedance rates of European aquatic environmental quality standards  
– 5–15% of European surface water monitoring stations showed exceedances by herbicides; 3–8 % of stations by insecticides; exceedances of fungicides were less prevalent | Mohaupt et al. 2020 |
| Africa | 2000–2018 (publication) | Not reported | Organochlorines Current use pesticides | – Concentrations of pesticides reported in African surface waters range from 0.06 ng/L to 69 μg/L (insecticides), 0.2 ng/L to 14 μg/L (herbicides), and 0.1 ng/L to 9 μg/L (fungicides)  
– Highest concentrations reported for chlorpyrifos, chlorpyrifos-ethyl, malathion, diazinon, endosulfan, DDT and spiroxamine | K’oroje et al. 2020 |
| Africa | 2000 – 2018 (publication) | 22 studies from 7 African countries | Organochlorines | – Average values in surface waters: $\Sigma$-DDT = 1271 ± 1721 μg/L; dieldrin = 793 ± 1760 μg/L; aldrin = 384 ± 1043 μg/L; $\Sigma$-HCH = 159 ± 368 μg/L; HBC = 77 ± 104 μg/L; methoxychlor = 49 ± 85 μg/L  
– OCP concentration were many times higher than levels in other parts of the world where OCPs were still used during the same period (e.g. Japan, China, Iran, India and Mexico) | Taiwo 2019 |
| Caribbean and Pacific | 1997 – 2001 | 33 samples from marine surface slicks | Organochlorine pesticides (OCPs) | – OCPs detected in 31 out of 33 samples  
– Concentrations observed were below commonly accepted toxic levels to animals and humans  
– Traces of OCPs were observed in areas far away from human habitation | Menzies et al. 2013 |
| Europe (91 river basins across the continent) | 2006 – 2010 | 4,001 monitoring sites | 223 organic chemicals, including 98 pesticides | – 14% of the monitoring sites were likely to be acutely affected by organic chemicals and 42% likely to be chronically affected  
– Pesticides were responsible for 81%, 97% and 96% of the observed exceedances of acute risk thresholds for fish, invertebrates and algae respectively | Malaj et al. 2014 |
| South Asia | 1988 – 2011 | 13 studies from 3 countries | Organochlorine pesticides (OCPs) | – All studies reported 1 or more OCPs in surface water at concentrations above detection levels  
– Ranges of concentrations detected : $\Sigma$-DDT = non detectable (ND) – 400 μg/L; $\Sigma$-HCH = ND – 75 μg/L; endosulfan = ND – 66 μg/L | Ali et al. 2014 |
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<tr>
<td><strong>National (selected country-wide or review studies)</strong></td>
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</table>
| Brazil | Up to December 2015 (publication) | 17 studies | 43 current use pesticides | − Pesticides were detected in 14% of the samples in concentrations above the LOQ of the analytical method used  
− From the 43 pesticides investigated, 34 were quantified at least once  
− Freshwater water quality criteria (WQC) for the protection aquatic life were compiled from the literature for 31 of the 34 pesticides  
− A potential risk to aquatic life was identified for 59% of the pesticides with the occurrence data in Brazil  
− This review only encompasses 43 compounds, which are 11% of the pesticides approved in Brazil for agricultural use |
| China | 1995 – 2013 (publication) | National review: 30 studies for surface water 51 studies for sediment | Mainly organochlorine pesticides (OCPs); some current use pesticides | − Risk assessments only conducted for Σ-DDT and lindane, based on Norwegian quality criteria for sediment and surface water  
− Quality criteria for Σ-DDT in surface water: 13% of all cases = good, 22% = bad, 4% = very bad  
− Quality criteria for Σ-DDT in sediment: 58% of all cases = good, 3% = bad, 3% = very bad  
− Quality criteria for lindane in surface water: 73% of all cases = good, 16% = bad, 5% = very bad  
− Quality criteria for lindane in sediment: 54% of all cases = good, 10% = bad, 10% = very bad |
| China | 2013 | 26 surface water and sediment sampling locations in the Yellow River estuary | Organochlorine pesticides (OCPs) | − Σ-HCH was detected in all surface water and sediment samples; and Σ-DDT in all surface water and 96% of sediment samples  
− Mean concentration of Σ-HCH in surface water = 19 μg/L and in sediment = 20 μg/L; Σ-DDT in surface water = 10 μg/L and in sediment = 7 μg/L  
− No environmental risk assessment |
| China | 2016 | 96 samples from 16 rivers in eastern China | 9 neonicotinoid insecticides | − Average concentrations of the 9 neonicotinoids combined were 343 ng/L during the dry season, and 174 ng/L during the wet season  
− 27% of river water samples exceeded the thresholds for acute ecological risks  
− 84% of river water samples exceeded the thresholds for chronic ecological risks  
− Contamination levels were higher than those found in the USA and Japan |
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| Egypt            | 2013                             | 60 samples from 20 sampling sites along the River Nile | Organochlorine pesticides (OCPs) & organophosphate (OP) pesticides | – Organochlorine pesticides detected were dieldrin, endrin, p,p’-DDE, p,p’-DDD and p,p’-DDT  
– organophosphorus pesticides detected were triazophos, ethoprophos, quinalphos, chlorpyrifos, fenitrothion, ethion, fenamiphos and pirimiphos-methyl  
– dieldrin and p,p’-DDT residues in some sampling sites exceeded drinking water guidelines of WHO | Dashan et al. 2016 |
| Ethiopia         | 2015                             | 46 sediment samples from 1 river basin | 16 organochlorine pesticides (OCPs) | – All samples contained measured concentrations of at least 1 OCP  
– Total concentrations of OCPs, ranged from 6.63 to 206.13 ng/g dry weight (dw)  
– Heptachlor, heptachlor epoxide, p,p’-DDT and β-HCH had highest concentrations  
– Adverse ecological effects were expected to occur mainly due to p,p’-DDT and γ-HCH | Dirba et al. 2018 |
| Ghana            | 2001 – 2016 (publication)       | 8 studies        | Organochlorine pesticides (OCPs) | – Range of OCP concentrations in surface water = from below limit of detection – 6350 ng/L  
– Concentrations in surface water of Σ-DDT and Σ-endosulfan showed significant increase from 2004 – 2012; concentrations of Σ-HCH did not  
– No aquatic risk assessment conducted | Bruce-Vandervijie et al. 2019 |
| Hungary          | 1990 – 2015                      | National monitoring programme | 49 pesticides and degradation products | – Pesticide residues detected in 32 – 61% of samples  
– Main surface water contaminants were triazines (atrazine, propisochlor), chloroacetamides (acetochlor, metolachlor), and phenoxy carboxylic acids (2,4-D, MCPA) during the late 90s, followed by triazines (atrazine, prometryn, and diazinon) and chloroacetamides (acetochlor) after the turn of the millennium, while glyphosate and neonicotinoids were more frequently detected in latter years of the programme | Székács et al. 2015 |
| India            | 1990 – 2014                      | 14 studies       | organochlorine pesticides (OCPs) | – Surface water bodies throughout India  
– Σ-DDT = not detected (ND) – 6121 ng/L; Σ-HCH = ND – 4911; endosulfan = ND – 130 ng/L | Yadav et al. 2015 |
| Italy            | 1997 – 2013 (publication)       | 10 studies       | 137 pesticides | – 54.3% of reported maximum pesticides concentrations in surface water were above the environmental quality standards  
– Pesticides considered to represent the most severe threat for the Italian water resources were AMPA (glyphosate metabolite), terbuthylazine, diuron, 2,4-D, terbutryne, malathion, metolachlor, pendimethalin and linuron. | Meffe & de Bustamante 2014 |
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| Japan            | 1987 – 2016                       | 34 samples from 11 rivers | 9 organophosphorous pesticides | – High risks for aquatic organisms = 56% of cases  
– Low risk for aquatic organisms = 18% of cases  
– Diazinon and fenitrothion pose highest risks to aquatic environments | Derbalah et al. 2019 |
| The Netherlands  | 2013 – 2018                       | 96 sampling locations | Plant protection products | – Exceedance of national surface water quality criteria (chronic exposure) declined between 2013 to 2015 with 15% for chronic exposure and with 30% for acute exposure  
– Number of sampling locations with exceedances by at least one pesticide did not significantly decline | PBL 2019 |
| Romania          | 2016                              | 19 streams       | 244 pesticides and metabolites | – Up to 50 pesticides were detected simultaneously, resulting in sum concentrations between 0.02 and 37 μg/L  
– Streams in low intensity agriculture, despite a minor reported use of agrochemicals, exhibited similar levels of pesticide pollution as in regions of high intensity agriculture  
– The sum concentration as well as the toxicities were in a similar range as in high intensity agricultural streams of Western Europe | Schreiner et al. 2021 |
| South Africa     | 1977 – 2011                       | 41 studies       | OCPs and current use pesticides | – Even more recent studies focus primarily on OCPs  
– Widespread occurrences of OCPs with some banned organochlorine residues still present in the aquatic environment  
– Atrazine frequently detected in surface waters | Ansara-Ross et al. 2012 |
| Sudan            | 2004 – 2005                       | 27 samples from 3 locations | 22 pesticides | – Organochlorines detected in 70% of samples, pyrethroids in in 15% of samples, herbicides in 4% of samples, organophosphates not detected  
– Highest pesticide concentrations ranges for: Σ-heptachlor = non-detected (ND) – 1123 ng/L; Σ-DDT = ND – 427 ng/L; cypermethrin = ND – 630 ng/L; fenvalerate = ND – 600 ng/L; pendimethalin = ND – 1060 ng/L  
– Pesticide concentration appear to be lower and less frequently detected than in earlier studies in the Nile | Nesser et al. 2016 |
| Switzerland      | 2005 – 2012                       | 345,000 samples  | 60 pesticides | – 27% of evaluated pesticides showed exceedance of national regulatory acceptable concentrations (RACs) at 1 or more sampling sites  
– 95% of measured concentrations (including non-detections) of all pesticides were below their respective RACs  
– Exceedance of RACs occurred in small to medium surface waters, surrounded by vineyards  
– Mainly herbicides and fungicides exceeded RACs | Knauer 2016 |
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| Tanzania         | 2003 – 2014 (publication)         | 5 studies        | Mainly organochlorine pesticides (OCPs) | – Up to 7 OCPs measured in surface waters above detection levels in individual studies  
– No risk assessment | Elibariki et al. 2017 |
| USA              | 1962 – 2017                       | 259 studies with 5817 measured concentration covering 644 sampling sites | 32 insecticides and 6 degradation products | – 49% of measured pesticide concentrations exceeded US regulatory threshold levels  
– 70% of sampling sites experienced at least one exceedance of a US regulatory threshold level  
– Exceedance rate of pyrethroids = 81%; organophosphates & carbamates = 42%; organochlorines = 33%; neonicotinoids = 22%; phenylpyrazoles = 25%  
– Agricultural streams/rivers: 69%  
– Urban streams/rivers: 90%  
– Mixed streams/rivers: 46%  
– Exceedance rates did not significantly change from 1992–2001 to 2002–2011 for agricultural and mixed streams; they increased considerably for urban streams  
– Upward and downward trends in pesticide concentrations to large extent reflect changes in their use patterns | Stone et al. 2014 |
| USA              | 2012 – 2014                       | 38 streams in 24 US states; 149 samples | 6 neonicotinoids insecticides | – At least 1 neonicotinoid detected in 53% of the sampled sites  
– 2 or more neonicotinoids in 26% of samples  
– 8% of samples with detectable concentrations were >100 ng/L  
– No risk assessment conducted | Hladik & Kolpin 2016 |
## Annex 4.3-2 Recent reviews and studies of pesticide concentrations in ambient air.

Included are reviews published between 2010 and 2020

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<thead>
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<tbody>
<tr>
<td>Global</td>
<td></td>
<td>Baseline data and time trends for 5 regions of the world.</td>
<td>12 organochlorine pesticides and their metabolites</td>
<td>– Long time series monitoring data of legacy POPs in air are available from Asia, Central and Eastern Europe and Western Europe and Others Group, while information on changes in concentrations over time is very limited in Africa, the Pacific and in Latin American and Caribbean Group. &lt;br&gt;– Information on changes over time in concentrations of the newly listed POPs is still limited. &lt;br&gt;– Overall, concentrations of POPs measured in air have largely decreased. The steep decrease in air concentrations of legacy POPs such as organochlorine pesticide) seems to have followed their early regulation in the 1980s. &lt;br&gt;– By 2000, the majority of primary sources had been controlled and the relatively low levels that are currently measured do not show significant changes and are driven by secondary sources and, for some compounds, emissions from stockpiles/waste management practices.</td>
<td>UNEP 2017</td>
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<tr>
<td>Global (9 countries)</td>
<td>2011 – 2014</td>
<td>34 studies covering 475 cases (=pesticide-study combinations)</td>
<td>150 pesticide active ingredients and metabolites</td>
<td>– Most studies conducted on herbicides and insecticides, in Canada, USA, France, Spain and China; no studies conducted in low or lower-middle income countries. &lt;br&gt;– Organochlorine pesticides and metabolites represented 27% of cases. &lt;br&gt;– The more frequently detected CUPs worldwide are the fungicides chlorothalonil and folpet, and the insecticides chlorpyrifos, dimethoate, malathion and phosmet, with average concentrations ranging from 0.01 to 11.6 ng/m³. &lt;br&gt;– Inhalation exposure of CUPs in the general population does not represent a significant concern, except in some cases for chlorpyrifos. The combined risk resulting from exposure to OP, pyrethroid and carbamate pesticides was also considered to be acceptable.</td>
<td>Coscollà &amp; Yusà 2016</td>
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<td>Region (coverage)</td>
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</table>
| Global            | 1988 – 2008                       | 16 studies on air concentrations in developing and developed countries | DDTs       | – Most data from the 1990s  
– DDTs in ambient air is compiled from Congo, Malawi and Zimbabwe in Africa; southern Mexico, the Brazilian mountains and Costa Rica in Latin America; and India, Vietnam, Thailand and the Solomon Islands in S-SE Asia.  
– Concentrations of DDTs a factor 10-100 higher in tropical (generally developing) than in temperate (generally industrialised) countries  
– Most of the developing countries described in this review are located in the tropical regions where climatic conditions favour dissipation of DDT and other chlorinated pesticides  
– Continuing use of DDT in indoor residual spraying programs in some parts of the region and emissions from old pesticide storage areas may be attributed to the higher DDTs levels in the developing regions |

| Global            | 2005 - 2008                       | 34 – 46 sampling sites on all continents | OCPs: HCHs, HCB, chlordanes, heptachlor, aldrin, dieldrin, endrin, DDTs, and metabolites  
CUPs: endosulfans, trifluralin, chlorothalonil, dacthal, pendimethalin |  
– Organochlorine pesticides such as α- and γ-hexachlorocyclohexane, endosulfans, DDT and its metabolites, and chlordane-related compounds tend to be more prevalent in developing countries, especially in Asia  
– Current use pesticides such as trifluralin and chlorothalonil showed higher levels in Europe and North America  
– Levels of hexachlorobenzene, hexachlorocyclohexanes and chlordanes decline in most world regions; levels of organochlorine pesticides in India, however, remained exceptionally high  
– The CUPs, including endosulfans, did not display clear trends over the four years of sampling, except that the levels of α-endosulfan and chlorothalonil were decreasing in the European atmosphere |

| Regional          | 2010                              | 17 air samples on a latitudinal transect from the East China Sea to the High Arctic (33.23–84.5° N). | 6 current-use pesticides (CUPs): trifluralin, endosulfan, chlorothalonil, chlorpyrifos, dacthal (DCPA) and dicofol. |  
– In all oceanic air samples, the six CUPs were detected, showing highest level (>100 pg/m³) in the Sea of Japan  
– Gaseous CUPs decreased from East Asia (between 36.6 and 45.1° N) toward Bering and Chukchi Seas |

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<tbody>
<tr>
<td>Mochungong &amp; Zhu 2015</td>
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<td>Shunthirasingham et al. 2010</td>
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<td>Zhong et al. 2012</td>
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</table>
| Arctic, Antarctica, Tibetan Plateau            | 1990 – 2014 (review)              | 66 reviews for the Arctic, 2 reviews for the Antarctic, 1 review Tibetan Plateau | Organochlorine pesticides (OCPs)          | – Concentrations of chemicals in the Antarctic are generally lower than those of the Arctic; similar concentration ranges of HCB, α-HCH, γ-HCH and α-endosulfan are apparent between the Arctic and Tibetan Plateau;  
  – Atmospheric concentrations of most OCPs in the Arctic, Antarctic and Tibetan Plateau do not show consistent downward trends over the review period (Tables S1, S2 & S3 of the supplementary materials) | Wang et al. 2019 |
| Alps                                           | 2005 – 2013                       | 3 high Alpine stations in Austria, Germany & Switzerland | Organochlorine pesticides (OCPs)          | – OCP concentrations were significantly lower than those in regions adjacent to greater emission sources in other continents (e.g., China, South America) but higher than those in the Arctic  
  – Temporal trend of the single compounds was evaluated: The majority of OCPs did not increase during 2005–2013, but a statistically significant decline was detected during 2006–2013 only for endosulfan and α-HCH | Kirchner et al. 2016 |
| West Africa (Togo, Benin, Nigeria, and Cameroon) | 2012                              | 25 OCPs 7 sampling sites | Organochlorine pesticides (OCPs)          | – High atmospheric concentrations of HCHs and DDTs were found, at average concentrations of 441 pg m⁻³ (range 23–2718) and 403 pg m⁻³ (range 91–1880), respectively  
  – Mirex had the lowest concentrations, ranging between 0.1 and 3.3 pg m⁻³  
  – There was significant evidence, based on chemical signatures of the contamination that DDT, aldrin, chlordane and endosulfan were recently applied at certain sites | Isogai et al. 2016 |
| South Asia                                     | (1987 – 2013; review)             | 7 research papers      | Organochlorine pesticides (OCPs)          | – Ambient air concentrations of HCHs ranged from 0.3 to 1690 pg m⁻³, and from 0.3 – 2900 pg m⁻³ for DDTs  
  – Highly populated and agricultural areas along the India coast were found contaminated with higher levels of OCPs, possibly originating from fresh use of DDT for vector control and agricultural purposes  
  – Elevated concentrations of γ-HCH and HCB also indicated recent use of these pesticides | Ali et al. 2014 |
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</table>
| Arctic            | (2008 – 2013; review)            | Air and ice cores     | Current-use pesticides (CUPs) Organochlorine pesticides (OCPs) | − Ambient air concentrations compiled from reviewed studies:  
  o Dacthal: 0.02 – 0.1 pg/m³  
  o Trifluralin: < LOD – 1.95 pg/m³  
  o Chlorothalonil: 0.1 – 2.1 pg/m³  
  o Chlorpyrifos: 0.5 – 2.0 pg/m³  
  o Endosulfan: α-endosulfan = 0.4 - 130 pg/m³; β-endosulfan: < LOD  
  o Methoxychlor: < 0.003 pg/m³  
  o Dicofol: 0.9 – 2.5 pg/m³  
  − The time trends derived from ice cores show increasing concentrations for chlorpyrifos, endosulfan and trifluralin | Vorkamp & Rigét 2014 |
| Latin America and Caribbean | 2014 – 2015 for emerging POPs 2005 – 2015 for other OCPs | 9 sampling sites in 7 countries | 27 OCPs, including emerging POPs: pentachloroanisole (PCA) and dicofol | − PCA had elevated concentrations at an urban site in Chile (49-222 pg/m³) and concentrations ranging <1-8.5 pg/m³ at the other sites in this study  
  − Dicofol indicators were detected at the agricultural site of Sonora (Mexico) at concentrations ranging 30-117 pg/m³  
  − Atmospheric concentrations of γ-HCH and the endosulfans significantly decreased in this region from 2005 to 2015  
  − Concentrations of the chlordanes, DDT and PCBs remained similar from 2005 to 2015, suggesting implemented restrictions have not yet led to decreases in atmospheric levels in this region after | Rauert et al. 2018 |
| National (selected studies) | | | | | |
| West Antarctica | 2010 – 2018 | Seven sampling sites in one location | 25 organochlorine pesticides (OCPs), congeners and metabolites | − HCB, HCHs, DDTs and endosulfans were detected in most air samples, while chlordane (cis- and trans-), nonachlor (cis- and trans-), oxychlordane, heptachlor, heptachlor epoxide (cis- and trans-), aldrin, dieldrin, endrin, and mirex were not detectable in over 90% atmospheric samples in this study  
  − Relatively low concentrations organochlorine pesticides (OCPs) (Σ13OCPs: 101-278 pg/m³) were found in the atmosphere of West Antarctica  
  − The concentrations of HCHs, DDTs and endosulfans were found to show decreasing temporal trends over the period 2011 – 2017; HCB concentrations remained stable  
  − The atmospheric half-life values for HCHs, DDTs and endosulfans in Antarctic air were estimated as 2.0, 2.4 and 1.2 years, respectively  
  − Long-range atmospheric transport was considered to be the main contributing factor to the atmospheric levels of the POPs in West Antarctica | Hao et al. 2019 |
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<tbody>
<tr>
<td>Brazil</td>
<td>2013-2015 (and comparison with 2008 data)</td>
<td>Two Conservation Unit sites in the Rio de Janeiro state</td>
<td>Current use pesticides (CUPs) and Organochlorine pesticides (OCPs)</td>
<td>– Atmospheric concentrations of legacy OCPs showed background air levels&lt;br&gt;– Endosulfan concentrations decreased between 2008 and 2015 (max concentrations 5500 pg m$^{-3}$ and 2000 pg m$^{-3}$ respectively)&lt;br&gt;– Chlorpyrifos concentrations increased over the same period (max concentrations 40 and 165 pg m$^{-3}$, respectively)</td>
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### Annex 4.3-3 Recent reviews of pesticide concentrations in soils and their risks to soil organisms

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<tbody>
<tr>
<td>Global</td>
<td>1993 – 2012 (publication)</td>
<td>73 journal publications, globally</td>
<td>p,p'-DDT, p,p'-DDE, HCB, α-, β-, and γ-HCH</td>
<td>OCP concentrations from agricultural and background land were evaluated</td>
<td>Camenzuli <em>et al.</em> 2016</td>
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<td>For the period 2003 – 2012 and for all chemicals, the mean concentration in agricultural soil is significantly higher than the concentration in background soil</td>
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<td>A decrease in the global mean concentration is discernible for p,p'-DDT and p,p'-DDE from the first to the second decade, but it is statistically significant only for p,p'-DDT in agricultural soil</td>
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<td>The mean concentration of HCB in agricultural soil and in background soil does not significantly decrease from the first to the second decade</td>
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<td>The 3 HCH isomers decrease in background soils, but not in agricultural soils, from decade 1 to decade 2</td>
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<td>The expected decrease in concentrations of p,p'-DDT and α-HCH in both agricultural and background soil, based on emission modelling, is not supported by measurements. The possibility of new and/or illegal emissions must be kept in mind</td>
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<td>Global</td>
<td>2013 – 2017 (publication)</td>
<td>7 studies in 4 countries</td>
<td>Neonicotinoid insecticides</td>
<td>The current body of evidence shows that detectable levels of neonicotinoids are found in agricultural soils over a year after treated seeds were planted</td>
<td>Wood &amp; Goulson 2017</td>
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<td>Neonicotinoids known not to have been recently used can still be present in soils several years after the last application date</td>
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<td>Neonicotinoids do not continue to accumulate indefinitely but instead plateau after 2–6 years of repeated application</td>
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<td>The studies show that overall, annual sowing of neonicotinoid-treated seed results in chronic levels of soil contamination in the range of 3.5–13.3 ng/g for clothianidin and 0.4–4.0 ng/g for thiamethoxam. This which will act as a constant source of exposure for soil-dwelling organisms, and for neonicotinoid transport into the wider environment</td>
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<td>Region (coverage)</td>
<td>Monitoring (or publication) period</td>
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| Global            | n.a.                              | Global review   | Fungicides in vineyard soils | – Copper originating from the intensive application of Cu-based fungicides belongs to the most important contaminants of vineyard soils  
– Concentrations exceed European legislative limits in the majority of the studied vineyards  
– The intensive application of synthetic organic fungicides has led to increased concentrations of these chemicals in vineyard soils | Komárek et al. 2010 |
| Polar regions     | 1998 – 2015                       | Review of publications about the Arctic, Antarctic, Tibetan Plateau | DDTs, HCHs, HCB | – Recent ΣHCH concentrations range from n.d. to 5700 pg/g  
– Recent ΣDDT concentrations range from 20 to 1200 pg/g  
– Recent HCB concentrations range from 20 – 1500 pg/g  
– Soil in cold regions are considered as sinks of POPs | Wang et al. 2019 |
| Regional          |                                   |                 |            |          |           |
| Europe            | 2015                              | 317 agricultural topsoil samples from 11 EU Member States and 6 main cropping systems | 76 pesticides | – Pesticide residues were present in 83% of the tested soils and 58% of the soils contained multiple residues  
– Glyphosate and its metabolite AMPA, DDTs and the broad-spectrum fungicides boscalid, epoxiconazole and tebuconazole were most frequently found and the at the highest concentrations  
– Maximum individual pesticide content was 2.05 mg/kg while maximum total pesticide content was 2.87 mg/kg  
– Risks to standard soil organisms did generally not exceed acceptable levels.  
– The presence of mixtures of pesticide residues in soils are the rule rather than the exception | Silva et al. 2019 |
| National          |                                   |                 |            |          |           |
| China             | Review of papers published since 2000 | agricultural soils | OCPs       | – OCPs have been widely detected in agricultural soils throughout China  
– Total concentrations of OCPs ranged from <LOD (limit of detection) to 3520 ng/g, with a mean of 59±53 ng/g  
– p,p'-DDE exhibited the highest concentration (mean of 15 ± 21 ng/g, n = 66), followed by p,p'-DDT (mean: 13 ± 16 ng/g, n = 66) and chlordane (mean: 8.4 ± 27 ng/g, n = 15).  
– Most of the concentrations were considered safe under Chinese environmental legislation, though some exceeded acceptable levels  
– Concentrations of OCPs in almost all recent studies are lower than those that were identified decades ago, indicating that the residues of OCPs have decreased significantly after they were banned for agricultural uses | Sun et al. 2018 |
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| China             | n.a.                              | 241 agricultural soil sites, across the Yangtze River Delta | 9 organophosphates | – OPs were present in 93% of samples  
– Total concentrations of the 9 OPs ranged from <3.0 to 521 ng/g dry weight, with a mean of 64.7 ng/g dry weight  
– Dimethoate was most detected, followed by methyl-parathion and parathion  
– There was no significant difference in microbial communities among the sample sites, indicating that OPPs in these soils do not cause significant effects on microbiota | Pan et al. 2018 |
| Czech republic    | 2015                              | 75 arable soils | 53 CUPs and 15 transformation products | – Arable soils were found to frequently contain multiple residues of pesticides at noticeable levels several months following the last possible application  
– In 99% of the soil samples, at least one pesticide was present > LOQ  
– In 81%, at least one pesticide was present at ≥0.01 mg/kg, the generic soil limit for individual non-chlorinated pesticides in the Czech Republic  
– The soils contained multiple pesticide residues frequently (51% soils with ≥5 pesticides)  
– Most frequent detections were of triazine herbicides (89% of soils) and conazole fungicides (73% of soils) | Hvězdová et al. 2018 |
| Ghana             | 2014 – 2015                       | 32 samples from cocoa farms | 15 OCPs and metabolites | – 4 OCPs were detected:  
  o Lindane in 31.3 % of the soil samples, at a mean concentration of 0.04 ± 0.01 mg/kg  
  o beta-HCH in 26.6 % of samples, at a mean concentration of 0.03 ± 0.01 mg/kg  
  o dieldrin in 62.5 % of samples, at a mean concentration of 0.02 ± 0.00 mg/kg  
  o p,p'-DDT in 50 % of samples, at a mean concentration of 0.03 ± 0.01 mg/kg  
– Concentrations of OCPs recorded in the soil samples were generally below their respective US MRLs for agricultural soils  
– The authors conclude that the occurrence of OCP residues in soil may be attributed to the illegal use of the pesticides by farmers or due to their historic use, since OCPs are prohibited from agricultural use in Ghana | Fosu-Mensah et al. 2016 |
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<tr>
<td>France</td>
<td>2016</td>
<td>180 soil samples from winter cereal crops, grasslands, hedgerows, some of which were untreated or under organic farming. 155 samples of earthworms (<em>Allolobophora Chlorotica</em>) from the same locations.</td>
<td>31 CUPs analyzed (9 insecticides, 10 fungicides, 12 herbicides)</td>
<td>– 27 pesticides detected&lt;br&gt;– All the soils contained at least one CUP; 83% ≥ 5 CUPs; and 38% ≥ 10&lt;br&gt;– The herbicide diflufenican, the insecticide imidacloprid, and the fungicides boscalid and epoxiconazole were most frequently detected&lt;br&gt;– 92% of earthworms contained at least one of the pesticides, and 34% ≥ 5 pesticides.&lt;br&gt;– The long-term, plateau, predicted environmental concentrations in soils (PECs), as defined in EU risk assessment, were exceeded for 11 pesticides (in 94% of samples)&lt;br&gt;– A high risk of chronic toxicity to earthworms was found in 46 % of samples, both in treated cereals and nontreated habitats considered as refuges</td>
<td>Pelosi <em>et al.</em> 2021</td>
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<td>French West Indies (Guadeloupe)</td>
<td>2003 – 2009</td>
<td>Soil samples from 1045 plots from (former) banana plantations. Chlordecone; applied between 1972 and 1993</td>
<td>Chlordecone concentrations ranged from 0.011–52.1 mg/kg of dry soil&lt;br&gt;– 8% of plots contained &lt;0.1 mg chlordecone/kg soil; i.e. the threshold below which no MRL exceedance in subsequent root crops is expected&lt;br&gt;– 34% of plots contained &gt; 1.8 mg chlordecone /kg soil; i.e. the threshold above which almost all subsequent root crops are expected to exceed the MRL&lt;br&gt;– High chlordecone residues in soil were thus present 10 to 35 years after its application</td>
<td>Levillain <em>et al.</em> 2012</td>
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<td>India (Assam region)</td>
<td>2009</td>
<td>175 surface soil samples from agricultural fields, fallow and urban lands</td>
<td>14 OCPs and metabolites</td>
<td>Mean concentrations of total HCHs ranged from 705 – 825 ng/g and of total DDTs from 757 – 903 ng/g&lt;br&gt;– Residue levels were among the highest found so far in India; soils from paddy fields contained most HCH and DDT residues&lt;br&gt;– DDT and HCH soil residues originated both from the long past as well as from recent sources (vector control and agricultural use)</td>
<td>Mishra <em>et al.</em> 2012</td>
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<td>Kazakhstan, Poland</td>
<td>2012 - 2014</td>
<td>Poland (89 samples), Kazakhstan (32 samples)</td>
<td>OCPs</td>
<td>DDT, DDE and HCHs were detected in 20 – 50% of soil samples&lt;br&gt;– Average total concentrations of DDT in Polish and Kazakh soil samples were 0.104 and 0.097 mg/kg respectively&lt;br&gt;– The authors conclude that, even though concentrations were relatively low, OCPs continue to be a ubiquitous contaminant in soils</td>
<td>Łozowicka <em>et al.</em> 2016</td>
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<td>Region</td>
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| Nepal   | 2017                              | 147 soil samples from agricultural land            | 12 CUPs and degradation products & 8 OCPs                                  | - Pesticides were detected in 60% of the soil samples (25% had a single residue, 35% had multiple residues)  
- Overall, the concentration of pesticides ranged from 1.0 to 251 µg/kg, with a mean of 16 µg/kg  
- Residues of dichlorvos, dimethoate, omethoate, phorate, α-γ-HCH and α-β-endosulfan were below LOD. Chlorantraniliprole and imidacloprid residues were the most frequent; chlorpyrifos and p,p'-DDT were detected in the highest concentrations  
- The ionic ratio of DDT and its degradation products suggested a continuing use of DDT in the area  
- Low/no pesticide concentrations were detected in soils from IPM fields | Bhandari et al. 2020 |
| Switzerland | 2015                              | 702 soil in 169 cultivated fields over the entire lowland of Switzerland | 5 neonicotinoid insecticides (imidacloprid, clothianidin, thiamethoxam, thiacloprid, acetamiprid) | - Neonicotinoids were detected in 93% of organic soils and more than 80% of soils in “ecological focus areas” (EFAs)—two types of arable land supposedly free of insecticides  
- Between 5%–9% of above-ground invertebrate species may be exposed to lethal concentrations of clothianidin, and 32%–41% to sublethal concentrations, in “integrated production” and conventional fields  
- Between 1%–7% of the beneficial invertebrate species may be exposed to sublethal concentrations of neonicotinoids in EFAs and organic fields  
- The authors conclude that diffuse contamination by neonicotinoids may harm a significant fraction of non-target beneficial species. The use of neonicotinoids on crops may threaten biodiversity in refuge areas, while also potentially jeopardizing the practice of organic farming by impeding the biological control of pests | Humann-Guilleminot et al. 2019 |
| Tanzania | no period                          | Literature review                                   | Mainly OCPs                                                               | - Most studies analyzed OCPs  
- In virtually all samples, OCPs were detected, in spite of the fact that the use of most of these have been prohibited for a long time  
- Concentrations exceeding clean-up action levels occurred in former pesticide storage locations | Elibariki & Maguta 2017 |
## Annex 4.3-4 Recent reviews of pesticide concentrations in groundwater and drinking water.

The studies were selected from a literature search conducted using Web of Science for papers from 2010 until June 2020 using the following search criteria: TS=(pesticide*) AND TS=(groundwater* OR subterranean OR drinking). The title and summary of the resulting 3095 hits were evaluated, of which 175 papers were downloaded and analysed in more detail.

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<tr>
<th>Region (coverage)</th>
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| Global            |                                   |                                                          | Pesticides form the 1st and 2nd EU watchlist (5 neonicotinoids; 2 other insecticides; 2 herbicides) | – Most studies from USA, followed by EU. Few data for other regions  
– Among the 5 neonicotinoids, imidacloprid was the most frequently studied and detected  
– Average imidacloprid concentrations ± 8 ng/L to 3 µg/L (10 studies)  
– Other neonicotinoids were only observed in 1 or 2 water resources  
– Only one study available for the other pesticides from the watchlists (8 µg oxadiazion/L in Italy) | Pietrzak et al. 2019 |
| Global (21 countries) | Studies published between 2001 and 2017 | 73 studies (GW) | Organochlorines and organophosphates | – Most studies conducted in Asian countries  
– Diversity and concentrations lower than in surface waters  
– Concentrations of organophosphates were generally higher than organochlorines due to their widespread use | Pirsaheb et al. 2017 |
| Global (6 countries) | 2000 - 2015 | 13 studies (GW) | Pesticide transformation products (TPs) | – Few pesticide TPs are usually included in monitoring studies  
– TPs of atrazine and terbutylazine are the most studied TPs  
– The most abundant pesticide TPs in groundwater derive from the chloroacetanilide herbicides acetochlor, alachlor and metolachlor, the s-triazine herbicides atrazine and terbutylazine, and the herbicides chloridazon and dichlobenil  
– TPs derived from banned pesticides have consistently been detected in groundwater due to their long residence time in the subsurface or the slow release of their precursors from the soil  
– Pesticide TPs are occasionally more ubiquitous and abundant than their parent molecules  
– Pesticide TPs have occasionally been quantified at levels above the EU groundwater quality standard of 0.1 µg/L | Postigo & Barceló 2015 |
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<td>Regional</td>
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<td>Africa</td>
<td>Studies published between 2000 and 2018</td>
<td>NR (130 pesticide detections in freshwater resources combined for 13 countries) (GW + DW)</td>
<td>Review on contaminants of emerging concern including pesticides. Data available for 11 insecticides and 8 herbicides</td>
<td>– Despite an increase in the last decade, information is available for only few compounds and countries&lt;br&gt;– In many African countries, groundwater is mostly used for drinking without any treatment&lt;br&gt;– Pesticide concentrations detected in groundwater and drinking water ranging 0.1 ng/L to 18.4 μg/L and 0.02 ng/L to 34 μg/L, respectively</td>
<td>K’oreje et al. 2020</td>
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<td>6 countries in Europe, Africa and Oceania (Germany, Australia, France, South Africa, the Netherlands and Spain)</td>
<td>November 2015</td>
<td>One (duplicated) drinking water sample per country (DW)</td>
<td>11 pesticides (8 herbicides, 2 insecticides, 1 fungicide)</td>
<td>– None of the pesticides were detected in Germany, Australia and South Africa&lt;br&gt;– Atrazine was detected in France and Spain; Simazine in the Netherlands and Spain; Diuron in Spain&lt;br&gt;– The maximum pesticide concentration detected (37 ng atrazine/L in Spain) was below the EU standard</td>
<td>Leusch et al. 2018</td>
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<td>Overseas departments of France (Guadeloupe, Martinique, Reunion, Mayotte and French Guiana)</td>
<td>April - June 2012 (1st campaign); September 2012 - January 2013 (2nd campaign)</td>
<td>80 samples during two campaigns (40 sampling points/campaign) (GW)</td>
<td>Review on 66 target organic micropollutants (including 1 synergist and 16 pesticides: 8 herbicides, 4 insecticides, 3 fungicides and 1 metabolite)</td>
<td>– 11 pesticides detected, with greatest detection frequencies for the herbicides pentachlorophenol (55%) and atrazine (38%)&lt;br&gt;– Several of the pesticide concentrations exceed the EU groundwater quality standard: pentachlorophenol (9 samples; max. 418 ng/L), atrazine (3 samples; max. 420 ng/L), diuron (1 sample; 258 ng/L) and fenarimol (1 sample; 121 ng/L)</td>
<td>Vulliet et al. 2014</td>
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<td>National (selected country-wide or review studies)</td>
<td>Winter of 2018 (Jan-Feb)</td>
<td>Nationwide: 90 water treatment plants geographically distributed all over Sweden (DW)</td>
<td>3 herbicides (bentazon, atrazine, quinmerac)</td>
<td>– Concentrations of atrazine and bentazon were higher than in surface water&lt;br&gt;– Atrazine was detected in all samples, whereas quinmerac and bentazon were not or rarely detected, respectively</td>
<td>Karki et al. 2020</td>
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<td>China</td>
<td>June 2019</td>
<td>Nationwide: 789 tap water and 95 groundwater samples (GW + DW)</td>
<td>Herbicides 2,4-D and MCPA</td>
<td>– MCPA concentrations were generally higher than those of 2,4-D&lt;br&gt;– The cumulative concentration of the 2 herbicides in tap water of China was up to 125 ng/L (median: 1.38 ng/L)&lt;br&gt;– Higher concentrations were found in surface water derived tap water than in groundwater&lt;br&gt;– The median cumulative concentration in groundwater was approximately five times lower than that in tap water.&lt;br&gt;– The highest concentrations were observed in July, and the lowest in October (related with pesticide applications)&lt;br&gt;– The highest concentrations were found in Northeast China and were related with intensive herbicide use</td>
<td>Sun et al. 2020</td>
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<td>China</td>
<td>June 2019</td>
<td>Nationwide: 789 tap water and 95 groundwater samples (GW + DW)</td>
<td>Atrazine and its metabolites (ATZs)</td>
<td>– At least one of the analytes was found in all the water samples&lt;br&gt;– The median sum concentrations of ATZs (sATZs) was 21.0 ng/L (range: 0.02 ng/L - 3.04 mg/L)&lt;br&gt;– The level of ATZs in groundwater from rural area of China was about 1/3 of that found in tap water</td>
<td>Wang et al. 2020</td>
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<td>Saudi Arabia</td>
<td>NR</td>
<td>Nationwide: 993 well water samples from all 13 administrative regions (GW)</td>
<td>22 organochlorine insecticides</td>
<td>– Pesticides were not detected in any of the well water samples&lt;br&gt;– However, previous studies reported pesticide residues in groundwater of the country</td>
<td>Alquwaizany et al. 2019</td>
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<td>Martinique</td>
<td>2009–2014</td>
<td>Nationwide: 282 samples from 21 sites (twice a year at 18 sites; monthly in some years at 3 sites) (GW)</td>
<td>Chlordecone and its metabolite chlordecone-5b-hydro (5bCLD)</td>
<td>– Chlordecone decreased or remained stable during the time period&lt;br&gt;– 5bCLD showed an increasing, although rather erratic, evolution, probably due to the greater influence of hydrological conditions&lt;br&gt;– Most concentrations were &lt; 0.1 μg/L with higher concentrations in banana cropping areas</td>
<td>Cattan et al. 2019</td>
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<td>Bangladesh</td>
<td>not limited</td>
<td>National review: 3 studies (GW)</td>
<td>7 insecticides (organochlorines and organophosphates)</td>
<td>– DDT (and metabolites) encountered in concentrations up to 1.2 mg/L&lt;br&gt;– High DDT concentrations encountered years after ban, which may also be partly due to an apparent illegal use&lt;br&gt;– Little information available, but groundwater pollution is likely since groundwater levels in Bangladesh are high, and soil is mainly coarse</td>
<td>Hasan et al. 2019</td>
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<td>Monitoring (or publication period)</td>
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| Spain            | Studies including monitoring data from 1993-2012 | National review: 12 studies (GW) | EU Watchlist pesticides (5 neonicotinoids, 2 carbamates, 1 oxadiazole and 1 semicarbazone) | – Only imidacloprid and methiocarb were detected in the GW bodies of Spain. However, this may also be at least partly due since the other pesticides were only studies in 1 or 2 cases.  
– Mean imidacloprid and methiocarb concentrations generally below, and maximum concentrations above 0.1 μg/L | Jurado et al. 2019 |
| India            | Studies between 2001 and 2015 | National review: 12 studies (GW) | 10 insecticides (organochlorines and organophosphates) | – Average concentrations of almost all insecticides and in almost all studies > 0.1 μg/L  
– Since pesticide use is expended to increase, groundwater pollution is likely to increase even further | Malyan et al. 2019 |
| India            | Studies since 1995 | National review (45 studies including other micropollutants) (GW) | Insecticides (organochlorines (OCP), organophosphates (OPP) and synthetic pyrethroids (SP)) | – Vast majority of studies for OCP, followed by OPP. Only few studies with SP  
– Many (maximum) concentrations > 0.1 μg/L  
– Higher concentrations during/after monsoon season | Sackaria & Elango 2019 |
| The Netherlands  | Routine monitoring data: 2010 – 2014; monitoring campaign: May and June 2016 | Routine monitoring data: 29,766 records from all 10 ten water companies (GW)  
Monitoring campaign: 90 groundwater locations used as drinking water source in The Netherlands and Flanders (GW) | 408 pesticides (routine monitoring data) + 24 pesticides (monitoring campaign): 4 herbicides, 12 fungicides, 6 insecticides, 1 acaricide and 1 plant growth regulator | – 15 out of 24 recently authorized pesticides were detected, including neonicotinoids  
– Pesticides (and/or metabolites) were detected in the majority of drinking water sources.  
– In one third of the abstraction areas pesticide and/or metabolites concentrations exceeded water quality standards according to the WFD  
– Monitoring should focus on priority pesticides and be kept up to date with recently authorized pesticides | Sjerps et al. 2019 |
| Italy            | 2010 - 2015 | 11 alluvial aquifers of central Italy (GW) | 42 pesticides (16 insecticides; 18 herbicides; 8 fungicides) | – Increasing trends in pesticide concentrations over the study period were encountered for several pesticides  
– Some pesticides banned in 2009 showed a persistent occurrence  
– Mean concentrations were > 0.1 μg/L for 3 pesticides | Di Lorenzo et al. 2018 |
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<tr>
<td>Ireland</td>
<td>Monthly sampling between March 2010 to March 2012</td>
<td>Nationwide: 7 sites (GW)</td>
<td>10 pesticides and 6 of their metabolites</td>
<td>2 metabolites were encountered in higher concentrations than their active ingredients &lt;br&gt; Highest detections were encountered in sites with well drained soils underlain by gravel and limestone aquifers and within gravel lenses in lower permeability subsoil &lt;br&gt; Metabolites accounted for the majority of exceedances of 0.1 µg/L</td>
<td>McManus et al. 2017</td>
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<td>England and Wales</td>
<td>Since 2003 with a small number of samples collected from 1992 onwards.</td>
<td>Nationwide: 2650 sites as part of the England and Wales Environment Agency’s National Monitoring Programme (GW)</td>
<td>15 pesticides (including metabolites)</td>
<td>Atrazine, its metabolite atrazine-desethyl and simazine in the top 5 out of &gt; 800 organic compounds &lt;br&gt; Maximum concentrations detected for diazinon (&gt; 150 µg/L) and chlorotoluron (&gt; 30 µg/L) &lt;br&gt; Although a large monitoring dataset, it did not provide sufficient data for any compound for one site to determine a trend. &lt;br&gt; However, there appeared to be a declining overall trend in both frequency and concentrations of atrazine detections from 2004 to 2009</td>
<td>Manamsa et al. 2016</td>
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<td>France</td>
<td>2011: campaigns in the spring (485 sites) and fall (475 sites)</td>
<td>Nationwide: 494 groundwater sites (GW)</td>
<td>103 pesticides (48 herbicides, 29 fungicides and 26 insecticides)</td>
<td>43 pesticides were detected in at least 1 sample, with 14 and 3 (atrazine and 2 of its metabolites) of those in at least 10 and 96 samples, respectively &lt;br&gt; Detected pesticides were dominated by herbicides (68% of sites), followed by fungicides (7.5%) and insecticides (1.4%) &lt;br&gt; The ratios between the occurrence of parent molecules and metabolites varied depending on the pesticide &lt;br&gt; 32 pesticides (including metabolites) exceeded the legal standard at least once. More than half of these compounds have already been banned</td>
<td>Lopez et al. 2015</td>
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<td>South Africa</td>
<td>February, April, July and October 2012 (4 seasons)</td>
<td>Water treatment plants in 7 major South African cities (DW)</td>
<td>Qualitative screening of 700 compounds (including several pesticides); quantitively screening of 2 pesticides (atrazine and terbutylazine)</td>
<td>Most frequently detected pesticides in the qualitative screening were atrazine (63%), metolachlor (75%) and terbutylazine (100%) &lt;br&gt; The seasonal distribution of atrazine fitted with its agricultural use as herbicide for summer crops &lt;br&gt; Detected levels of atrazine and terbutylazine were at least an order of magnitude less that the guideline values set by EPA and WHO, respectively &lt;br&gt; However, detected levels were &gt; 0.1 µg/L in many occasions at several sampling sites</td>
<td>Odendaal et al. 2015</td>
</tr>
<tr>
<td>Region (coverage)</td>
<td>Monitoring (or publication) period</td>
<td>Extent of review (GW = groundwater; DW = drinking water)</td>
<td>Pesticides</td>
<td>Outcomes</td>
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| Hungary           | 1990–2015                         | Nationwide: seven monitoring projects in over twenty sampling campaigns (GW) | 49 pesticides (including metabolites) | – Contamination rates of 32–61% were denoted in the monitoring projects.  
– Standards were rarely exceeded; only in the cases of point contaminations, where higher concentrations were determined for atrazine (concentrations up to 7540 ng/L). |
| India             | NR (studies published between 2005 and 2014) | National review (10 studies) (GW) | Persistent organic pesticides (DDTs, HCHs, endosulfan) | – Concentrations up to 0.94 μg/L (DDTs), 1.1 μg/L (HCHs) and 8.9 μg/L (endosulfan) have been detected in groundwater.  
– High concentrations of HCHs and endosulfan isomers and DDT metabolites have been detected across India. |
| Spain             | 4 consecutive years: 2007 (June–November), 2008 (June–November), 2009 (May–October) and 2010 (April–September). | 265 samples from 112 wells and piezometers coming from 29 different aquifers located in 18 ground waterbodies from Catalonia (GW) | 22 pesticides (18 herbicides and 4 insecticides) | – Pesticide concentrations in groundwater tend to decrease with time.  
– Several aquifers had pesticide concentrations that exceeded EU quality standards.  
– Pesticides that exceeded 0.1 μg/L more than once were atrazine, terbutylazine and the triazine metabolites DEA and DIA. |
| Ireland           | 2007 - 2008                        | Nationwide: 845 samples from 158 monitoring points (GW) | 13 pesticides (9 herbicides, 4 insecticides) | – MCPA and mecoprop were the most frequently detected pesticides in groundwater.  
– Mecoprop and diuron concentrations > 0.1 μg/L were noted. In addition, all detected 2,4-D and bentazone concentrations were > 0.1 μg/L. |
| United States     | 1993–2011                          | Nationwide: 2542 samples from 1271 wells in 58 nationally distributed well networks (GW) | 83 pesticides | – Pesticides were frequently detected (53% of all samples).  
– Concentrations seldom exceeded human-health benchmarks (1.8% of all samples).  
– For agricultural networks, concentrations of atrazine, metolachlor, and prometon decreased in time.  
– For urban networks, deethylatrazine concentrations increased and prometon concentrations decreased.  
– For major aquifers, concentrations of deethylatrazine and simazine increased. |

Reference: Székács et al. 2015  
Yadav et al. 2015  
Köck-Schulmeyer et al. 2014  
McManus et al. 2014  
Toccalino et al. 2014
<table>
<thead>
<tr>
<th>Region (coverage)</th>
<th>Monitoring (or publication) period</th>
<th>Extent of review (GW = groundwater; DW = drinking water)</th>
<th>Pesticides</th>
<th>Outcomes</th>
<th>Reference</th>
</tr>
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<tr>
<td>Lebanon</td>
<td>DW: December 2010 - December 2011&lt;br&gt;GW: 5 times between November 2010 and November 2011</td>
<td>Nationwide (GW + DW)</td>
<td>67 pesticides from various chemical classes</td>
<td>– Most frequently detected pesticides in both groundwater and drinking water samples were diazinon, DDE and DDD, hexachlorobenzene, aldrin, dieldrin and tetradifon&lt;br&gt;– All were quantified at low levels (&lt; 20 ng/L)</td>
<td>Kouzayha et al. 2013</td>
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<tr>
<td>New Zealand</td>
<td>September - December 2010&lt;br&gt;National review: 162 wells in 14 regions (GW)</td>
<td>22 organochlorines; 4 organophosphates; 23 organonitrogen herbicides; 17 acid herbicides</td>
<td>– Pesticides were detected in 38 wells (23%), with two or more pesticides detected in 15 wells (9%)&lt;br&gt;– A total of 22 different pesticides were detected with herbicides (n = 17) as the most common pesticide group, followed by insecticides (3) and fungicides (2)&lt;br&gt;– Concentrations of 9 pesticides exceeded 0.1 µg/L in 21 cases (7% of wells with pesticides detected).&lt;br&gt;– Comparisons with earlier surveys (since 1990) indicate that a similar percentage of wells had pesticide detections at comparable levels and with the same types of pesticides</td>
<td>Close &amp; Skinner 2012</td>
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<td>Pakistan</td>
<td>1990 - 2010&lt;br&gt;Nationwide: 6 studies (GW)</td>
<td>Organochlorines</td>
<td>– HCH isomers around 0.1 µg/L (max. 16.7 µg/L)&lt;br&gt;– Concentration ranges: heptachlor 0.02 – 0.17 µg/L (1 study); endrin 0.1–0.2 µg/L (1 study); dieldrin 0.06 µg/L (1 study); DDT traces – 400 µg/L (4 studies); DDT isomers traces – 0.82 µg/L (3 studies)&lt;br&gt;– High DDT levels attributed to dumping, illegal use and (inappropriate) storage</td>
<td>Eqani et al. 2012</td>
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<tr>
<td>Region (coverage)</td>
<td>Monitoring (or publication) period</td>
<td>Extent of review (GW = groundwater; DW = drinking water)</td>
<td>Pesticides</td>
<td>Outcomes</td>
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<td>Spain</td>
<td>Studies up to 2012</td>
<td>National review (GW)</td>
<td>80 pesticides (herbicides, insecticides and fungicides)</td>
<td>- The most studied pesticides have been triazines followed by phenyl urea herbicides, anilides and organophosphorus insecticides &lt;br&gt; - Out of the 80 studied pesticides, 61 were reported in &lt; 4 studies and 30 were not detected in any groundwater sample &lt;br&gt; - Groundwater is considerably less contaminated than other water bodies &lt;br&gt; - (max.) concentrations of many pesticides &gt; 0.1 μg/L, including alachlor (9.95 μg/L) and metolachlor (5.37 μg/L), malathion (3.5 μg/L), atrazine (3.45 μg/L), chlorfenvinphos (2.5 μg/L), dimethoate (2.3 μg/L), DEA (1.98 μg/L), chlortoluron (1.7 μg/L), simazine (1.69 μg/L); parathion-methyl (1.5 μg/L), TBA (1.27 μg/L) and linuron (1.01 μg/L)</td>
<td>Jurado et al. 2012</td>
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<tr>
<td>Pakistan</td>
<td>Studies from 1988 to 2006</td>
<td>National review: 8 studies (GW)</td>
<td>Several (mostly insecticides)</td>
<td>- High variation in detection frequencies (between 0% and 100%) depending on the pesticide and area &lt;br&gt; - Cotton growing areas showed higher pesticide detections and concentrations (often greater than 0.1 μg/L) &lt;br&gt; - Higher pesticide groundwater concentrations probably related with the existence of ponding irrigation systems</td>
<td>Tariq et al. 2007</td>
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### Annex 4.3-5 Recent reviews and large scale studies on the effects of pesticide use on vertebrate wildlife

Included are reviews and studies published between 2010 and 2020

1. Recent reviews or large scale studies on the effects of pesticide use on wild bird (and some mammal) populations.

<table>
<thead>
<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Organisms</th>
<th>Effects observed</th>
<th>Reference</th>
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</table>
| Global    | Systematic review   | Scientific evidence published since 2013 about the impact of neonicotinoids on nontarget organisms | Birds              | – There is considerable variation in the lethality of neonicotinoids to birds, both among bird species and individual pesticides, ranging from non-toxic to highly toxic  
  – It is difficult to judge whether clearly demonstrated lethal and sublethal effects of seeds treated with certain neonicotinoids are manifested in wild bird populations in the field  | Wood & Goulson 2017    |
| Global    | Systematic review   | Direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Mainly laboratory-based studies available.                    | Mainly wild birds  | – Exposure to seeds treated with certain neonicotinoids at dosages expected in the field was found to pose a risk to granivorous birds  | Gibbons et al. 2015     |
|           |                     | Two field studies on bird populations identified: 1 of imidacloprid and 1 of fipronil.                                           | Insectivorous birds| – No reductions in bird abundances were observed in both studies                                                                                                                                       |                         |
|           |                     | One field study of effect of fipronil use in locust control on mammals                                                          | Lesser hedgehog tenrec | – Decline in tenrec populations, likely due to depletion of termite prey                                                                                                                                  |                         |
| Global    | Systematic review   | 27 farmland bird and 22 farmland mammal species. 57 scientific publications.                                                     | Farmland birds & mammals | – Evidence for indirect effects of pesticides at the population level of 4 European farmland bird species  
  – Studies on long-term populations effects of pesticide use in agriculture on mammals are lacking, but some studies show adverse short-term effects  
  – Pesticides were considered to be among the major causes for population declines of farmland birds  | Jahn et al. 2014       |
| Global    | Narrative review    | 65 articles addressing relationship between rice cultivation and impacts on aquatic birds, published from 1980s – 2010              | Aquatic birds in rice habitats | – Direct mortality of many avian species documented as a result of rice pesticide applications  
  – Pesticides cited were organochlorines, organophosphates and carbamates  
  – Food resources of birds affected by pesticide applications in rice, but no resulting population effects cited  | Parsons et al. 2010    |
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<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Organisms</th>
<th>Effects observed</th>
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<td>Regional</td>
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| North America                   | Narrative review  | Factors assessed: declines in aerial insects, contamination (incl. pesticides), breeding habitat loss, climate change, nonbreeding ground effects | Aerial insectivore birds   | – While no single threat appears to be the cause of aerial insectivore declines, existing evidence suggests that several factors could be contributing to the declines  
  – As general hypothesis, the authors propose that changes in availability of high-quality prey, due to complex interactions of multiple effects (e.g. broad application of pesticides, agricultural intensification and other land use changes, changes in climate), have variably impacted combinations of fledging success, post-fledging survival, and nonbreeding season body condition of aerial insectivores, all of which contribute to variations in population trends | Spiller & Dettmers 2019        |
| North America                   | Systematic review | 122 studies, covering 77 breeding bird species. Parameters assessed (among others); pesticide lethal and sublethal toxicity | Farmland birds             | – Pesticides were the most predominant factor negatively affecting farmland bird populations (42% of all studies)  
  – Aerial insectivores and shrubland species were most commonly affected by pesticides (64% of studies for aerial species, 70% for shrubland)  
  – Pesticides affected food availability of birds (100% of studies), their survival (43% of studies) and reproduction (26% of studies) | Stanton et al. 2018            |
| Estonia, France, Germany, Ireland, Netherlands, Poland, Spain, Sweden | Large-scale monitoring | 270 cereals farms. 13 components of agricultural intensification assessed, among which: Number of applications and total amount of a.i. applied of insecticides, herbicides, fungicides. | Breeding birds             | – Application of fungicides (and correlated insecticides) was significantly and negatively associated with the total abundance of all breeding birds surveyed, as well as four individual breeding bird species.  
  – Pesticides did not have any associations with the abundance of birds during winter, suggesting that effects of insecticides or fungicides occurred through impact on food supply during the nestling period. | Emmerson et al. 2016           |
| National                        |                   |                                                                                 |                            |                                                                                                                                                                                                                                                                                                                                                   |                                 |
| USA                             | Surveys & models  | Population abundance of 29 species of grassland birds, 637 species of non-grassland birds, 36 species of insectivorous birds and 631 species of non-insectivorous birds. Annual mass of individual neonicotinoids applied at county-level | Birds                      | – The use of neonicotinoids resulted in annual decreases of 4% and 3% in population abundance of grassland birds and insectivorous birds, respectively, over the period 2008 – 2014  
  – When the longer-term effects of neonicotinoids on bird populations were considered, through their reduction of the number of birds left to reproduce, the average annual effect on grassland birds was 12% and on insectivorous birds 5%  
  – The average annual reduction in non-grassland and non-insectivorous bird populations due to neonicotinoid use was about 2% | Li et al. 2020                  |
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<tr>
<th>Country</th>
<th>Study type</th>
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<th>Organisms</th>
<th>Effects observed</th>
<th>Reference</th>
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| USA          | Narrative review | Direct and indirect effects of pesticides, and other drivers, on bird populations in the USA. | Birds                          | – The hypothesis that pesticides, particularly neonicotinoids, are indirectly affecting bird population status via reductions in food resources should be considered with caution and within context of other more likely causes  
– While it would be disingenuous to suggest that insecticides do not pose any potential risk to non-target arthropods proximal to insecticide use, and thus indirectly to avian species, it would also be misleading to suggest that these compounds are the primary driver for such indirect effects | Brain & Anderson 2019     |
| USA          | Surveys          | Bobwhite abundance related to county-level total neonicotinoid use, in Texas.  
Other variables assessed: climate and land-use data. | Northern bobwhite (grassland bird) | – Of the six predictor variables tested in this study, the strongest negative association was between bobwhite abundance and neonicotinoid use  
– Neonicotinoid use was significantly negatively associated with bobwhite abundance in the time periods following neonicotinoid introduction (1994-2003) or after their widespread use (2004-2012)  
– Treated seeds probably present the biggest hazard to bobwhites and other granivorous species | Ertl et al. 2018           |
| USA (California) | Surveys          | Abundance index based on 3 sets of bird survey data related to county-level total pesticides applied.  
Other variables assessed: land-use, harvested crop land, predator abundance, climate data. | Ring-necked pheasant           | – Major changes in agricultural practices over the last three decades were associated with declines in pheasant numbers and likely reflected widespread loss of habitat  
– Recent negative impacts on pheasant numbers were also associated with relatively high levels of pesticide application | Coates et al. 2017         |
| USA          | Surveys          | Number of breeding bird species;  
Fraction of farmland treated with herbicide or insecticide;  
Lethal pesticide risk | Grassland birds | – Best predictors of bird species declines were the (acute) lethal risk from insecticide use modelled from pesticide impact studies, followed by the loss of cropped pasture  
– A re-analysis of data by Hill et al. suggested that population trends of grassland birds in the U.S. were primarily associated with habitat availability, rather than insecticide use or insecticide acute toxicity | Mineau & Whiteside 2013  
Hill et al. 2014               |
| The Netherlands | Surveys          | Imidacloprid concentrations in surface water.  
15 passerine species that are common in farmlands and depend on invertebrates during the breeding season. | Farmland birds | – Higher concentrations of imidacloprid in surface water were consistently associated with lower or negative population growth rates of passerine insectivorous bird populations | Hallman et al. 2014         |
2. Recent reviews of the risks and/or effects of pesticides to amphibians at environmentally relevant concentrations.

<table>
<thead>
<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Organisms</th>
<th>Effects observed</th>
<th>Reference</th>
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</table>
| Global  | Systematic review & meta-analysis | Behavioural changes induced by chemicals, including pesticides 116, mainly laboratory-based, studies | Amphibians  | – Most studies focussed on insecticides  
– Insecticides generally invoked the strongest behavioural responses: they significantly increased rates of abnormal swimming, reduced activity and reduced the capacity to exhibit escape responses  
– Note: it was not specified whether effect concentrations were environmentally relevant | Sievers et al. 2019 |
<p>| Global  | Narrative review                | Evidence of pesticide effects on amphibians under current conditions use       | Amphibians  | – The review concludes that exposure of amphibians does occur, and that this exposure may lead to decline of populations and harm individuals, which would be of high concern. Therefore, a specific environmental risk assessment scheme is needed for these groups | EFSA 2018 |</p>
<table>
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<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Organisms</th>
<th>Effects observed</th>
<th>Reference</th>
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</table>
| Global | Narrative review | Effects of endocrine disrupting chemicals (EDCs), including pesticides, in laboratory experiments and field monitoring | Amphibians, primarily frogs & toads | – Effects on reproduction (laboratory): Exposure to the herbicide atrazine in leopard frogs induce feminising effects on the male gonads (including 'intersex' – oocytes within testes) at concentrations measured in some aquatic environments
– There is now a substantial and growing body of evidence from field studies indicating that agriculture, herbicides and/or pesticides are associated with increased intersex in anurans. Some of the strongest associations between intersex induction and EDCs come from studies that have analysed the effects of the agricultural environment or mixtures of agrochemicals, rather than those focused on single compounds
– There are significant knowledge gaps on the effects of EDCs in amphibians and data are lacking for studies on wild populations. This prevents drawing definitive conclusions on the associations between endocrine disruption and wild amphibian populations | Orton & Tyler 2015 |
| Global | Systematic review & meta-analysis | Effects of pesticides on survival and growth 66 survival studies & 45 growth studies, primarily laboratory-based | Amphibians | – At ecologically relevant concentrations:
– Organophosphates, carbamates, neonicotinoids, phosphonoglycines (with POEA surfactant), triazines, adversely affected amphibian survival
– Organophosphates and phosphonoglycines also adversely affected amphibian growth | Baker et al. 2013 |
| Global | Systematic review & meta-analysis | Effects of pesticides on survival, mass, time to hatching, time to metamorphosis and frequency of abnormalities. 16 laboratory & mesocosm studies | Amphibians | – At ecologically relevant concentrations:
– Pesticide exposure resulted in significant reduction of amphibian survival.
– Effects of pesticides on body mass, developmental time and frequency of abnormalities were not statistically significant, partly due to high heterogeneity among studies. | Egea-Serrano et al. 2012 |
| National | Field monitoring | Pesticides: cypermethrin, chlorpyrifos, endosulfan, glyphosate and 2,4-D. Enclosures in 91 ponds adjacent to agricultural field were monitored | 4 amphibian species common in ponds in agricultural landscapes | – Applications to adjacent fields with the 3 insecticides reduced survival at 48h to ≤1 – 10%. No significant effects on acute survival observed for the most application with only herbicides
– All pesticides, including herbicides, impaired the mobility of the amphibians (tadpoles) | Agostini et al. 2020 |
### Study Coverage

Country | Study type | Study coverage | Organisms | Effects observed |
--- | --- | --- | --- | --- |
USA | Field monitoring | Samples of water, sediment and frog tissue from 21 sites in 7 states. Samples analyzed for >90 pesticides and metabolites, and for the amphibian chytrid fungus *Batrachochytrium dendrobatidis* (Bd) | Frogs | – Thirty-nine pesticides and pesticide degradates were detected in one or more of the samples collected during the study  
– Pesticide occurrence in water or sediment was not a strong predictor of occurrence in tissue, but pesticide concentrations in tissue were correlated positively to agricultural and urban land, and negatively to forested land  
– Frogs that tested positive for Bd were associated with sites that had higher total fungicide concentrations in water and sediment, but lower insecticide concentrations in sediments relative to frogs that were Bd negative  
– There were no other differences in pesticide occurrence between individual frogs that were positive or negative for Bd |

United Kingdom | Field monitoring (1992 – 2000) | Ranavirus-consistent common frog mortality events in the UK in relation to the use of garden chemicals | Common frog (*Rana temporaria*) | – Ranavirosis occurrence (i.e. presence/absence) was not significantly associated with use of garden chemicals  
– Ranavirosis prevalence (i.e. proportion of the estimated total frog population killed in the mortality event) was positively associated with the use of herbicides and of slug pellets, in addition to several other abiotic and biotic variables |

### Recent reviews of the risks and/or effects of pesticides to reptiles at environmentally relevant concentrations.

Country | Study type | Study coverage | Organisms | Effects observed |
--- | --- | --- | --- | --- |
Global | Narrative review of toxicity studies | 16 articles of laboratory experiments of the toxicity of pesticides to lizards | Lizards | – Most studies assessed locomotor performance, histopathology, oxidative stress, neurotoxicology, and genetic damage  
– It was not clear from the review whether observed effects would occur at environmentally relevant concentrations |

Global (but focus on Europe) | Narrative review | Evidence of pesticide effects on reptiles under current conditions use | Reptiles | – Few laboratory and field studies of pesticide effects on reptiles are available. Some studies indicate that adverse effects on reptiles occur of pesticides at environmentally relevant pesticide concentrations, but other studies do not find such effects  
– However, the review concludes that exposure of reptiles does occur, and that there is evidence that active substances and authorised plant protection products in Europe do have toxic impacts on reptiles |
<table>
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<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Organisms</th>
<th>Effects observed</th>
<th>Reference</th>
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<td>Regional and national</td>
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<tr>
<td>Europe</td>
<td>Assessment of risk of exposure, in Europe</td>
<td>Exposure risk is estimated based on occurrence of reptiles in agricultural areas where pesticides are used, reptile physiology and their life-history</td>
<td>Reptiles</td>
<td>– About 1/3 of all European species of reptiles exhibit a high risk of exposure to pesticides. This is especially the case in Southern Europe, with a particular focus on vineyards&lt;br––&gt;– Of the 21 species and 3 subspecies of reptiles with special conservation status in the EU, nearly half are at above-average risk of pesticide use</td>
<td>Mingo et al. 2016&lt;br&gt;Wagner et al. 2015</td>
</tr>
<tr>
<td>Germany</td>
<td>Field monitoring study</td>
<td>Fitness and enzymatic activity in lizards sampled from sites along a gradient of agricultural intensity (vineyards with mainly fungicide applications), compared to a natural, unexposed, site</td>
<td>Common wall lizard (<em>Podacris muralis</em>)</td>
<td>– Exposure to pesticides induced oxidative stress in wall lizards, which can have severe implications for individuals&lt;br––&gt;– Neurotoxic effects were not observed&lt;br––&gt;– An evident decrease in fitness of individuals was observed with increasing land use intensity (and presumed pesticide exposure)</td>
<td>Mingo et al. 2017</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Laboratory studies</td>
<td>Oral acute toxicity of rodenticides (brodifacoum, coumatetralyl, pindone, diphenacine, cholecalciferol) and herbicides (glyphosate, clopyralid, triclopyr, metsulfuron-methyl, haloxyfop-methyl)&lt;br&gt;Dietary risk assessment</td>
<td>Western fence lizard (<em>Sceloporus occidentalis</em>)</td>
<td>– Only pindone and triclopyr were toxic to fence lizards below 1750 μg/g (LD₅₀ = 550 μg/g)&lt;br––&gt;– Acute dietary risk to reptiles to the tested rodenticides and or herbicides was low&lt;br––&gt;– Research into sub-lethal effects is also required</td>
<td>Weir et al. 2016</td>
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<tr>
<td>Portugal</td>
<td>Field monitoring study</td>
<td>4 sites under intensive agriculture compared to 2 sites under organic agriculture.&lt;br&gt;Mixture of herbicide treatments in intensive agriculture sites.</td>
<td>Lacertid lizards</td>
<td>– Herbicide concentrations in soil (sum of 7 a.i.'s: mesotrione, glyphosate, bentazon, dicamba, dimethenamid-p, alachlor and terbuthylazine) ranged from 10-100 μg/kg soil in intensively cultivated sites; and from 0 -10 μg/kg soil in organic sites&lt;br––&gt;– No significant differences were observed between intensive and organic sites for population size and other demographic parameters&lt;br––&gt;– Lizards from intensively cultivated sites had a significantly lower body condition index and more blood parasites than animals from organic sites&lt;br––&gt;– No significant effects were observed for standard metabolic rate, locomotor performance, glutathione oxidative pathways and related enzyme activity, lipid peroxidation and liver and testis histology&lt;br––&gt;– Further results on thyroid and testes histology strongly suggest that exposure of lizards to the mixture of herbicides had thyroid disrupting effects that ultimately affected the male reproductive system</td>
<td>Amaral et al. 2012a, b&lt;br&gt;Bicho et al. 2013</td>
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Annex 4.3-6 Recent large-scale studies and partial reviews of the effects of pesticide use on biodiversity

Included are studies, published between 2009 and 2020, that link pesticide use to biodiversity parameters such as number of species, taxonomic richness, etc.

<table>
<thead>
<tr>
<th>Country</th>
<th>Study type</th>
<th>Study coverage</th>
<th>Elements of biodiversity studied</th>
<th>Effects observed</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Global</td>
<td>Systematic review</td>
<td>73 peer-reviewed studies of entomofauna declines from various parts of the world, published since 1984</td>
<td>Insects</td>
<td>– Almost half of insect species are rapidly declining and a third are being threatened with extinction</td>
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<td>– The main drivers of species declines appear to be in order of importance: i) habitat loss and conversion to intensive agriculture and urbanisation (50% of reports); ii) pollution, mainly that by synthetic pesticides and fertilisers (26% of reports)</td>
<td>Sánchez-Bayo &amp; Wyckhuys 2019</td>
</tr>
<tr>
<td>Global</td>
<td>Meta-analysis</td>
<td>20 studies, 49 observations comparing organic with conventional farming</td>
<td>Soil organisms</td>
<td>– Differences in soil biodiversity between organic and conventional farming practices were not detected</td>
<td>De Graaff et al. 2019</td>
</tr>
<tr>
<td>Global</td>
<td>Meta-analysis</td>
<td>94 studies, 184 observations comparing organic with conventional farming</td>
<td>arthropods, birds, microbes &amp; plants</td>
<td>– Species richness on organic farms was on average 34% higher than on conventional farms</td>
<td>Tuck et al. 2015</td>
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<td>– Plants benefited the most from organic farming; but arthropods, birds &amp; microbes also showed a substantial positive effect</td>
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<td>– Current studies are heavily biased towards northern and western Europe and North America, while other regions with large areas of organic farming remain poorly investigated</td>
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</tr>
<tr>
<td>Global</td>
<td>Meta-analysis</td>
<td>39 studies on 23 crops in 14 countries on 6 continents</td>
<td>Wild bees</td>
<td>– Organic farm management (lacking or having highly reduced use of pesticides and fertilizers) resulted in a 50% higher wild bee richness when compared to conventional farming</td>
<td>Kennedy et al. 2013</td>
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<td>Regional and national</td>
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<td>Japan</td>
<td>Moderate-scale monitoring</td>
<td>21 irrigation ponds</td>
<td>Wide range of freshwater organisms</td>
<td>– A fungicide and an insecticide, alone or in combination with other stressors (invasive alien fish, concrete bank protection) had a significantly negative correlation the taxonomic richness of freshwater animals sampled in the study ponds</td>
<td>Ito et al. (2020)</td>
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<tr>
<td>Country</td>
<td>Study type</td>
<td>Study coverage</td>
<td>Elements of biodiversity studied</td>
<td>Effects observed</td>
<td>Reference</td>
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<td>USA</td>
<td>Moderate-scale</td>
<td>4 sites in California, monitored between 1972 and 2012</td>
<td>67 species of butterflies</td>
<td>– A negative association was detected butterfly diversity (Shannon index) and increasing neonicotinoid applications, while controlling for land use and other factors</td>
<td>Forister et al. 2016</td>
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<td>USA</td>
<td>Moderate-scale</td>
<td>4 no-input, 6 organic and 15 conventional apple orchards</td>
<td>Wild bees</td>
<td>– Pesticide use did not adversely affect total bee species richness</td>
<td>Mallinger et al. 2015</td>
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<tr>
<td>USA</td>
<td>moderate-scale</td>
<td>19 apple orchards with various pesticide use intensities</td>
<td>Wild bees</td>
<td>– Species richness of solitary wild bees decreased significantly with increasing pesticide use intensity; but richness of social wild bees did not</td>
<td>Park et al. 2015</td>
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<td>France</td>
<td>Large-scale</td>
<td>66 cereal fields located in three French departments</td>
<td>Farmland and non-farmland birds</td>
<td>– Herbicide dose was associated with negative effects on the Community Specialization Index. Overall, the proportion of habitat specialists, particularly of herbivorous species, decreased, and the proportion of generalists increased as herbicide doses increased. However, herbicide dose was positively correlated with bird richness and total abundance. No influence of insecticide or fungicide doses could be detected</td>
<td>Chiron et al. 2014</td>
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<td>Germany, France,</td>
<td>Large-scale</td>
<td>72 sampling sites</td>
<td>Stream invertebrates</td>
<td>– Pesticide residues were associated with effects on both the species and family richness in both regions (statistically significant) Decrease in taxonomic richness between the uncontaminated and highly contaminated categories ranged from 42% for the European species-level data to 27% for the Australian family-level data Effects in Europe were detected at concentrations below environmental standards</td>
<td>Beketov et al. 2013</td>
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| Estonia, France, Germany, Ireland, Netherlands, Poland, Spain, Sweden | Large-scale monitoring | 270 cereals farms. 13 components of agricultural intensification assessed, among which: Number of applications and total amount of a.i. applied of insecticides, herbicides, fungicides | Wild plants, carabid beetles, breeding birds | – Number of wild plant species declined as the frequency of herbicide and insecticide application and the amounts of active ingredients of fungicides increased  
– Number of carabid species was negatively affected by the amounts of active ingredients of insecticide applied  
– Bird species diversity declined with increasing frequency of fungicide application (note: frequencies of fungicide and insecticide applications were closely correlated) | Geiger et al. 2010  
Emmerson et al. 2016 |
| Italy                           | Large-scale monitoring | Vine fields in northern Italy with or without applications of the insecticide fenitrothion | Wild bees, bumblebees, butterflies | – At field scale: Wild bee species richness declined after 2 or 3 insecticide applications, but not bumblebee or butterfly richness.  
– At the landscape level: richness of wild bees, bumblebees and butterflies was lower in areas with higher pesticide loads | Brittain et al. 2010 |
| Canada                          | Retrospective review | Comparison of areas where imperilled species occur versus areas where they have been lost. Pesticides variables were area treated with herbicides or with insecticides, or total area treated with pesticides (herbicide + insecticides + fungicides) | 62 species of mammals, birds, amphibians, reptiles | – High losses of imperilled species were observed in regions with high proportions of agricultural land cover. However, losses of imperilled species are significantly more strongly related to the proportion of the region treated with agricultural pesticides. Species losses were more strongly related to herbicide use than to use of other pesticides | Gibbs et al. 2009 |
References


