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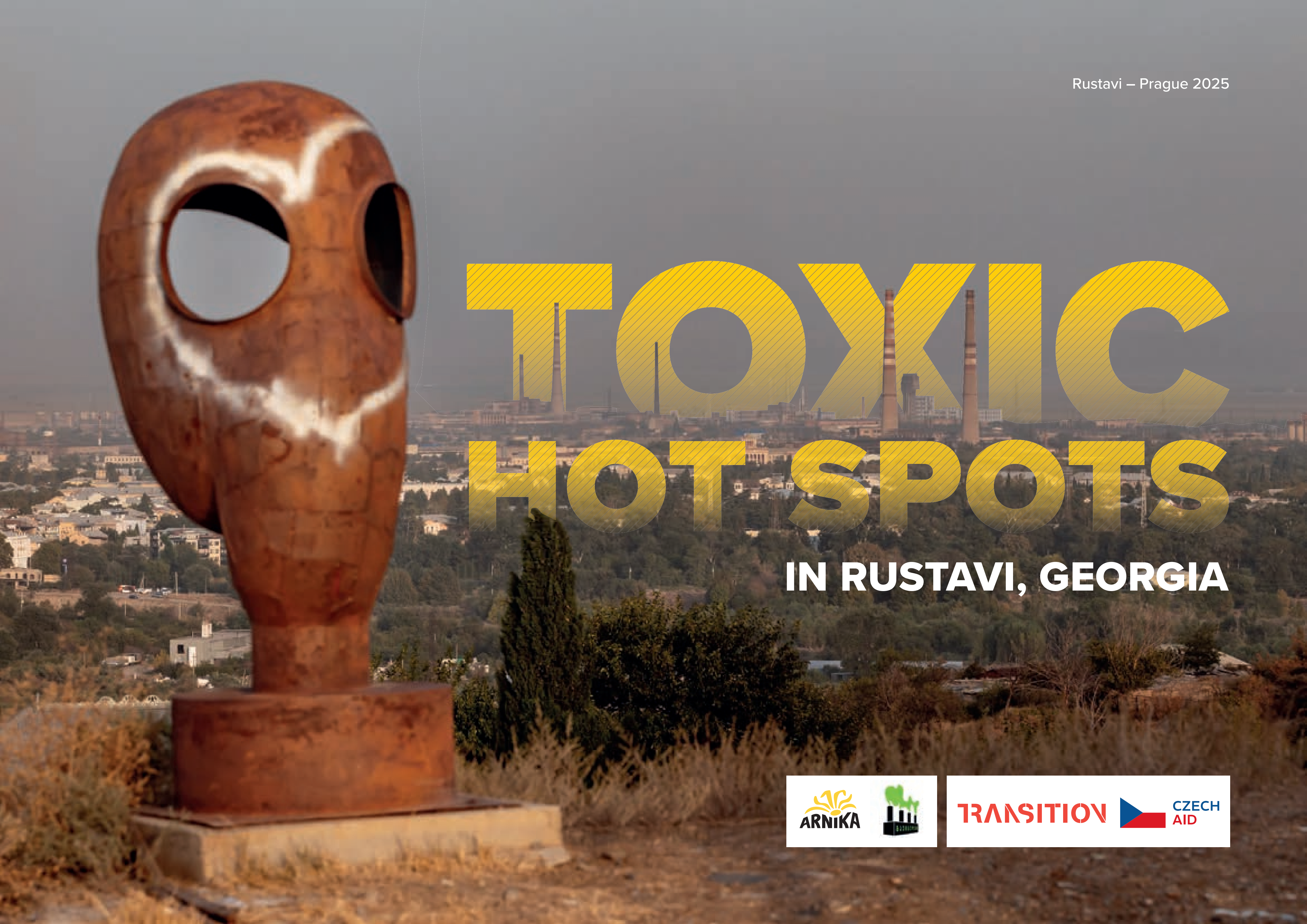
TOXIC HOTSPOTS

IN RUSTAVI, GEORGIA



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CONTENT

SUMMARY

This study presents the results of environmental sampling and chemical analysis of persistent organic pollutants (POPs) and heavy metals in and around the city of Rustavi, Georgia. The aim was to identify local toxic hotspots and assess the potential health and environmental risks associated with contamination from legacy and ongoing industrial activities.

Rustavi has a long-standing industrial legacy, including large-scale metallurgical and cement production facilities, which have been identified as key sources of pollution. Soil and dust samples collected near these industrial areas—particularly around metallurgical plants, cement factories, and slag dumps—revealed elevated concentrations of several hazardous substances. For example, street dust near the industrial zone (GE-RD-1) contained mercury, lead, and cadmium levels more than 4.5, 24, and 26 times higher than background values, respectively. Soil from playgrounds near industrial areas also showed elevated levels of cadmium and zinc, exceeding hygienic standards for children's sandboxes.

In addition to heavy metals, various POPs were detected in environmental samples. The highest levels of PCBs were found in soils between metallurgical facilities and in the nearby village of Tazakendi (up to 510 ng/g dm). Dust samples near industrial facilities contained up to 98 ng/g dm of PCBs—over 4,800 times higher than background levels in the reference village of Udabno.

Free-range chicken eggs collected in Rustavi and Tazakendi also showed severe contamination with POPs. Concentrations of PCDD/Fs and dl-PCBs ranged from 0.73 to 2.37 pg WHO-TEQ/g fw, while a supermarket egg contained only 0.02 pg WHO-TEQ/g fw. Based on average adult body weight, consumption of just one local egg per day would lead to an intake of PCDD/Fs and dl-PCBs exceeding the EFSA tolerable daily intake (0.25 pg WHO-TEQ/kg bw/day) by up to 373%.

Fish samples from the Mtkvari River contained up to 18 ng/g fw of PCBs and over 85 ng/g fw of DDT. Estimated dietary intake for women ranged up to 7.1 ng/kg bw for PCBs and 33.7 ng/kg bw for DDT. While these values remain below provisional TDI and RfD levels for DDT, they reflect substantial cumulative exposure.

The results of this study clearly point to the legacy and ongoing impact of Rustavi's metallurgical and cement industries as primary drivers of environmental contamination. The highest pollution levels were consistently found in locations closest to industrial facilities and areas where slag and other waste materials have been processed or reused.

The presence of DDT and its metabolites in both environmental samples and locally produced food strongly suggests recent use of this banned pesticide. This practice poses a serious long-term health risk, particularly in a region already heavily burdened by industrial pollution. Alarmingly high DDT concentrations were found in soils from newly refurbished children's playgrounds across the city.

These findings highlight the urgent need for environmental and public health interventions, including improved risk communication, targeted clean-up efforts, stricter enforcement of environmental regulations, and the ongoing monitoring of contaminants in food and the environment.

ABBREVIATIONS

ABS – Acrylonitrile Butadiene Styrene
AAS – Atomic Absorption Spectrometr
AhR – Aryl Hydrocarbon Receptor
ATSDR – Agency for Toxic Substances and Disease Registry
BDS – BioDetection Systems
BEQ – Bioanalytical Equivalent
BFRs – Brominated Flame Retardants
BTBPE – 1,2-Bis(2,4,6-tribromophenoxy) ethane
bw – body weight
DBDPE – Decabromodiphenyl Ethane
DBNPG – Dibromoneopentyl Glycol
DDT – Dichlorodiphenyltrichloroethane
dl-PCBs - dioxin-like Polychlorinated Biphenyl
dm – dry matter
DMSO – Dimethyl Sulfoxide
DP – Dechlorane Plus
e.g. – exempli gratia (for example)
EFSA – European Food Safety Authority
et al. – Et alia
EU – European Union
FAO – Food and Agriculture Organisation
fw – fresh weight
GC-MS-NCI – Gas Chromatography Coupled with Mass Spectrometry and Negative Chemical Ionisation
GC-MS/MS-EI – Gas Chromatography Coupled with Tandem Mass Spectrometry and Electron Ionisation
GPC – Gel Permeation Chromatography
HBB – Hexabromobenzene
HBCD – Hexabromocyclododecane; HBCDs – Hexabromocyclododecanes
HCBD – Hexachlorobutadiene
HCB – Hexachlorobenzene
HCH – Hexachlorocyclohexane
HIPS – High-Impact Polystyrene
IARC – International Agency for Research on Cancer
ICP-MS – Inductively Coupled Plasma Mass Spectrometry
ISO/IEC – International Organisation for Standardization / International Electrotechnical Commission
IUCN – International Union for Conservation of Nature
LC – Least Concern
LOQ – Limit of Quantification
MAS – Münster Analytical System
MRL – Maximum Residue Limit
ndl-PCBs – Non-dioxin-like Polychlorinated Biphenyls
OBIND – Octabromo-1,3,3-trimethylpheny-1-indan
OCPs – Organochlorine Pesticides
PBDE – Polybrominated Diphenyl Ethers (PBDEs)
PBDD/Fs – Polybrominated dibenzo-p-dioxins and dibenzofurans
PCBs – Polychlorinated Biphenyls

PCDD/Fs – Polychlorinated dibenzo-p-dioxins and dibenzofurans
PeCB – Pentachlorobenzene
POPRC – Persistent Organic Pollutants Review Committee
POPs – Persistent Organic Pollutants
PP – Polypropylene
PVC – Polyvinyl Chloride
RfD – Reference Dose
SL – Standard Length
SOPs – standard operating procedures
TDBPP – tris(2,3-dibromopropyl) phosphate
TDI – tolerable daily intake
TEFs – Toxic Equivalency Factors
TEQ - Toxic Equivalent
TL – Total Length
UHPLC-ESI-MS/MS – Ultra High-Performance lLquid Chromatography Coupled with Tandem Mass Spectrometry
UNDP – United Nations Development Programme
UNIDO – United Nations Industrial Development Organisation
USA – United States of America
US EPA – United States Environmental Protection Agency
WHO – World Health Organisation
WWTP – Wastewater Treatment Plant

1. INTRODUCTION

The city of Rustavi in southeastern Georgia has a long-standing industrial legacy. Originally developed during the Soviet era as a hub for heavy industry, the city was home to more than 90 large-scale enterprises, including metallurgical, chemical, and cement plants. Although many of these facilities have been downsized or shut down, their environmental legacy persists to this day. Recent assessments indicate that Rustavi remains an industrial centre, with over 400 manufacturing enterprises active in 2023 (UNIDO 2023).

The UNIDO figure covers a wide range of manufacturing enterprises – from small workshops to large-scale industrial facilities – across multiple sectors such as metallurgy, rubber and plastics, and furniture production. According to data obtained from the Ministry of the Environmental Protection and Agriculture of Georgia (Gavigudet), at least 161 of these enterprises are subject to environmental permits or technical regulations, and many are significant sources of air pollution, particularly metallurgical plants, cement factories, chemical producers, and waste-processing facilities.

The Mtkvari River (Kura), which flows through Rustavi, is the main river system in the South Caucasus. It has been heavily impacted by untreated wastewater, industrial discharges, and agricultural runoff (Klise et al. 2009; TACIS 2003). Historical studies, including those conducted under the UNDP/GEF project on reducing trans-boundary degradation in the Kura-Aras Basin, have documented serious pollution concerns across the region (UNDP/GEF 2004).

As part of a collaborative investigation between Arnika (Czech Republic), and Gavigudet (a civil society movement in Rustavi), this study assesses toxic hot spots in Rustavi and its surroundings, focusing on the presence of persistent organic pollutants (POPs) and heavy metals in environmental and food samples. The study includes analyses of contaminated soils (particularly from children's playgrounds), outdoor dust, sediments, locally sourced free-range chicken eggs, and fish from the Mtkvari River.

POPs—such as polychlorinated biphenyls (PCBs), dioxins (PCDD/Fs), DDT, and brominated flame retardants (BFRs)—are of particular concern due to their persistence in the environment, bio-accumulative nature, and potential to harm human health even at low concentrations. Many of these substances have been banned or severely restricted under international treaties such as the Stockholm Convention, yet they continue to pose threats in areas with an industrial past or poor waste management infrastructure.

This study aims to:

» Identify contaminated environmental media and food items that may represent significant exposure pathways for local communities;

» Highlight locations with particularly elevated contamination requiring further investigation or remediation;

» Provide evidence-based recommendations for Georgian authorities, civil society, and international partners to support pollution reduction and public health protection efforts.

The findings presented in the following chapters reveal alarming levels of toxic substances in both environmental samples and local food items such as eggs and fish. These results underline the urgent need for improved chemical safety governance, environmental monitoring, and pollution prevention measures in Rustavi and other affected areas in Georgia.

2. SAMPLING AND ANALYSES

2.1. Description of Sampling Locations

2.1.1. City of Rustavi, Georgia

The city of Rustavi was historically home to approximately 90 major industrial facilities—primarily large-scale, state-owned enterprises in heavy industry—which significantly contributed to environmental pollution. According to Gigauri et al. (2023), key sources included a metallurgical plant, cement production, chemical enterprises, and vehicle emissions, all of which released hazardous substances into the air, soil, and water. During the Soviet and post-Soviet periods, Rustavi hosted extensive operations such as the Rustavi Metallurgical Plant, the Rustavi Azot fertilizer factory, and various petrochemical and non-ferrous metal processing facilities (U. S. Geological Survey 2012).

Although many of these major facilities are no longer operational or have significantly reduced their activities, their environmental legacy persists. As of 2023, Rustavi is home to 415 active manufacturing businesses, employing an estimated 3,970 people (UNIDO 2023), but other estimates go over 4,000 (Gujaraidze 2021; GeoWelResearch 2021; Government of Georgia, 2014).[1] While these businesses represent a broader and more diverse mix—including small and medium-sized enterprises—metallurgy and associated industries remain economically dominant. Other notable sectors include rubber and plastic products and furniture manufacturing.

POPs such as dioxins and PCBs were not directly measured in the available studies. However, given Rustavi's industrial profile—marked by high-temperature processes and outdated waste management systems—the likelihood of their presence remains high, as documented in similar industrial areas across the former Soviet Union (Grechko et al. 2021a; Petrlik et al. 2015a; Petrlik et al. 2018).

Photo 2.1: Steel factories in the Industrial area in Rustavi. Photo: Ondřej Petrlík

1 Employment in heavy industry in Rustavi may be significantly higher than the UNIDO estimate of slightly over 4,000 employees when considering major industrial facilities such as Rustavi Steel (~2,000 employees) (Government of Georgia 2014), Rustavi Azot (according to their own website up to 2,000 employees), and HeidelbergCement Georgia (~1,200 employees) (Gujaraidze 2021), as well as other metallurgical, chemical, and related plants. This would bring the total potentially closer to, or above, 6,000 employees. Local stakeholders estimate that the total number could be as high as 8,000. However, precise data for the industrial sector and this specific area are not available.

Photo 2.2: Tazakendi village with industrial background. Photo: Ondřej Petrlík

Photo 2.3: Mtkvari River near Rustavi. Photo: Ondřej Petrlík

2.1.2. Tazakendi village, Georgia

Tazakendi is a village in the Gardabani Municipality of the Kvemo Kartli region (Wheatley 2004), Georgia, predominantly inhabited by ethnic Azerbaijanis. The community mainly relies on agriculture and livestock farming. Like other Azerbaijani minority settlements in the region, Tazakendi is particularly vulnerable due to limited knowledge of the Georgian language, which seriously restricts residents' access to environmental information and their ability to participate in decision-making processes.

The village lies outside the city of Rustavi but within the same Kvemo Kartli region. Tazakendi was selected for sampling due to its proximity to major industrial pollution sources in Rustavi and potential exposure pathways affecting rural minority communities.

2.1.3. Mtkvari (Kura) River

The Mtkvari River (known as Kura in Russian) is the principal watercourse of the South Caucasus region, originating in northeastern Türkiye and flowing through Georgia and Azerbaijan before emptying into the Caspian Sea. It stretches over 1,500 kilometers, with a total basin area of approximately 188,400 km². Along its course, the Mtkvari passes through diverse landscapes including mountains, steppes, and agricultural plains. In eastern Georgia, the river flows through the city of Rustavi, located southeast of the capital Tbilisi, near the border with Azerbaijan. In Rustavi, the Mtkvari is exposed to various industrial discharges and urban runoff, as the city has historically been a center of heavy industry. This section of the river is part of the lower Mtkvari basin, which is known to be particularly vulnerable to pollution from untreated wastewater, agricultural runoff, and emissions from former and existing industrial facilities (Bakradze et al. 2017).

2.1.4. Udabno Village, Georgia

Udabno, meaning "desert" in Georgian, is a small, remote village located in the Kakheti Region in eastern Georgia, over 30 km away (as the crow flies) from Rustavi. Established in the mid-1980s as a resettlement community for eco-migrants from the Svaneti highlands, Udabno lies at an altitude of 750 meters above sea level and re-

Photo 2.4: Udabno was chosen as a reference locality free from any industrial influence. Photo: Ondřej Petrlík

mains relatively isolated, surrounded by arid steppe landscapes. It is also known for its proximity to the historic David Gareja monastery complex (georgia.to 2025). We chose Udabno as a reference location with an uncontaminated environment.

2.1.5. Description of the prevailing winds

According to the wind-rose for Rustavi, most of the winds are from the North-West, followed by South and South-Easterly directions (see Table 2.1 and wind-rose in Figure 2.1).

2.2. Sampling

In September 2024, a total of 44 environmental and food samples were collected in and around the city of Rustavi, including Tazakendi village, for the purpose of this study. The sampling campaign included eight pooled egg samples (seven from free-range hens and one from a supermarket for reference), twelve fish samples (mostly pooled), two slag samples, eleven soil samples (including seven collected at children's playgrounds), four sediment samples, and five road dust samples. In addition, two pooled free-range chicken egg samples from other post-Soviet countries were included for comparison. To establish reference background levels, one soil sample and one dust sample were collected in the rural village of Udabno, located far from any major pollution sources.

TABLE 2.1: WIND DIRECTIONS IN RUSTAVI.
Source: (World Weather 2024).

N	NE	E	SE	S	SW	W	NW
9.6%	1%	6.6%	18.1%	20.7%	6%	5.6%	32.3%

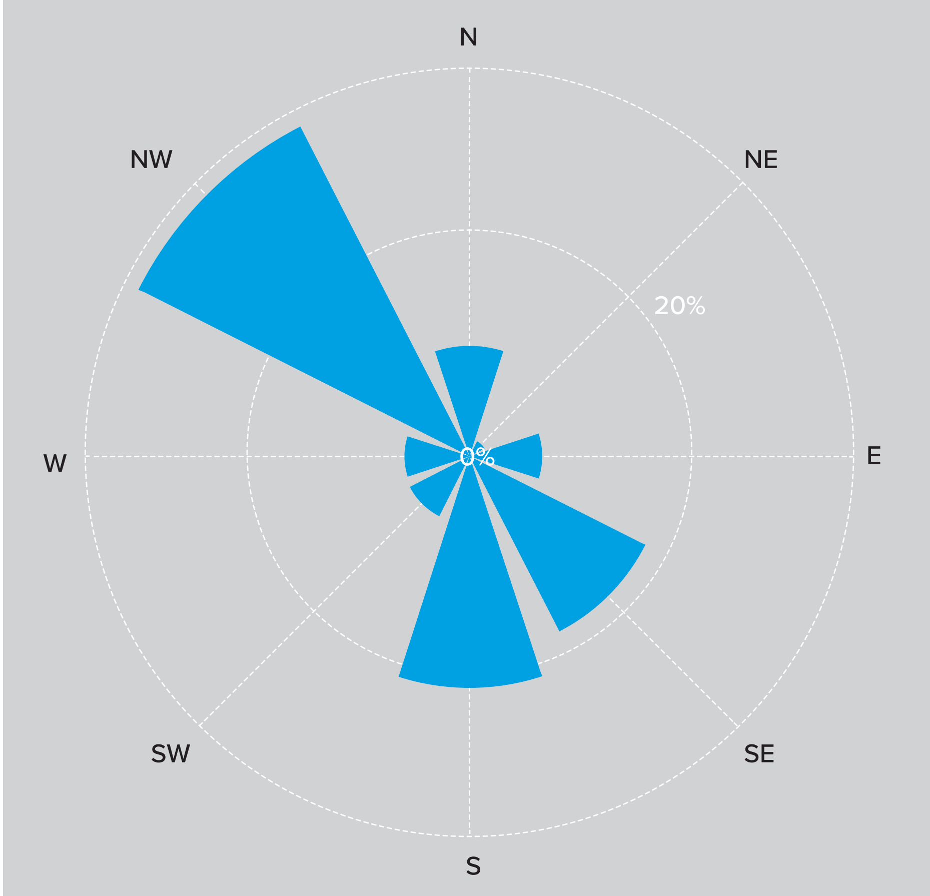

Figure 2.1: Wind rose for Rustavi. Source: (World Weather 2024).

Photo 2.5: Example of a children's playground in Rustavi. Sampling site: GE-RPG-6A. Photo: Ondřej Petrlík

All solid environmental samples—including soils, sediments, dust, and slag—were collected as pooled composite samples. Sampling was conducted using stainless steel tools, and the materials were homogenized in a stainless-steel bowl. When the amount of collected material exceeded the quantity required for analysis, a quartering technique was applied. Samples were placed into PE zip-lock bags or 250 ml polyethylene containers and kept cool during storage and transport. Each site was documented in terms of its proximity to pollution sources and local land use, providing important context for interpreting the analytical results. Detailed information about individual samples is provided in the respective analytical chapters. Fish sampling methods are described in Chapter 5.

2.2.1. Egg samples

We collected seven free-range chicken egg samples and one sample of eggs obtained in a supermarket in Rustavi as a reference sample. Pooled egg samples consistently comprised two to five individual eggs from free-range hens from the same location, often from the same family and/or flock. The eggs were collected in typical plastic egg packaging and boiled for approximately 7 minutes. The homogenates from the edible parts of the eggs were used for laboratory analysis.

2.2.2. Soil samples

Soil was collected using a stainless-steel shovel or small grab device. Vegetation was first removed, and soil was sampled from a depth of about 5–7 cm across four to eight points within a defined area (typically 3×3 metres).

2.2.2.1. Soil sampling at children's playgrounds

At each playground, topsoil was collected either directly from the surface or, when that was not possible, from the immediate surroundings. Seven soil samples were collected from six children's playgrounds, all located within the city of Rustavi. A seventh sample was collected in the village of Udabno as a reference site (see below). The sites were situated at varying distances from the industrial zone. The playgrounds closest to industrial activities were GE-RPG-1, GE-RPG-2, and GE-RPG-4. GE-RPG-3 and GE-RPG-5 were located somewhat further away, while GE-RPG-6 (with two samples A and B taken there) was the farthest away from the industrial area and the only sample collected from a children's playground in the Old Town, situated on the opposite side of the Mtkvari River. At this last site, two distinct samples were collected – GE-RPG-6A and GE-RPG-6B – due to differences in surface materials.

2.2.2.2. Soil sampling in non-playground environments

Soil samples (e.g., GE-RS-2, GE-RS-3, GE-RS-4) were also collected from locations such as housing areas near former industrial sites, a brownfield between an inactive metallurgical facility and an operating cement plant, and the village of Tazakendi — a residential area potentially influenced by nearby ferroalloy and cement production.

Two waste samples (GE-RW-1 and GE-RW-2) were taken from small heaps of slag next to the roads. One of these samples originated from a larger industrial dumping area associated with slag processing.

2.2.3. Sediment samples

Sediment samples were collected from rivers and lake in the Rustavi area using a stainless-steel shovel or a core device, depending on site conditions. Sediment was taken from three to six points along a designated stretch of the bank or shore, pooled, and homogenized. Sediments were collected from depths of 5 to 45 cm.

In total, four sediment samples were collected. GE-RSED-1 was collected from a small artificial lake located in Rustavi Central Park, fed by the Mtkvari River and representing a standing water body potentially influenced by urban runoff. GE-RSED-2 was taken from the Mtkvari River near the road bridge connecting Old and New Rustavi. GE-RSED-3 was collected approximately 2.8 km downstream from GE-RSED-2, near former slag dumps and grazing areas. GE-RSED-4 was collected approximately 13 km further downstream from GE-RSED-2, near the village of Ilmazlo in the Marneuli district, just below the outlet of an industrial wastewater treatment plant.

2.2.4.Dust samples

Dust samples were collected from designated outdoor surfaces exposed to ambient air using a clean brush. Sampling sites (GE-RD-1 to GE-RD-5) included road surfaces and unpaved areas near industrial infrastructure, such as cement factories, metallurgical plants, and slag dumps. These locations were selected due to the likelihood of atmospheric deposition and residual industrial pollution.

2.2.5. Reference samples

To provide a background level for comparison, one soil sample (GE-UPG-1) was collected from a children's playground in the centre of Udabno village, and one dust sample (GE-UD-1) was taken from a nearby unpaved road. The site was selected due to its distance from any major anthropogenic or industrial pollution sources.

2.3. Analytical Methods

Chemical analyses were done in three specialized laboratories. Seven indicator PCB congeners, DDT and its metabolites, hexachlorocyclohexane (HCH), hexachlorobenzene (HCB), pentachlorobenzene (PeCB) and hexachlorobutadiene (HCBD), brominated flame retardants (BFRs), dechlorane plus (DP), and seven UV stabilizers were analyzed in the laboratory at the University of Chemistry and Technology, Prague, Faculty of Food and Biochemical Technology, Department of Food Analysis and Nutrition. The extraction of samples and analytical method were described elsewhere (Hloušková et al. 2014; Pulkrabova J et al. 2011). Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), dixin-like PCBs (dl-PCBs) and seven heavy metals (mercury, cadmium, lead, copper, zinc, chromium, and arsenic) were analysed in chemical laboratories of the State Veterinary Institute, Prague. DR CALUX dioxin-like activity was analysed by the BioDetection Systems (BDS) in Amsterdam, Netherlands, and PBDD/Fs in the Münster Analytical System (MAS) laboratory based in Münster, Germany.

Photo 2.6: Dust sampling from the road between cement and fero-alloys plants in Rustavi. Photo: Ondřej Petrlík

2.3.1. Persistent Organic Pollutants

Brominated flame retardants (BFRs): Three hexabromocyclododecane (HBCD) isomers[2,3] 16 polybrominated diphenyl ether (PBDE) congeners[4], and six novel BFRs[5] (nBFRs) were analyzed in the egg samples. PBDEs were isolated from the samples by Soxhlet extraction followed by gel permeation chromatography (GPC) cleanup. The analysis was performed using gas chromatography coupled with mass spectrometry and negative chemical ionisation (GC-MS-NCI). HBCD isomers were isolated by acetonitrile and analysis was conducted by ultra high-performance liquid chromatography coupled with tandem mass spectrometry with electrospray ionisation in negative mode (UHPLC-ESI-MS/MS).

Selected PCB congeners, HCBD, PeCB, HCB, DDT and its metabolites, and DP isomers were isolated from the samples by Soxhlet extraction followed by GPC cleanup. Analysis was conducted by gas chromatography coupled with tandem mass spectrometry and electron ionisation (GC-MS/MS-EI). All these analyses were conducted by the ISO/IEC 17025:2018 accredited Metrological and Testing Laboratory (University of Chemistry and Technology, Prague, Czech Republic).

Together with DP, seven indicator PCB congeners, HCBD, PeCB, and HCB, BFRs were analysed in all samples. Additionally, three pooled egg samples were also analysed by the DR CALUX® bioassay and for PBDD/Fs. Seven UV stabilizers were analysed in pooled egg samples.

2.3.2. DR CALUX Bioassay analysis

Three egg samples were sent to the Dutch ISO 17025 certified laboratory BDS performing the cell-based screening analysis DR CALUX® according to the European Standard EC/644/2017. The procedure for the BDS DR CALUX® bioassay has been described in detail by Besselink et al. (2004a).

For the method DR CALUX and the sum parameter PCDD/Fs expressed as bioanalytical equivalents (BEQ[6]; semi) and sum parameter PCDD/Fs and dl-PCBs (BEQ; semi), the method used is shake extraction with organic solvents (hexane); the extracts are cleaned on an acid silica column. The cleaned extracts are dissolved in DMSO. The DR CALUX activity is determined (24h exposure). The response of the sample is corrected for the background and subsequently corrected for the apparent bioassay recovery with a reference sample at the level of interest. The evaluation is done on the maximum levels for PCDD/Fs and for the sum of PCDD/Fs and dl-PCBs, from which cut off values have been established (2/3 of maximum levels). After the evaluation, an estimation is given of the samples in the form of BEQ outcomes.

2.3.3. Heavy metals

The analysis of heavy metals in the samples was carried out using standardized procedures of the State Veterinary Institute in Prague. Mercury was determined using atomic absorption spectrometry with an automated mercury analyzer (AAS-AMA, SOP 70.4). Zinc was measured by flame atomic absorption spectrometry (AAS, SOP 70.2). The remaining elements—lead, cadmium, copper, chromium, zinc, and arsenic—were analyzed using inductively coupled plasma mass spectrometry (ICP-MS, SOP 70.75). Each measurement method follows internal standard operating procedures (SOPs) to ensure accuracy and reliability. Measurement uncertainties are expressed as expanded uncertainties with a coverage factor k=2, corresponding to a 95% confidence level.

2 An isomer is each of two or more compounds with the same formula but a different arrangement of atoms in the molecule and different properties.
3 α-, β- and γ-HBCD
4 PBDE 28, 47, 49, 66, 85, 99, 100, 153, 154, 183, 196, 197, 203, 206, 207 and 209
5 This group of chemicals is represented by the following chemicals: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBBz), octabromo-1,3,3-trimethylpheny-1-indan (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT).
6 A bioanalytical equivalent (BEQ) is a unit of measure in the field of bioassays.

3. PERSISTENT ORGANIC POLLUTANTS (POPS) IN SAMPLES FROM RUSTAVI HOT SPOTS

3.1. Introduction, Sampling and Analyses

A total of 41 environmental and food samples were collected in the Rustavi area for POPs analysis. These included 2 samples of waste slag, 7 soil samples from children's playgrounds, 4 soil samples from other locations, 5 outdoor dust samples, 3 sediment samples from the Mtkvari River, and 1 sediment sample from a pond in a public park in Rustavi. In addition, 7 samples of free-range chicken eggs and 12 fish samples were collected.

As reference samples, one soil sample near a playground and one dust sample from rural roads were collected in the village of Udabno. For comparison with the egg samples, one pooled sample of supermarket eggs from Rustavi was also included.

As already noted in Chapter 2, Sampling and Analyses, most of the samples were composite—composed of multiple subsamples or, in the case of eggs and fish, of several specimens of the same species and approximately the same age, professionally homogenized either directly in the field or in chemical laboratories (for eggs and fish).

The results of the analyses for soil, slag, and dust are presented in Tables 3.1–3.3 of this chapter; for eggs in Tables 4.1 and 4.2 in Chapter 4; and for fish in Table 5.1 in Chapter 5. The discussion of results for eggs and fish is provided in the dedicated Chapters 4 (eggs) and 5 (fish). This chapter therefore focuses primarily on the results of POPs analyses in waste (slag), soil, and dust.

The analytical laboratory procedures are described in Subchapter 2.3 Analytical Methods.

3.2. Results

Analytical results for POPs in soil, dust, and waste samples from the Rustavi area, compared with reference samples of dust and soil from the village of Udabno, are summarized in Tables 3.1–3.3. The results are discussed by sample type, as soils from children's playgrounds represent a specific case, and dust is a different matrix than soil.

TABLE 3.1: POPS IN SAMPLES OF SLAG AND SOIL FROM RUSTAVI AND TAZAKENDI, APPART FROM PLAYGROUNDS. Levels are in ng/g dry matter (dm).

Sample ID	GE-RW-1	GE-RW-2	GE-RS-1	GE-RS-2	GE-RS-3	GE-RS-4
Location	Roadside slag heap	Slag heap withiin larger slag processing site	Area between metallurgi-cal facilities	Adjacent to apartment building with backyard poultry	Near the cement kiln	At the edge of Tazakendi
Sample type	slag	slag	soil	soil	soil	soil
Dry weight	100%	100%	100%	100%	100%	100%
7 PCB	9.4	45	459	11.3	9.2	510
6 PCB	7.1	43	345.18	8.83	6.8	500
PeCB	0.09	2.31	0.89	0.42	0.23	0.25
HCB	0.06	0.59	0.37	0.46	0.13	0.18
HCBD	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Σ HCH	0.13	0.16	0.89	1.94	0.14	0.58
Σ DDT	0.91	1.5	7.6	235	1.2	3.3
p.p'-DDT/p.p'-DDE	0.75	0.03	0.04	3.47	0.38	0.36

3.2.1. POPs in soil

This section presents the results of POPs analyses in soil and slag samples collected from various urban and peri-urban locations in Rustavi and the nearby village of Tazakendi. These sites were selected to represent a mix of industrial, residential, and mixed-use environments. The aim was to assess background and hotspot contamination levels outside of playgrounds, with attention to the influence of nearby metallurgical and cement industries.

Soil samples collected from various locations in Rustavi demonstrated highly variable but, in some cases, extremely elevated levels of POPs, particularly polychlorinated biphenyls (PCBs). The highest concentrations of ∑7PCBs were found in Tazakendi village (GE-RS-4; 510 ng/g dm) and in the area between metallurgical plants (GE-RS-1; 459 ng/g dm). These values are exceptionally high and comparable to those found at historically contaminated industrial sites in other countries.

By contrast, samples from residential zones (GE-RS-2 and GE-RS-3) showed significantly lower but still notable PCB levels (11.3 and 9.2 ng/g, respectively), suggesting background contamination even outside the immediate industrial areas.

Levels of DDT and its metabolites were highest in the soil near a residential building with backyard poultry (GE-RS-2), reaching 235 ng/g.[7] The p,p'-DDT/p,p'-DDE ratio in this sample was 3.47, strongly suggesting recent or ongoing use or release of technical DDT, which is unexpected given its banned status. Other sites showed much lower DDT levels (1.2–7.6 ng/g) and ratios below 0.5 (ATSDR 2022; US EPA 2008a; Woldetsadik et al. 2021), consistent with older residues.

7 See also free-range chicken eggs sample GE-R-EGG-4 which had very high level of DDT and metabolites of 7,120 ng/g fat (Chapter 4).

PeCB, HCB, and HCHs were detected in all samples, though at relatively low concentrations, whereas HCBD was below the limits of quantification (LOQs).

The two analyzed slag samples did not contain high levels of POPs. Only the concentration of 7 PCB congeners—45 ng/g dm—can be considered elevated when compared to the reference soil sample. However, concentrations one order of magnitude higher were observed in two soil samples (GE-RS-4 and GE-RS-1).

These findings highlight the substantial legacy—and possibly ongoing—inputs of hazardous POPs into urban and peri-urban soils of Rustavi. In the case of PCBs, the primary sources are likely the metallurgical and cement industrial facilities. The elevated PCB levels in samples GE-RS-1 and GE-RS-4, as well as the high DDT concentration in sample GE-RS-2, raise significant concerns about long-term environmental health and potential human exposure, particularly for individuals living or working in the affected areas.

3.2.2. POPs in soil from children playgrounds

The following section focuses on soil contamination at children's playgrounds in Rustavi, a critical exposure setting due to the vulnerability of the target population. The samples were collected from various playgrounds across the city and compared with a reference site from the rural village of Udabno. Special attention is given to DDTs and PCBs, both due to their high concentrations and their known adverse effects on child health.

Soil samples collected from playgrounds in Rustavi revealed elevated concentrations of several POPs, particularly DDT and PCBs, compared to the reference sample from Udabno village (GE-UPG-1), which serves as a background level for Georgia. The most contaminated sites—GE-RPG-1, GE-RPG-2, and GE-RPG-3—contained ∑DDT concentrations exceeding the reference level (0.31 ng/g dm) by more than 1,000 to 3,500 times. The p,p'-DDT/p,p'-DDE ratio in the reference sample was 0.17, consistent with historical contamination, whereas values above 0.5 (ATSDR 2022; US EPA 2008a; Woldetsadik et al. 2021) in several playground samples—particularly 0.86 in GE-RPG-1—suggest recent or ongoing DDT inputs.

PCBs were also detected at significantly elevated levels. While the reference sample had PCB levels below the LOQ (<0.02 ng/g dm), GE-RPG-2 contained 24.3 ng/g, GE-RPG-4 10.4 ng/g, and GE-RPG-3 4.97 ng/g of ∑7PCBs. Even the sample GE-RPG-5, which was not among the most contaminated overall, contained 3.62 ng/g—more than 180 times the LOQ. These values confirm a significant local source of contamination, likely linked to legacy or recent industrial activity or the use of contaminated fill material. PCBs were historically used in electrical transformers in Georgia (Government of Georgia 2018), which may be one such source.

TABLE 3.2: POPS IN SAMPLES OF SOIL FROM RUSTAVI'S PLAYGROUNDS (GE-RPG-1 – GE-RPG-6B) AND REFERENCE SITE IN UDABNO VILLAGE (GE-UPG-1). Levels are in ng/g dm. All samples had 100% od dry weight.

Sample ID	GE-RPG-1	GE-RPG-2	GE-RPG-3	GE-RPG-4	GE-RPG-5	GE-RPG-6A	GE-RPG-6B	GE-UPG-1
7 PCB	1.97	24.3	4.97	10.4	3.62	0.44	1.82	<0.02
PeCB	0.33	0.79	0.25	0.37	0.13	0.03	0.10	<0.02
HCB	0.31	0.22	0.15	0.28	0.48	0.08	0.13	0.02
HCBD	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Σ HCH	3.98	2.55	4.17	3.44	0.48	0.12	0.31	0.06
Σ DDT	1,087	280	776	265	340	3.85	9.67	0.31
p.p'-DDT/p.p'-DDE	0.86	0.28	0.46	0.65	0.49	NA	NA	0.17

HCHs were detected at levels up to 4.17 ng/g (GE-RPG-3), compared to 0.06 ng/g in the reference sample. Although HCH concentrations were markedly higher in some sites, they were lower than levels of DDTs or PCBs and are therefore of comparatively lower concern, though they still indicate some level of contamination.

These findings raise concerns due to the presence of vulnerable populations at these sites. Young children are particularly at risk because of frequent hand-to-mouth activity and higher intake of contaminants relative to their body weight. For example, soil from GE-RPG-1 contained 1,087 ng/g of ∑DDT and 1.97 ng/g of ∑7PCBs.

Although some studies have used higher soil ingestion rates to estimate children's exposure (ATSDR 2001; Calabrese et al. 1997; Petrlik et al. 2015a), Moya and Phillips (2014), in a detailed meta-review, reported values ranging from 400 to 41,000 mg/day. A conservative estimate of 100 mg/day, as recommended by the US EPA (2008b) and von Lindern et al. (2016), is used here as a baseline. In addition, we also consider the lower bound of Moya and Phillips (2014) range (400 mg/day) and the older ATSDR estimate of 1,000 mg/day (ATSDR 2001) for young children, which reflects possible pica-like behavior.

Based on three ingestion scenarios, the estimated daily intake of DDTs and PCBs varies depending on the amount of soil ingested. At an ingestion rate of 100 mg/day, the daily intake is estimated at 108.7 ng/day for DDTs and 0.197 ng/day for PCBs. For an ingestion rate of 400 mg/day, the corresponding daily intake increases to 434.8 ng/day of DDTs and 0.788 ng/day of PCBs. At the highest ingestion rate of 1,000 mg/day, which corresponds to the ATSDR estimate, the daily intake reaches 1,087 ng/day of DDTs and 1.97 ng/day of PCBs. For a child weighing 15 kg, these values translate to 7.25, 29.0, and 72.5 ng/kg bw/day of DDTs and 0.013, 0.053, and 0.131 ng/kg bw/day of PCBs for the respective ingestion scenarios.

Although no current tolerable daily intake (TDI) for DDT is defined by the EFSA, older WHO values suggested 10 µg/kg bw/day, but these are now outdated. In Australia, the TDI for DDT is set at 2 µg/kg bw/day (Australian Government 2011). Under the ATSDR scenario (1,000 mg/day), the estimated DDT intake would reach 0.0725 µg/kg bw/day, or about 3.6 % of the Australian TDI.

While these intake levels do not exceed existing guidance values, the potential for repeated daily exposure—combined with the cumulative and long-term toxicity of

TABLE 3.3: POPS IN SAMPLES OF DUST FROM RUSTAVI (GE-RD-1 – GE-RD-5) AND REFERENCE SITE IN UDABNO VILLAGE (GE-UD-1). Levels are in ng/g dm; all samples of dust had 100% dry weight.

Sample ID	GE-RD-1	GE-RD-2	GE-RD-3	GE-RD-4	GE-RD-5	GE-UD-1
Locality	Between metallurgical plants	Residential area with panel housing	By the slag storage	By the slag storage	Near ferro- alloy plant	Reference site in distant village Udabno
7 PCB	98	4.1	1.8	2.1	25	<0.02
PeCB	1.35	0.39	0.40	0.32	3.75	0.03
HCB	0.80	0.84	0.17	0.12	6.80	0.08
HCBD	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Σ HCH	0.67	0.12	0.13	0.06	0.08	0.10
Σ DDT	8.29	0.51	1.50	<0.02	1.27	0.11
p,p'-DDT/p,p'-DDE	0.30	0.69	0.15	NA	0.77	NA

these compounds, including neurodevelopmental effects, endocrine disruption, and possible carcinogenicity—warrants further investigation.

The results strongly support the need for site-specific risk assessment and consideration of remedial actions, particularly at the most contaminated locations.

3.2.3. POPs in outdoor dust

This section examines the presence of POPs in outdoor dust, an important but often overlooked environmental medium that can serve as a significant exposure route in urban and industrial areas. Samples were collected from different types of locations in Rustavi—including residential areas, industrial zones, and roadways—and compared with a reference dust sample from the village of Udabno. The aim is to evaluate the spatial distribution and possible sources of contamination in surface particles.

TABLE 3.4: POPS IN SEDIMENT SAMPLES FROM MTKVARI RIVER (2–4) AND PARK LAKE (1) IN RUSTAVI. Levels are in ng/g dm.

Sample ID	GE-RSED-1	GE-RSED-2	GE-RSED-3	GE-RSED-4
	Lake	Mtkvari River		
	Park Lake	Point near the Park Lake	Near Rustavi Forest	Downstream from Waste Water Treatment Plant (WWTP)
Dry weight	15%	74%	77%	65%
7 PCB	2.95	0.41	0.38	1.22
6 PCB	2.31	0.35	0.34	0.97
PeCB	0.15	0.03	0.03	0.08
HCB	0.29	0.08	0.07	0.35
HCBD	<0.02	<0.02	<0.02	<0.02
Σ HCH	0.49	0.38	0.20	0.30
Σ DDT	31.07	11.48	3.35	1.96
p.p‘-DDT/p.p‘-DDE	0.09	0.50	0.71	0.59

Outdoor dust samples collected in Rustavi revealed significant localised contamination with PCBs and other POPs, particularly in areas near industrial facilities. The most contaminated dust sample (GE-RD-1), taken from a location between two metallurgical plants, contained nearly 98 ng/g dm of ∑7PCBs, a value more than 4,800 times higher than the reference sample from the village of Udabno, where PCBs were below LOQ. Elevated levels were also found near the ferroalloy facility (GE-RD-5), with ∑7PCBs at 25 ng/g dm.

HCB was also present in concentrations as high as 6.80 ng/g dm in GE-RD-5—over 80 times higher than in the reference site—indicating strong industrial influence. The presence of PeCB in all urban samples, with the highest concentration again at the ferroalloy site (3.75 ng/g dm), further supports this conclusion.

While DDT levels in dust were generally lower than in soil, sample GE-RD-1 (8.29 ng/g dm) still showed substantial contamination. The p,p’-DDT/p,p’-DDE ratio in two samples exceeded 0.5 (0.69 in GE-RD-2 and 0.77 in GE-RD-5), suggesting either recent or ongoing sources of DDT input (ATSDR 2022; US EPA 2008a; Woldetsadik et al. 2021) in the town area.

Overall, the results show that airborne particles and road dust represent an additional exposure route for residents, particularly children who might play or move near dusty roads and unpaved areas. The concentrations observed—especially of PCBs—indicate a clear link to industrial activities and point to a need for risk assessment and pollution control, including dust suppression, urban greening, and possibly access restrictions in the most polluted zones.

3.2.4. POPs in sediments

The final part of this chapter presents results from sediment samples collected in Rustavi’s aquatic environments, including the Mtkvari River and a park lake. These samples provide insight into historical and ongoing contamination patterns, as sediments act as both sinks and secondary sources of POPs. Differences between lake and river sediments, as well as upstream and downstream locations, help identify potential point sources and assess broader environmental trends.

Sediment samples collected from the Mtkvari River and Park Lake in Rustavi revealed notable differences in the levels of POPs. The highest concentrations were consistently found in the lake sediment sample (GE-RSED-1), particularly for ∑DDT (31.07 ng/g dm), ∑HCH (0.49 ng/g dm), and ∑7PCBs (2.95 ng/g dm). These levels were several times higher than those measured at riverine locations.

Among river sites, POP concentrations generally decreased in sample further from the lake GE-RSED-3. Interestingly, the sample collected downstream from the WWTP (GE-RSED-4) showed slightly elevated levels of PCBs and HCB compared to upstream samples, suggesting a potential local source.

The ratio of p,p'-DDT to p,p'-DDE was lowest in the lake sediment (0.09), indicating historical use and advanced degradation of DDT, while higher ratios in river sediments (up to 0.71 in GE-RSED-3) may suggest more recent or ongoing inputs (ATSDR 2022; US EPA 2008a; Woldetsadik et al. 2021).

4. POPS IN FREE RANGE CHICKEN EGGS FROM RUSTAVI AND TAZAKENDI VILLAGE

4.1. Sampling and Analyses

Seven pooled samples of free-range chicken eggs were collected from three locations in Tazakendi village, and from four locations in Rustavi. One reference sample was purchased from a supermarket in Rustavi as suggested in some previous studies (DiGangi and Petrlik 2005; Dvorská 2015; Dvorska et al. 2009). The number of individual eggs in each pooled sample ranged from 2 to 5 in this study (see Table 4.1).

All samples were analyzed for their content of individual PCDD/Fs and dl PCBs using GC/HRMS, and following the methods prescribed for controlling levels of these substances in foodstuffs according to EU regulations (European Commission 2012). The results are presented in pg WHO-TEQ per gram of fat. Toxic equivalency factors (TEFs) defined in 2005 (van den Berg et al. 2006) were used to evaluate dioxin toxicity in all samples. Three samples were also analysed for PBDD/Fs in the MAS laboratory in Germany and for dioxin-like activity by DR CALUX bioassay in Bio Detection Systems, Amsterdam, Netherlands.

The analyses of 16 PBDEs congeners, 3 HBCD isomers, 6 nBFRs, two stereoisomers of DP, DDT and its metabolites, 3 HCH setereoisomers, PeCB, HCB, HCBD, and ndl PCBs were conducted in a Czech certified laboratory in the Department of Food Chemistry and Analysis of the University of Chemistry and Technology in Prague.

All analytical methods are described in Chapter 2.3 of this publication.

4.2. Results

The results of the chemical analyses for the pooled samples of free-range chicken eggs are summarised in Table 4.1. Table 4.2 compares the measured levels in eggs with EU limits as they are set in the EU regulations (European Commission 2023; European Parliament and Council 2025).

TABLE 4.1: RESULTS OF THE POPS ANALYSES IN POOLED FREE-RANGE CHICKEN EGG SAMPLES FROM TAZAKENDI VILLAGE AND RUSTAVI IN COMPARISON WITH REFERENCE SAMPLE, COMMERCIAL EGGS BOUGHT IN SUPERMARKET IN RUSTAVI, AND WITH TWO FREE RANGE CHICKEN EGG SAMPLES FROM UKRAINE (DNIPRO-PRYDNIPROVSK) AND BELARUS (GATOVO).

	Locality	Tazakendi	Tazakendi	Tazakendi	Rustavi	Rustavi	Rustavi	Rustavi	Rustavi	Dnipro - Prydniprovsk	Gatovo
	Sample ID Units	GE-R-EGG-1	GE-R-EGG-2	GE-R-EGG-3	GE-R-EGG-4	GE-R-EGG-5	GE-R-EGG-6	GE-R-EGG-7	GE-R-EGG-SUP	L-48-EGG	LN 272/14
Eggs in sample	Number	3	2	4	3	5	3	3	4	2	4
Fat content	%	9.39	9.09	9.17	10.88	9.76	6.63	10.99	8.17	9.52	15.4
PCDD/Fs	pg TEQ/g fat	3.7	2.5	1.4	1.7	1.7	7.4	4.4	0.216	5.8	4.3
dl-PCBs		15.2	10	10.9	5	11.5	28.3	8.9	0.027	8.3	11.3
PCDD/F/dl-PCBs		18.9	12.5	12.3	6.7	13.2	35.7	13.3	0.24	14.1	15.6
PBDD/Fs		<1.1	11.3	NA	NA	NA	<1.1	NA	NA	NA	< LOQ
DR CALUX	pg BEQ/g fat	25	22	NA	NA	NA	29	NA	NA	NA	8.1
PeCB	ng/g fat	0.30	0.17	0.41	0.31	0.73	0.45	<0.1	<0.1	NA	NA
HCB		1.43	0.99	1.21	0.77	1.56	1.65	<0.1	<0.1	NA	2.9
HCBD		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA	NA
7 PCBs		58	31	29	117	51	138	16	6	NA	66
6 PCBs		37	20	18	107	33	102	11	5.7	NA	53
Σ of HCH		9.6	6.1	61	20	10	23	1.6	<0.1	NA	5
Σ of DDT		62	87	279	7,120	375	672	15	2.2	NA	231
Σ of HBCD		669	<4.2	5.2	<4.2	<4.2	<4.2	10	<4.2	NA	NA
Σ of PBDEs		< LOQ	1,231	3.7	0.11	< LOQ	114	< LOQ	< LOQ	NA	NA
decaBDE		<1.5	1,181	3.7	<1.5	<1.5	5	<1.5	<1.5	NA	NA
Σ of nBFRs		< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	NA	NA
Σ of DP		<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	NA	NA
p,p'-DDT/p,p'-DDE		0.30	0.37	0.96	0.95	0.55	0.43	0.24	0.78	NA	0.85
7 UV stabilizers	ng/g fw	0.49	0.71	0.59	<0.01	5.67	0.32	1.04	<0.01	NA	NA

TABLE 4.2: COMPARISON OF POPS IN EGGS WITH EU LIMITS FOR FOOD STUFF (EUROPEAN COMMISSION 2023; EUROPEAN PARLIAMENT AND COUNCIL 2025).
Limits for PCDD/Fs, dl-PCBs, and ndl-PCBs are set per g fat, while for DDT, HCH and HCB residues per g fresh weight (g fw).

	Locality	Tazakendi			Rustavi					Dnipro - Prydniprovsk	Gatovo	
	Sample ID (eggs) / Units	GE-R-EGG-1	GE-R-EGG-2	GE-R-EGG-3	GE-R-EGG-4	GE-R-EGG-5	GE-R-EGG-6	GE-R-EGG-7	GE-R-EGG-SUP	L-48-EGG	LN 272/14	EU Limits
PCDD/Fs	pg TEQ/g fat	3.7	2.5	1.4	1.7	1.7	7.4	4.4	0.216	5.8	4.3	2.5
PCDD/F/ dl-PCBs	pg TEQ/g fat	18.9	12.5	12.3	6.7	13.2	35.7	13.3	0.24	14.1	15.6	5
ndl-PCBs (6 PCBs)	ng/g fat	37	20	18	107	33	102	11	5.7	NA	53	40
∑ of DDT	ng/g fw	5.8	7.9	25.5	774	37	45	1.6	0.18	NA	36	50
alfa HCH	ng/g fw	0.04	0.01	0.07	0.18	0.07	0.07	<0.01	<0.01	NA	<0.01	20
beta HCH	ng/g fw	0.83	0.54	5.51	1.95	0.92	1.33	0.17	<0.01	NA	0.56	10
gama HCH	ng/g fw	0.03	<0.01	0.02	0.07	0.03	0.13	<0.01	<0.01	NA	0.2	10
HCB	ng/g fw	0.13	0.09	0.11	0.08	0.15	0.11	<0.01	<0.01	NA	0.44	20

4.3. Discussion

This study analysed POPs in pooled samples of free-range chicken eggs collected from the village of Tazakendi and urban Rustavi, comparing them with the reference sample of commercial eggs purchased in a Rustavi supermarket and with samples of free-range chicken eggs from the Ukraine (Dnipro-Prydniprovsk) and Belarus (Gatovo). Concentrations are reported on a fat weight basis (ng or pg per gram of fat).

4.3.1. PCDD/Fs, PCBs and PBDD/Fs

The levels of PCDD/Fs and dl-PCBs, expressed as WHO toxic equivalents (WHO-TEQ) set in 2005 (van den Berg et al. 2006), varied considerably among samples. Most samples from Rustavi showed elevated levels of the six PCB congeners that are included in the regulatory limits for non-dioxin-like PCBs (ndl-PCBs), reaching up to 107 ng/g fat, while dl-PCBs reached up to 28.3 pg WHO-TEQ/g fat. The EU limit for ndl-PCBs, set at 40 ng/g fat (European Commission 2023), was exceeded in three samples: GE-R-EGG-4, GE-R-EGG-6, and the sample from Gatovo.

As shown in Table 4.1 and Figure 4.1, dl-PCBs dominated the total WHO-TEQ values in all free-range egg samples from Rustavi, contributing between 67% and 89% of the total dioxin-like toxicity. A similar pattern was observed in egg samples from Gatovo and Prydniprovsk. This dominance of dl-PCBs was also found in eggs collected near metallurgical facilities in other locations (Grechko et al. 2021a; Petrlik et al. 2022a; Petrlik and Strakova 2018; Squadrone et al. 2015). The only exception was the supermarket egg sample from Rustavi, where PCDD/Fs were the dominant contributors to WHO-TEQ. These percent-

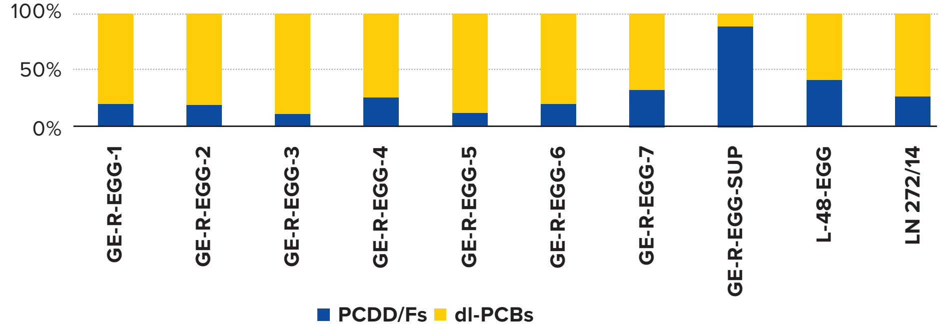

Figure 4.1: Contribution of PCDD/Fs and dl-PCBs to total WHO-TEQ in egg samples.

ages represent only the proportion of PCDD/Fs to PCBs in the overall profile and do not reflect the total concentration of these compounds. This relatively high percentage in the supermarket egg sample is due to its low total contaminant concentration, where even a small absolute amount of PCDD/Fs accounts for a large proportion compared to dl-PCBs.

The congener pattern of dl-PCBs was similar across all egg samples (see Figure 4.2) and corresponds to the profile of technical PCB mixtures, strongly suggesting these as the primary source of contamination. Nevertheless, secondary sources such as the processing of PCB-contaminated metal waste in metallurgical operations may also contribute (Petrlik et al. 2022a). In this regard, Rustavi appears similar to Alaverdi, Armenia (Grechko et al. 2021a; Petrlik and Strakova 2018).

The dl-PCB concentration of 28.3 pg WHO-TEQ/g fat detected in sample GE-R-EGG-6 is comparable to values reported in eggs from other highly contaminated industrial sites, such as Alaverdi, Armenia (26 pg WHO-TEQ/g fat); (Grechko et al. 2021a; Grechko et al. 2021b) and Rostovka, near the metallurgical hub of Temirtau in Kazakhstan (26.5 pg WHO-TEQ/g fat); (Petrlik et al. 2016; Šír et al. 2015). It is slightly lower than the 30 pg WHO-TEQ/g fat found in eggs from the heavily industrialized Piedmont region of Italy (Squadrone et al. 2015).

The levels of ndl-PCBs (6 congeners) at 107 and 102 ng/g fat in Rustavi egg samples are lower than those found near the old municipal waste incinerator in Maincy, France (111, 120, and 141 ng/g fat); (Pirard et al. 2004) or near a tyre pyrolysis plant in Vatra, in eggs from Ciobanovca, Moldova (144 ng/g fat); (Petrlik et al. 2021b; Petrlik et al. 2022b).

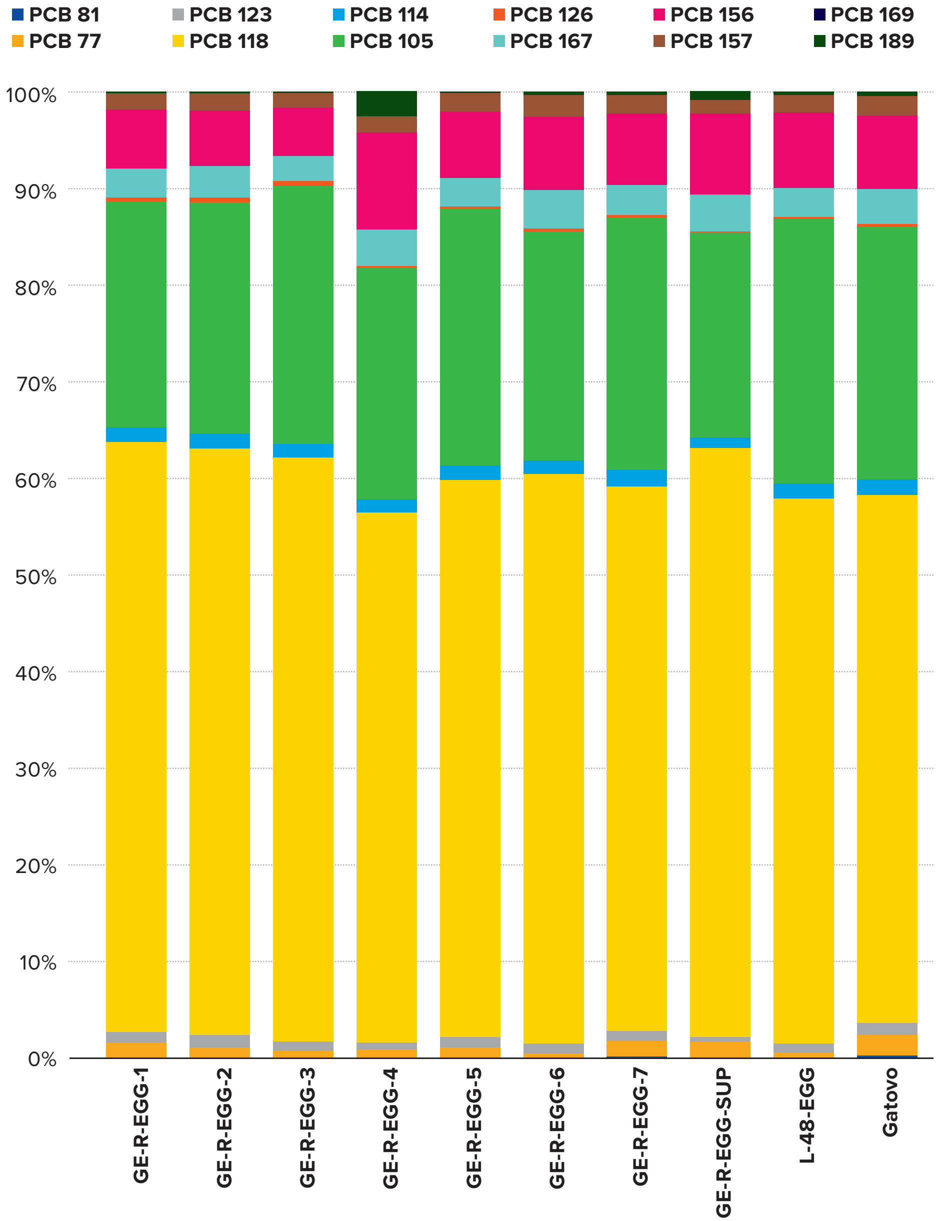

Figure 4.2: dl-PCB congener profile in chicken egg samples.

However, they exceed the maximum levels reported during the 2014–2015 waste fire crisis in Naples, Italy (Lambiase et al. 2017).

The highest combined PCDD/F and dl-PCB level was found in sample GE-R-EGG-6 (35.7 pg WHO-TEQ/g fat), collected at a location in Rustavi that lies directly in the wind corridor between the metallurgical plants to the northwest and southeast. This value exceeds the EU maximum limit for eggs (5 pg WHO-TEQ/g fat); (European Commission 2023) by more than seven times, indicating a severe contamination concern. It is also more than twice the levels detected in samples from Gatovo (Belarus) and Prydniprovsk (Ukraine)—both collected in industrialized areas, with the latter potentially affected by the ongoing military conflict.

Levels in GE-R-EGG-1, 2, 3, 5, and 7 were comparable to those in Gatovo and Prydniprovsk, but still exceeded the EU limit. Sample GE-R-EGG-1 had a PCDD/Fs/dl-PCBs concentration of 18.9 pg WHO-TEQ/g fat, exceeding the EU maximum level by more than threefold. In the other four samples, levels ranged between 12.3 and 13.3 pg/g fat, approximately two to three times above the limit. Even sample GE-R-EGG-4, with 6.7 pg/g fat, slightly exceeded the EU limit. Notably, in this sample—as in GE-R-EGG-2 and GE-R-EGG-3—PCDD/Fs were below the EU limit, and the exceedance was driven primarily by dl-PCBs.

In contrast, the supermarket egg sample (GE-R-EGG-SUP) showed lower levels of both PCDD/Fs and dl-PCBs, remaining within EU limits.

Dioxin-like PCBs were consistently elevated in all free-range egg samples, including those from Prydniprovsk and Gatovo, confirming widespread environmental contamination by PCBs in industrial areas across post-Soviet countries—particularly in proximity to metallurgical operations (Grechko et al. 2021a; Petrlik et al. 2019b; Petrlik et al. 2017; Petrlik et al. 2018; Šír et al. 2015). PCBs were widely used in electrical transformers in Georgia (Government of Georgia 2018).

The PBDD/F level of 11.3 pg WHO-TEQ/g fat found in sample GE-R-EGG-2 ranks among the highest globally measured in poultry eggs—it is currently the ninth highest reported. This value slightly exceeds the 10.8 pg WHO-TEQ/g fat found in eggs near the Ngara Market e-waste site in Nairobi (Ochieng Ochola et al. 2023) and is just below the 12.8 pg WHO-TEQ/g fat measured in Karawang, Indonesia (Ismawati et al. 2024), where lime kilns burn plastic waste.

Much higher concentrations have been recorded at known open plastic burning sites such as Agbogbloshie (503 pg WHO-TEQ/g fat) and in Kalasin province, Thailand (30 and 81 pg WHO-TEQ/g fat); (Dvorska et al. 2023a). However, the PBDD/F concentration in the Tazakendi sample exceeded values recorded near dumpsites in Nanyuki, Kenya and Pugu Kinyamwezi, Tanzania, where levels ranged from 4 to 5 pg WHO-TEQ/g fat (Teebthaisong et al. 2021).[8]

In sample GE-R-EGG-2, PBDD/Fs contributed to nearly half of the total dioxin-like toxicity. The combined concentration of PCDD/Fs, dl-PCBs, and PBDD/Fs was closely aligned with the DR CALUX bioassay result of 22 pg BEQ/g fat, demonstrating the relevance of bioassays such as DR CALUX for assessing dioxin-like contamination in biological samples.

PBDD/F levels in two other analysed egg samples (GE-R-EGG-1 and GE-R-EGG-6) were below LOQs (<1.1 pg WHO-TEQ/g fat).

4.3.2.DDT and other POPs pesticides

Regarding legacy pesticides, the levels of ∑DDTs in eggs from Rustavi were alarmingly high (see graph in Figure 4.3), particularly in sample GE-R-EGG-4, which contained 7,120 ng/g fat and 774 ng/g fresh weight, exceeding the EU maximum residue limit (MRL) of 50 ng/g fw (European Parliament and Council 2025) by more than an order of magnitude. These concentrations suggest either recent or ongoing inputs of DDT. The p,p'-DDT to p,p'-DDE ratio, a commonly used indicator of degradation or recent use, was at or above 0.5 in several samples, further supporting the hypothesis of relatively fresh contamination (Dvorska et al. 2009; US EPA 2008a; Woldetsadik et al. 2021).

High ∑DDT levels were also detected in three additional egg samples from Rustavi (GE-R-EGG-3, GE-R-EGG-5, and GE-R-EGG-6) and in the sample from Gatovo, indicating a broader pattern of DDT contamination across post-Soviet countries (Dvorská et al. 2011; Dvorská et al. 2012; Jelinek et al. 2024; Moklyachuk et al. 2014; Petrlik et al. 2015b; Šír et al. 2015). However, the contamination in GE-R-EGG-4 is exceptionally

8 PBDD/F levels reported in this study were calculated using ½ LOQ for congeners below the limit of quantification, and may therefore differ from previously published data.

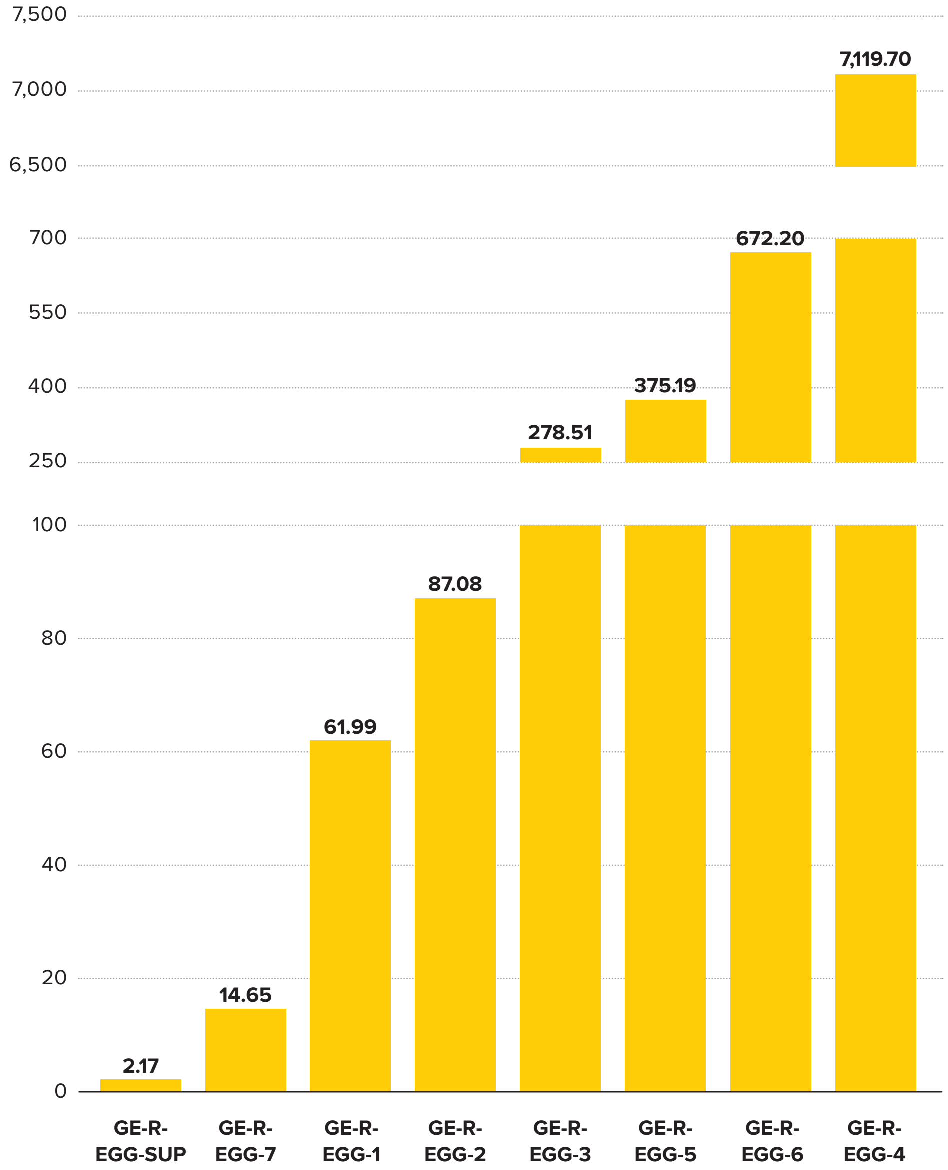

Figure 4.3: ∑DDT levels measured in egg samples from Rustavi and Tazakendi (in ng/g fat).

high and comparable to levels found near obsolete DDT stockpiles, such as in Echmiadzin, Armenia, where egg samples exceeded 5,500 ng/g fat (Dvorská et al. 2011). It is also nearly identical to the concentration found in eggs from Vikuge, Tanzania in 2004 (7,041 ng/g fat), one of the most highly DDT-contaminated sites in the world (Dvorska et al. 2009; Mng'anya et al. 2005; Petrlik et al. 2025b).

The concentration of ∑DDT in GE-R-EGG-4 is approximately three times higher than the levels measured in eggs from chickens roaming in the yard of a former pesticide warehouse and formulation facility in Klatovy–Luby, Czech Republic, where concentrations were around 2,000 ng/g fat (Dvorská et al. 2007).

Other POPs pesticides, such as hexachlorobenzene (HCB) and hexachlorobutadiene (HCBD), are sometimes included in this group due to their persistence and toxicity. In this study, HCBD was not detected in any egg samples, and HCB was present only at low concentrations.

Hexachlorocyclohexane (HCH) isomers were also detected, generally at low levels and well below EU limits—except for sample GE-R-EGG-3 from Tazakendi village, where the β-HCH isomer reached half of the EU limit. This same sample also showed the highest ∑DDT concentration among the three samples from Tazakendi: 279 ng/g fat, or 25 ng/g fresh weight, respectively.

4.3.3. Brominated Flame Retardants

Notably, brominated flame retardants such as HBCD and PBDEs were mostly below LOQ levels or detected at low levels in most samples, with two exceptions: sample GE-R-EGG-2 showed a very high concentration of PBDEs (1,231 ng/g fat), and sample GE-R-EGG-1 contained a very high level of HBCD (669 ng/g fat), indicating possible localized contamination. Photographs taken during sampling suggest a potential source of PBDE contamination in the case of GE-R-EGG-2: an old mattress was visibly present in the chicken run, which may explain the elevated PBDE levels, as these substances were commonly used as flame retardants in mattresses (Boor et al. 2015; Dodson et al. 2012; Thomas and Brundage 2006).

The PBDE concentration in GE-R-EGG-2 ranks as the 11^{th} highest ever reported in free-range egg samples globally (see Figure 4.4 and Table 4.3). It is slightly lower than levels found in eggs from the e-waste scrapyard in Agbogbloshie, Ghana (Petrlik et al. 2019a),

TABLE 4.3: HIGHEST LEVELS OF PBDES MEASURED IN FREE RANGE POULTRY EGGS GLOBALLY.		
Country, (year)	Total PBDEs in ng/g fat	Source of information
Kazakhstan, Balkhash - Rembaza (2014)	235	(Petrlik et al. 2017)
Nigeria, Abuja (2016)	303	(Oloruntoba et al. 2019)
Indonesia, Tangerang (SEM-E-1), (2019)	321	(Petrlik et al. 2020)
Tanzania, Kwamrefu (2012)	347	(Polder et al. 2016)
Thailand, Samut Sakhon (2016)	427	(Petrlik et al. 2017)
Kenya, Nairobi - hospital (2024)	431	(Petrlik et al. 2025a)
China, Wenling (2011)	564	(Qin et al. 2011)
Kenya, Nairobi - Dandora (2021)	639	(Ochieng Ochola et al. 2023)
Thailand, Phuket (2022)	850	(Saetang et al. 2024)
China, Wenling - duck eggs (2011)	982	(Labunska et al. 2013)
China, Wuhan (2014)	1,054	(Petrlik 2016)
Georgia, Tazakendi (GE-R-EGG2), (2024)	1,231	This report
Ghana, Agbogbloshie (2018)	1,258	(Petrlik et al. 2019a)
Indonesia, Bangun (2019)	1,457	(Petrlik et al. 2020)
China, Taizhou (2011)	1,778	(Labunska et al. 2013)
China, Taizhou (2012-2013)	3,620	(Labunska et al. 2014)
China, Quingyuan, Guangdong (2013)	4,736	(Huang et al. 2018)
China, Quingyuan, Guangdong (2016)	4,741	(Huang et al. 2018)
China, Guiyu - goose eggs (2013)	7,500	(Zeng et al. 2016)
China, Quingyuan, Guangdong (2010)	14,100	(Zheng et al. 2012)
Indonesia, Tropodo (2019)	27,159	(Petrlik et al. 2021a)
China, Guiyu (2013)	46,000	(Zeng et al. 2016)

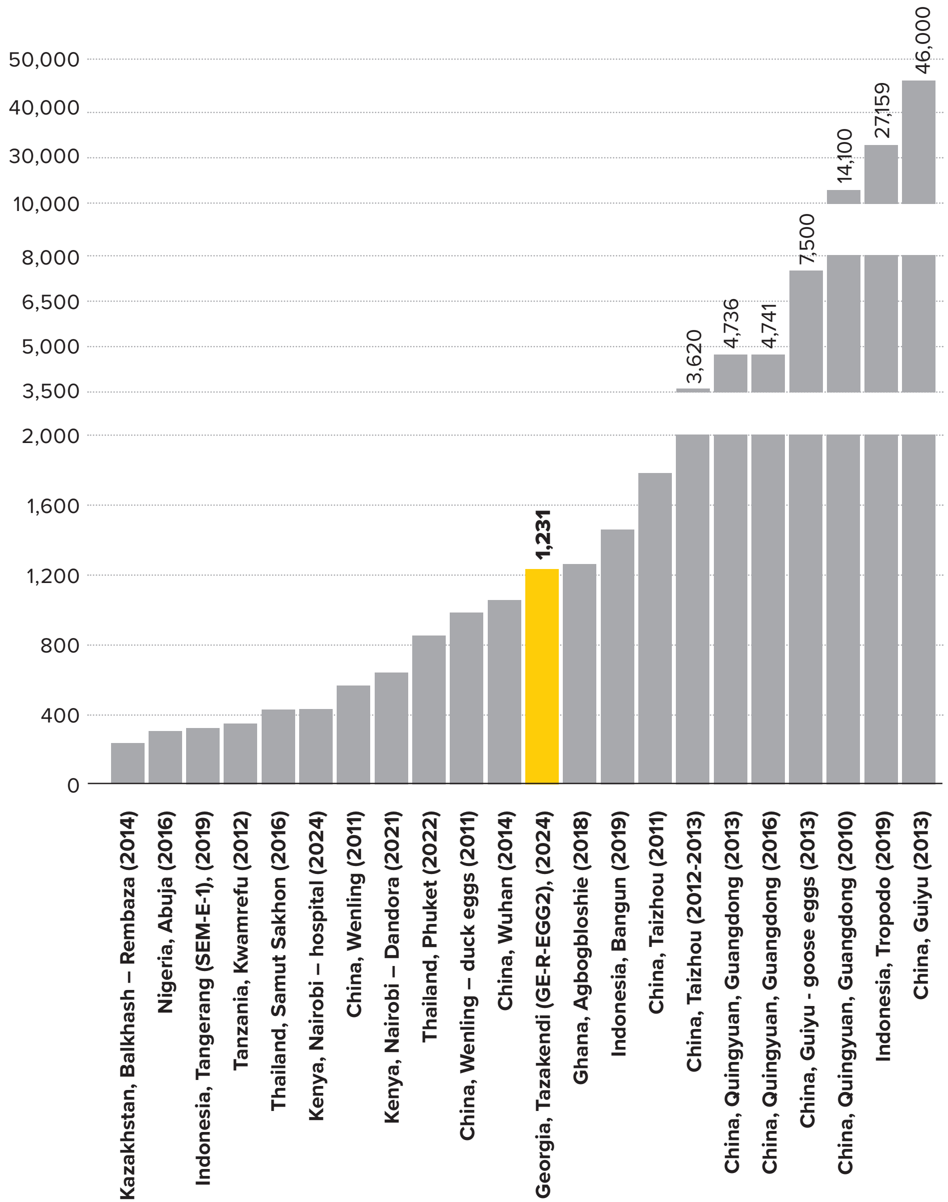

Figure 4.4: Highest levels of PBDEs measured in free range poultry eggs globally (in ng/g fat). Sources of information see Table 4.3.

and slightly higher than those reported in eggs collected near a municipal waste incinerator in Wuhan, China (Petrlik 2016).

The HBCD concentration in sample GE-R-EGG-1 is also among the highest recorded globally and is comparable to the 538 ng/g fat detected in a pooled egg sample from a plastic waste yard in Bangun, Indonesia (Petrlik et al. 2024).

4.3.4. Other POPs in Eggs

In addition to legacy POPs such as PCBs and DDTs, other classes of persistent organic pollutants may also contaminate food products, but their occurrence in free-range chicken eggs is rarely documented. In particular, data on UV stabilizers and other emerging POP-like compounds in eggs are very limited. This section presents, to our knowledge, the first dataset reporting the presence of UV stabilizers in free-range chicken eggs.

Out of eight analysed samples from Rustavi and Tazakendi, UV stabilizers were detected in six, with concentrations ranging from 0.32 to 5.67 ng/g fresh weight. The highest level was found in sample GE-R-EGG-5 from Rustavi (5.67 ng/g fw), followed by GE-R-EGG-7 (1.04 ng/g fw) and GE-R-EGG-2 (0.71 ng/g fw). Two samples—GE-R-EGG-4 and the supermarket egg sample (GE-R-EGG-SUP)—showed levels below the limit of quantification (<0.01 ng/g fw).

In five of the positive samples, the detected compound was UV 327, found at concentrations between 0.321 and 5.67 ng/g fw. In one sample—GE-R-EGG-1—UV 234 was detected above the LOQ (0.01 ng/g fw), with a concentration of 0.49 ng/g fw.

Egg samples from Dnipro (Ukraine) and Gatovo (Belarus) were not analyzed for UV stabilizers and are thus excluded from this comparison.

The detection of these substances in backyard eggs suggests potential environmental contamination—possibly from plastic waste, treated materials, or atmospheric deposition. The highest concentration in GE-R-EGG-5 may point to a localized source of pollution and should be considered in further assessments. According to photos from where the hens live, the source of contamination could be a plastic tablecloth, likely made of softened PVC (Causin 2016; Ngoc Do et al. 2022; POP RC 2021c), covering part of their run.

Finally, DP and HCBD levels were below the LOQ in all egg samples presented in this study; however, these compounds were not analyzed in egg samples from Prydniprovsk and Gatovo.

4.4. Conclusions

These findings point to significant POP contamination in eggs from Rustavi, which may pose health risks to consumers, especially considering that eggs are a common food source for children. The contamination pattern suggests multiple sources, including historical pesticide use and industrial pollution. The extremely high ∑DDT concentration in one Rustavi sample (GE-R-EGG-4) indicates either recent or ongoing inputs of banned pesticides, while elevated dl-PCB levels and exceedances of EU limits for PCDD/Fs + dl-PCBs point to current and/or legacy industrial sources, likely linked to the nearby metallurgical complex.

For other POPs, this study provides new evidence on the presence of UV stabilizers in free-range chicken eggs—an emerging class of pollutants rarely reported in food matrices. Their detection, along with isolated cases of high PBDE and HBCD concentrations, suggests that plastic waste and treated consumer products may contribute to local contamination.

The data for Tazakendi eggs shows generally lower contamination levels, although one sample contained elevated β-HCH, and several samples exceeded European reference values for certain POPs. This highlights the need for follow-up assessments, including source identification, risk evaluation for vulnerable populations such as children, and potential mitigation measures to prevent further exposure.

5. POPS AND HEAVY METALS IN FISH FROM THE MTKVARI RIVER AND PARK LAKE IN RUSTAVI

This section presents the concentrations of selected persistent organic pollutants (POPs) and heavy metals in pooled fish samples collected from various species (see Annex 2) and locations around Rustavi. Fish species analyzed include topmouth gudgeon, mursa, bulatmai barbel, European chub, common bleak, crucian carp and wels catfish, seven species in total, with ages ranging from less than 1 year to 5+ years (see Table 5.1).

5.1. Sampling and Analyses

In the Rustavi area, we collected a total of 12 fish samples for this study, originating from both the Mtkvari River and a lake located in the central park of Rustavi.

At sites like those where fish were caught, we also collected sediment samples (see Chapter 3.2.4). In seven cases, the fish samples were prepared as composite samples of fish from the same locality, species, and approximately the same size (age). Fish were caught between 14 and 17 September 2024 by local fishermen from Rustavi.

Detailed information on the samples is available in Table 5.1. The fish sampling site locations were labelled with numbers 1 to 8, with no fish obtained from site locations 2 and 5 during the sampling period.

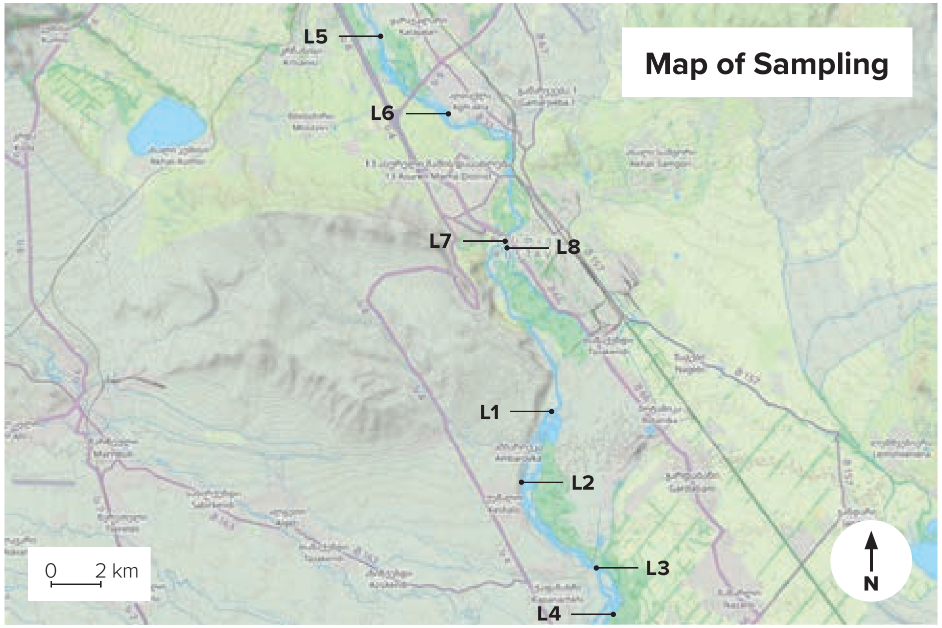

TABLE 5.1: BASIC DESCRIPTION OF FISH SAMPLES TAKEN FROM THE RUSTAVI AREA.

Sample ID	Fish length (cm)	Estimated age (years)		Species		Locality	
	Total / Fork	- by fishermen in Rustavi	- laboratory. Prague	Common name	Latin name	No.	Specification
GE-RF-1	11.5/9.5	4–5	4	top mouth gudgeon	Pseudorasbora parva	Loc 1	Gardabani-upper
GE-RF-2/1-2	12.3/10.2; 16.2/13.2	8 months. 1+	N/A	mursa	Luciobarbus mursa	Loc 1	Gardabani-upper
GE-RF-3/1-3	16.2/13.5; 17.1/14.3; 15.6/13.1	1	N/A	mursa	Luciobarbus mursa	Loc 3	WWTP-upper
GE-RF-4/1-2	18/14.7; 22.8/19.3	1+	1.5–2	bulatmai barbel	Luciobarbus capito	Loc 3	WWTP-upper
GE-RF-5	13.5/11.2	N/A	2	European chub	Squalius cephalus	Loc 4	WWTP-lower
GE-RF-6	14.1/11.5	N/A	1.5–2	common bleak	Alburnus alburnus	Loc 4	WWTP-lower
GE-RF-7/1-2	14.7/12.1; 20.2/16.4	N/A	N/A	mursa	Luciobarbus mursa	Loc 4	WWTP-lower
GE-RF-8	35/28.5	3	3-4	bulatmai barbel	Luciobarbus capito	Loc 4	WWTP-lower
GE-RF-9/1	67/62.5	2.5	N/A	wels catfish	Silurus glanis	Loc 6	Karajalari-lower
GE-RF-9/2-3	49.2/45.5; 44.8/41.5	1–1.5	N/A	wels catfish	Silurus glanis	Loc 6	Karajalari-lower
GE-RF-10/1-2	50/46.2; 41/38	1–1.5	N/A	wels catfish	Silurus glanis	Loc 7	Near „park“ - river
GE-RF-11/1-4	27.2/22; 29.2/24; 26.8/22.1; 29.8/22.3	3+	4+; 5+; 5; 4+	crucian carp	Carassius carassius	Loc 8	Central Park Lake

Immediately after capture, the fish were measured, and—where possible—scales were collected for age determination. We recorded both total length (from head to the end of the caudal fin) and fork length (from head to the base of the caudal fin) to support age estimation and facilitate size comparison. Local fishermen were also consulted to help identify fish species and estimate their age, which we subsequently verified using the collected scale samples and photographs of the fish. Fish scale samples that we had left over and available were analysed again to determine a comparable age estimate of some of the fish. This was done in Prague using a powerful microscope in a laboratory in the Faculty of Science of Charles University on July 18, 2025, (see Table 5.1).

Before transport to the laboratory, fish were gutted in Rustavi, and two fillet samples were taken from each fish without removing the skin, in line with the sampling protocol of the Biodiversity Research Institute used for the Global Fish & Community Mercury Monitoring Project in 2011 (BRI 2011). The samples were placed in zip-lock bags, frozen, and then transported to laboratories in the Czech Republic for analysis of POPs and heavy metals.

Fish samples were analyzed for six POPs and their groups (PeCB, HCB, HCBD, ndl-PCBs, three HCH isomers, and DDT with its metabolites) as well as for six heavy metals (mercury, lead, cadmium, copper, zinc, and arsenic). POP analyses were performed at the Department of Food Analysis and Nutrition, Faculty of Food and Biochemical Technology, University of Chemistry and Technology, Prague. The extraction procedures and analytical methods have been described elsewhere (Hloušková et al. 2014; Pulkrabova J et al. 2011). Heavy metal analyses were conducted using standardized

TABLE 5.2: RESULTS OF THE ANALYSES OF FISH FOR POPS AND HEAVY METALS FROM BROADER RUSTAVI AREA.

Locality		L1	L1	L3	L3	L4	L4	L4	L4	L6	L6	L7	L8	
Sample ID		GE-RF-1	GE-RF-2/1-2	GE-RF-3/1-3	GE-RF-4/1-2	GE-RF-5	GE-RF-6	GE-RF-7/1-2	GE-RF-8	GE-RF-9/1	GE-RF-9/2-3	GE-RF-10/1-2	GE-RF-11/1-4	
Species Name		topmouth gudgeon	mursa	mursa	bulatmai barbel	European chub	common bleak	mursa	bulatmai barbel	wels catfish	wels catfish	wels catfish	crucian carp	
	Units													EU limit
Age	Years	4	0.8–1+	1	1.5–2	2	1.5–2	N/A	3–4	2.5	1–1.5	1–1.5	4–5+	NA
Fish in sample	N	1	2	3	2	1	1	2	1	1	2	2	4	NA
Lipid	%	1.5%	5.6%	4.6%	3.3%	0.6%	3.3%	6.1%	3.0%	1.7%	2.5%	4.0%	2.6%	NA
PeCB		<0.005	0.10	0.09	0.05	<0.005	0.08	0.09	0.04	0.02	0.02	0.03	0.03	NA
HCB		0.33	0.61	0.51	0.24	0.12	0.30	0.57	0.28	0.21	0.08	0.33	0.33	NA
HCBD		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA
7 PCB	ng/g fw	15.7	21	13.6	4.5	3.8	6.8	18	6.4	5.7	3.2	8.7	8.8	NA
6 PCB		13.0	18	11.6	3.9	3.2	5.9	15.4	5.5	4.9	2.7	7.7	7.7	125
Σ HCH		0.63	0.90	0.78	0.52	0.14	0.53	0.90	0.43	0.34	0.31	0.39	0.50	10
Σ DDT		47	86	42	12.8	13.9	26	48	19	17	30	22	28	50
4 DDT		45	82	39	12.1	13.7	25	44	18	15.7	29	20	26	NA
Mercury		0.187	0.141	0.156	0.086	0.057	0.043	0.159	0.051	0.115	0.067	0.013	0.087	0.5
Lead		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.02	<0.02	<0.02	<0.02	<0.02	0.3
Cadmium	mg/kg fw	0.006	0.011	0.009	<0.005	0.005	<0.005	0.007	<0.002	<0.002	<0.002	<0.002	<0.002	0.05
Copper		0.59	1.82	1.39	0.30	0.53	0.93	1.24	0.41	0.11	0.14	0.50	0.11	NA
Zinc		35	28	15	8.4	22	16	23	9.3	5.3	6.6	19	7.2	NA
Arsenic		0.040	0.070	0.070	0.030	0.020	0.060	0.080	0.040	<0.01	<0.01	0.020	<0.01	NA

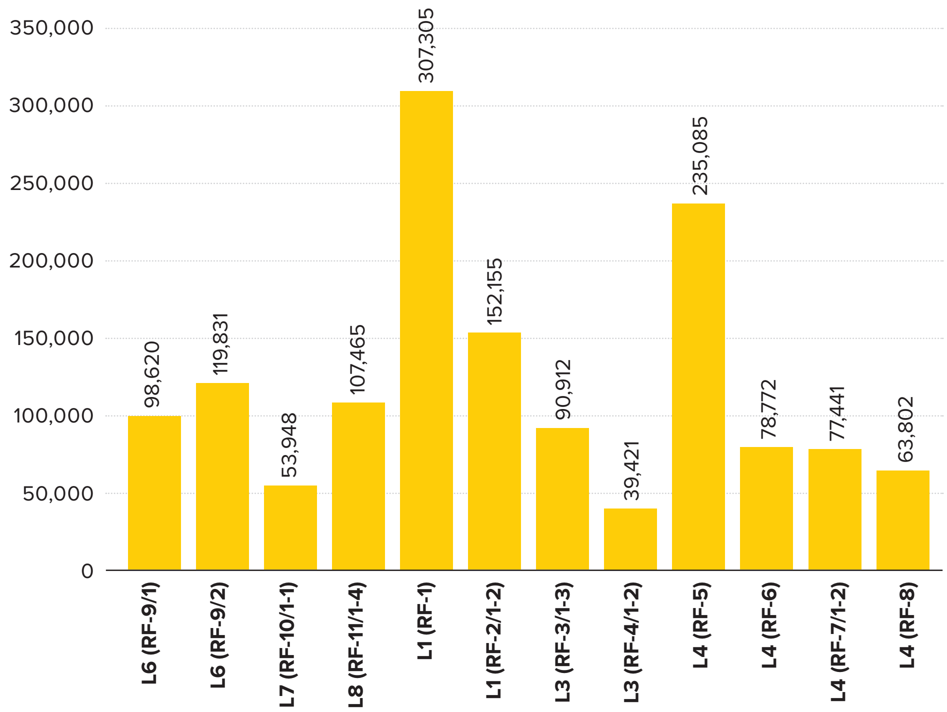

Figure 5.1: Concentration of ∑DDT in individual fish samples by locality (ng/g fat).

procedures at the State Veterinary Institute in Prague. The analytical methods are described in greater detail in Chapter 2 of this publication.

5.2. Results and Discussion

The analytical results from 12 fish samples collected in the broader Rustavi area reveal concerning levels of legacy POPs and heavy metals (see Table 5.2). Several substances approached or exceeded health-based reference values or environmental thresholds. While fish from the local river are not a major protein source for most residents, certain groups—such as fishing families or individuals consuming locally caught fish—may still be at elevated risk. These findings raise concerns regarding potential long-term ecological effects and possible health risks for those subpopulations that rely on locally sourced fish.

5.2.1. POPs: DDTs, PCBs and Chlorinated Industrial Chemicals

The most alarming finding is the elevated concentration of ∑DDT in fish sample GE-RF-2 (85.6 ng/g fw), which exceeds the EU maximum residue limit of 50 ng/g fw for DDT in fish (European Parliament and Council 2025). Other samples, such as GE-RF-3 and GE-RF-7, were close to this threshold (41.5 and 47.6 ng/g fw respectively), indicating a widespread but slightly lower contamination. These levels may not only reflect remobilization of residues from contaminated sediments or obsolete pesticide stockpiles but could also indicate recent inputs, as suggested by high p,p'-DDT/p,p'-DDE ratios in soil samples from the same region (see Section 3.2.2). UNDP Project Document from 2004 stated that *"recent studies indicate that there is strong evidence that the illegal application of banned chlorinated pesticides in the region is occurring"* (UNDP/GEF 2004).

The bar chart in Figure 5.1 shows the concentrations of ∑DDT (ng/g fat) in individual fish samples collected from multiple sites along the Mtkvari River and one urban lake (L8). For comparison of POP levels that accumulate in fat, values were recalculated per gram of fat rather than fresh weight, as this better reflects the relative contamination burden between fish samples, which would otherwise be distorted by species-specific fat content.

The highest concentrations were observed in L1 and L4, with values over 300,000 ng/g fat and several samples exceeding 100,000 ng/g fat. In location L1, a topmouth gudgeon (*Pseudorasbora parva*) reached 307,305 ng/g fat, while a mursa (*Luciobarbus mursa*) from the same site showed a lower but still extreme level (152,155 ng/g fat). Although species differences may partly explain this variation, these values clearly indicate a highly contaminated site.

Similarly, the highest ∑DDT concentration in location L4 (235,085 ng/g fat) was recorded in a European chub (*Squalius cephalus*), with three other species—common bleak (*Alburnus alburnus*), mursa, and bulatmai barbel (*Luciobarbus capito*)—showing slightly lower but still elevated levels ranging from 63,802 to 78,727 ng/g fat. These interspecies differences likely reflect variation in feeding ecology and lipid content, but the consistently high values across species suggest that local contamination is the overriding factor.

At location L3, ∑DDT concentrations ranged from 90,912 to 39,421 ng/g fat, indicating substantial contamination, though somewhat lower than at L1 and L4.

Fish from L6 (98,620 ng/g fat) and L8 (107,465 ng/g fat) also showed moderately high concentrations, while the lowest level was observed at L7 (53,948 ng/g fat). Still, all these values represent significant contamination from legacy or recent DDT use along the river.

∑7PCBs were detected in all fish samples, with concentrations up to 20.9 ng/g fw (GE-RF-2). ∑6 indicator PCBs exceeded 10 ng/g fw in six samples, with GE-RF-2 and GE-RF-1 showing the highest values (17.96 and 13.00 ng/g fw, respectively). While these values remain below the EU maximum residue limit (125 ng/g fw); (European Commission 2023), the co-occurrence with other POPs indicates a high toxic burden likely related to industrial sources.

Freshwater fish from a heavily contaminated area with metallurgical operations in the Ostrava region (Czech Republic) contained ∑7PCBs in concentrations ranging from 27 to 70 ng/g fw (Mach and Petrlík 2016)—higher than the levels observed in Rustavi samples. However, fish from less polluted locations in the Elbe River basin showed ∑7PCBs levels that were lower or comparable to those in Rustavi. Similarly, fish collected from four lakes in Poland contained ndl-PCBs at concentrations ranging from 0.08 to 27.30 ng/g fw (Mikolajczyk et al. 2022), which is within the comparable range as the fish from Rustavi (3.21–21 ng/g fw).

As with ∑DDT, concentrations are expressed per gram of fat to account for the lipophilic nature of PCBs and better reflect relative contamination levels between samples.

The highest PCB concentration was observed in a sample from locality L1 (102,601 ng/g fat), suggesting a local source of severe contamination. A second-highest value was found at L4 (64,121 ng/g fat), with other samples from L1 and L4 ranging between 20,000 and 37,000 ng/g fat. Moderately elevated levels were also observed in fish from L6 (30,087 and 13,000 ng/g fat), L3 (29,705 and 13,699 ng/g fat), and L8 (33,715 ng/g fat). Even the lowest concentration, recorded in a sample from L3 (13,699 ng/g fat), remains well above background levels typically found in uncontaminated systems. The spatial distribution of PCBs closely mirrors the pattern seen for DDTs, reinforcing the conclusion that the most contaminated sites are L1 and L4 and pointing to industrial activity along the Mtkvari River as a likely source.

Hexachlorobenzene (HCB) and hexachlorocyclohexane (HCH) isomers were also detected in most samples, with HCB concentrations ranging from 0.08 to 0.61 ng/g fw.

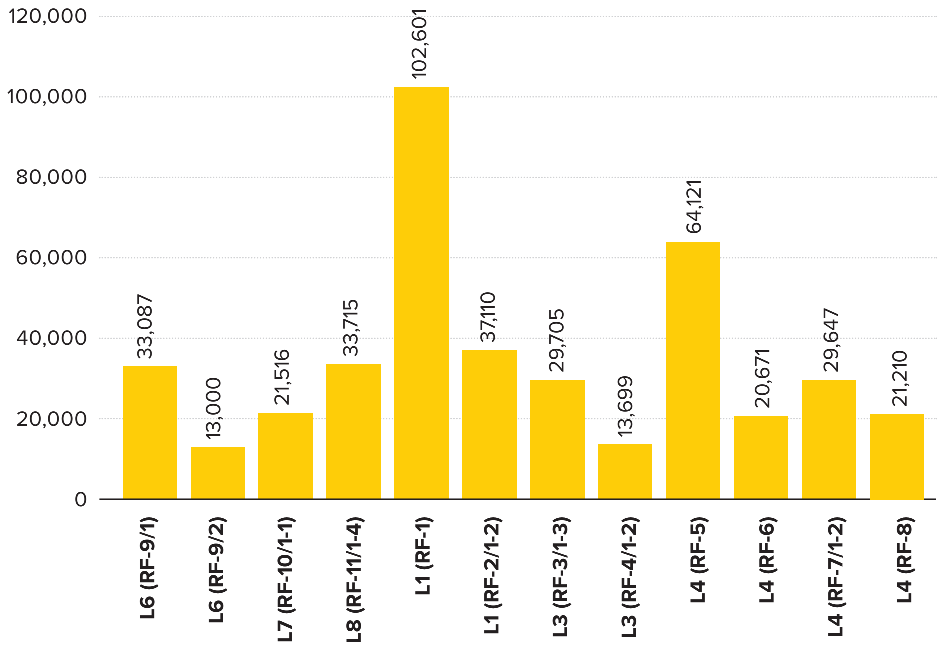

Figure 5.2: Concentration of 7 indicator PCBs in individual fish samples by locality (ng/g fat)

Although below regulatory thresholds, their presence confirms the environmental persistence of these compounds. Other POPs listed under the Stockholm Convention, such as pentachlorobenzene (PeCB) and hexachlorobutadiene (HCBD), were found only at trace levels or below the limit of quantification, consistent with patterns reported in less industrialized aquatic environments. Nevertheless, their detection supports the hypothesis of diffuse and longterm contamination stemming from historical industrial activities.

DDT, HCB, and other POPs have also been monitored in crucian carp from freshwater locations in Japan and Korea. In Japan, DDT concentrations ranged from 0.073 to 8.9 ng/g fw, and in Korea from 0.23 to 3.2 ng/g fw (Jeong et al. 2010), both lower than the 28 ng/g fw measured in the crucian carp composite sample from Rustavi. HCB concentrations in Japan reached up to 5.5 ng/g fw, in some cases exceeding the 0.33 ng/g fw found in the Rustavi sample, whereas in the Korean samples HCB concentrations were below the limits of detection (Jeong et al. 2010).

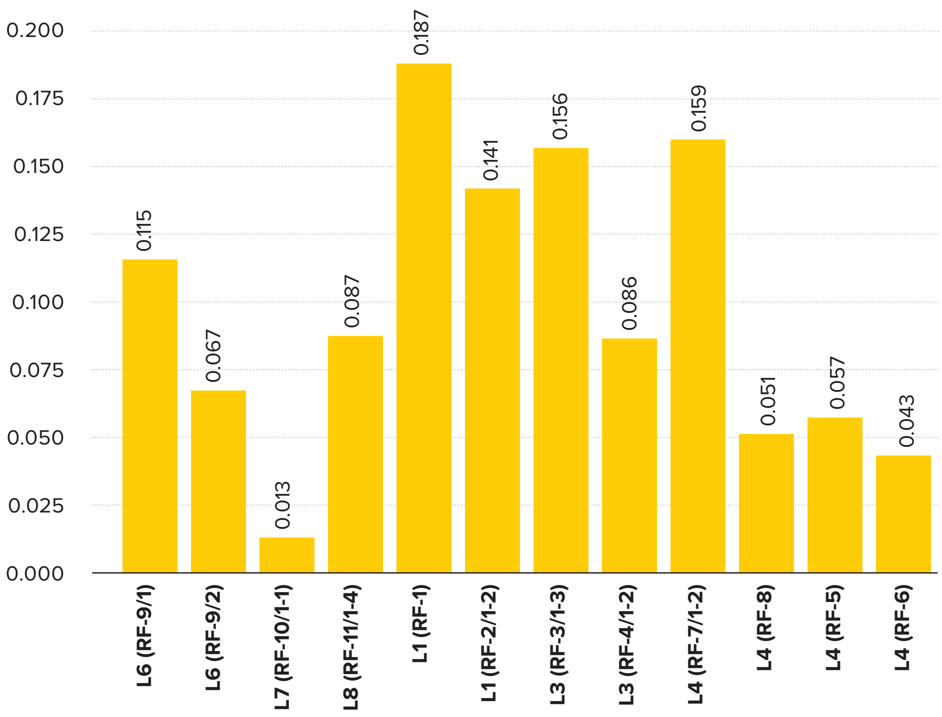

Figure 5.3: Mercury concentrations in fish samples by location (mg/kg fw).

5.2.2. Mercury and Other Heavy Metals

Mercury (Hg) concentrations in fish samples from the Rustavi area ranged from 0.013 mg/kg fw in a sample from location L7 to 0.187 mg/kg fw in a sample from L1 (see Figure 5.3). The highest levels were observed in fish from L1 (0.187 and 0.141 mg/kg fw), L3 (0.156 and 0.086 mg/kg fw), and L4 (0.159 mg/kg fw), while fish from L6, L7, and L8 generally exhibited lower concentrations, typically below 0.1 mg/kg fw.

Although all mercury concentrations remained below the EU maximum permissible level for fish intended for human consumption (0.5 mg/kg fw); (European Commission 2023), several samples—particularly from L1, L3, and L4—approached or exceeded 0.15 mg/kg fw. The highest observed value (0.187 mg/kg fw) was close to the U.S. EPA's fish consumption advisory threshold of 0.22 mg/kg fw[9] (US EPA 2001), a value that signals health risks for sensitive populations, including pregnant women and children. These findings raise concern due to the bioaccumulative nature of mercury and its well-documented neurotoxic effects. Although no regulatory limits were exceeded, the presence of elevated mercury levels in several sites suggests localized contamination, possibly linked to industrial activity. Site-specific investigations are warranted to clarify exposure pathways and sources.

Mercury concentrations in fish from the Mtkvari River near Rustavi were notably higher than those reported in chub samples from the Debed River in Alaverdi, Armenia, where levels ranged from 0.016 to 0.027 mg/kg fw (Grechko et al. 2021b). It is important to note that the studied section of the Mtkvari River has the character of a fast-flowing mountain river. Conditions necessary for mercury methylation—a critical process for the bioaccumulation of mercury in aquatic organisms (Rudd et al. 1980; Ullrich et al. 2001)—may not yet be fully established in this area. Similar cases have been documented in Kazakhstan, where elevated methylmercury concentrations occurred several dozen kilometers downstream from pollution sources (Mach et al. 2016; Petrlik et al. 2015b). It is therefore possible that more pronounced mercury contamination resulting from industrial sources in Rustavi may only become apparent further downstream along the Mtkvari River.

Publicly available studies on heavy metal pollution in the Mtkvari River near Rustavi remain scarce. While some monitoring has focused on ammonia contamination (Bakradze et al. 2017; Lomsadze et al. 2016), no detailed assessments of mercury in fish or sediments have been conducted to date. Heavy metal contamination has been studied in nearby tributaries such as the Mashavera and Kazretula rivers (Bakradze et al. 2017), both of which are influenced by mining operations of the RMG Copper company. A study by Poporadze et al. (2010) focused primarily on lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) in various environmental compartments—particularly in sediments and river water of the Mtkvari—but did not include specific data on mercury levels in either sediments or fish.

9 Figure derived from the reference dose used as U.S. EPA consumption guidelines for fish (0.2 mg.kg-1 methylmercury) based on the presumption that methylmercury counts for 90% of THg levels, limit value used by Canada is similar . Japan and/or UK use 0.3 reference dose. Source: (US EPA 2001)

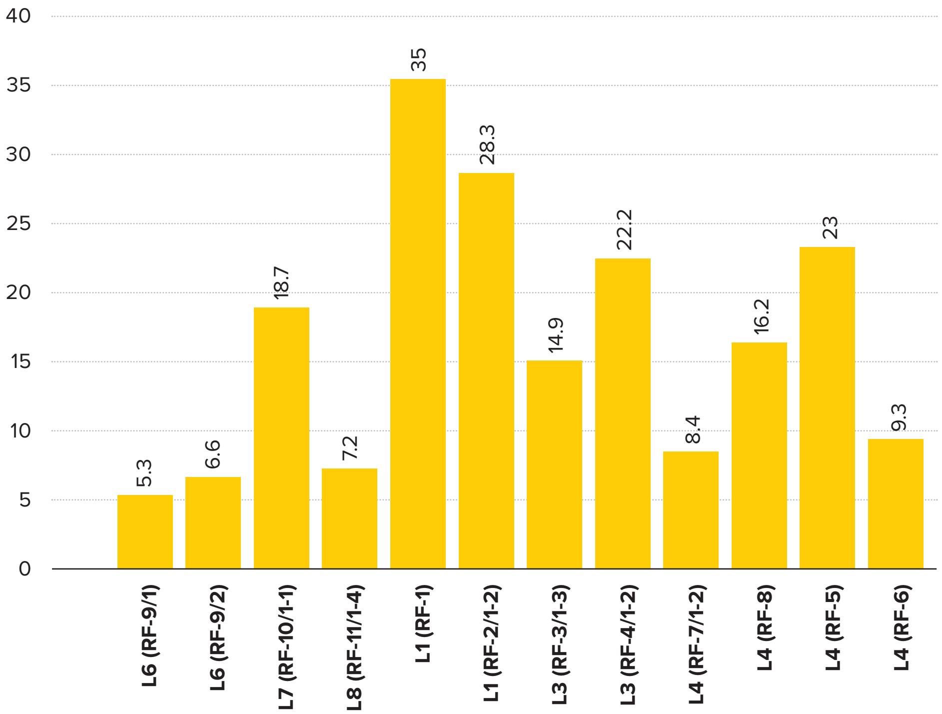

Figure 5.4: Zinc concentrations in fish samples by location (mg/kg fw).

Zinc (Zn) concentrations also varied considerably, ranging from 5.3 mg/kg fw (L6) to 35 mg/kg fw (L1). The highest levels were found in fish from L1 (35 and 28.3 mg/kg fw), followed by L4 (23 mg/kg fw) and L3 (22.2 mg/kg fw). These values fall within safe intake limits for humans, as zinc is an essential trace element, and the tolerable upper intake level (UL) for adults is 40 mg/day (Gibson et al. 2016). However, elevated zinc concentrations may be toxic to aquatic organisms (Javed and Usmani 2017; Skidmore 1964), affecting physiology, gill function, and reproduction (McGeer et al. 2000; Sorensen 1991). In industrialized water bodies, such levels may indicate discharges from metallurgical or wastewater sources and should be monitored for potential ecological impacts.

Copper (Cu) was found at lower but variable concentrations, with a maximum of 1.82 mg/kg fw in sample GE-RF-2. Lead (Pb) was below the detection limit (<0.02–<0.05 mg/kg fw) in all samples, and cadmium (Cd) concentrations were low (maximum 0.011 mg/kg fw), both remaining well below EU food safety limits (0.3 mg/kg fw for Pb, 0.05 mg/kg fw for Cd).

Arsenic (As), a known carcinogen, was detected in most samples at levels up to 0.08 mg/kg fw, though remaining below 0.1 mg/kg. While not exceeding food safety thresholds, its presence further underlines the complex mixture of contaminants in fish from this industrially influenced region.

These findings contrast with those of Mchedluri and Makharoblidze (2018), who reported no detectable mercury or cadmium in fish from various sites along the Mtkvari River in Tbilisi. The discrepancy may reflect differences in sampling sites, analytical sensitivity, or more localized contamination patterns in the Rustavi area.

5.2.3. Species-Specific and Spatial Trends

This section compares two species with multiple samples—wels catfish (*Silurus glanis*) and mursa (*Luciobarbus mursa*). For other species, only single samples were available.

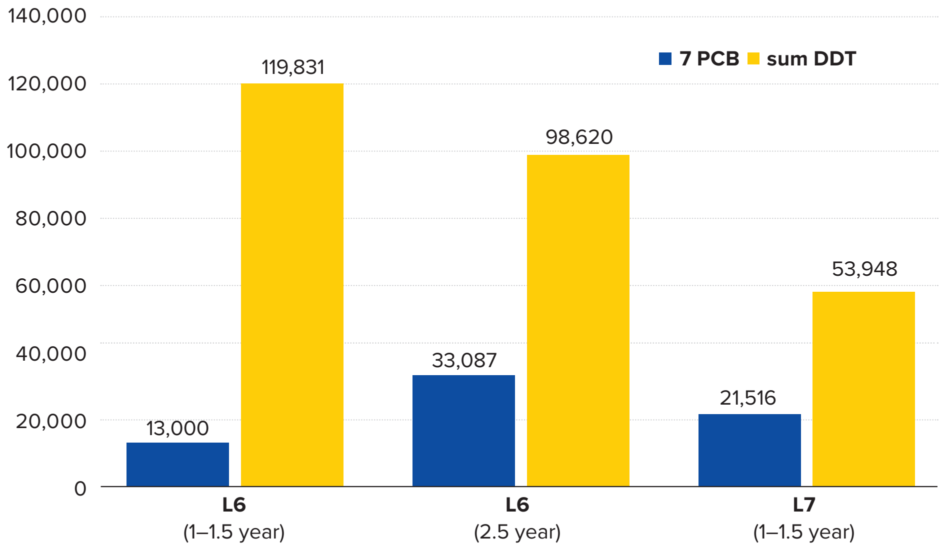

Figure 5.5: Concentration of 7 PCBs and ∑DDTs in wels catfish samples by location and age in ng/g fat.

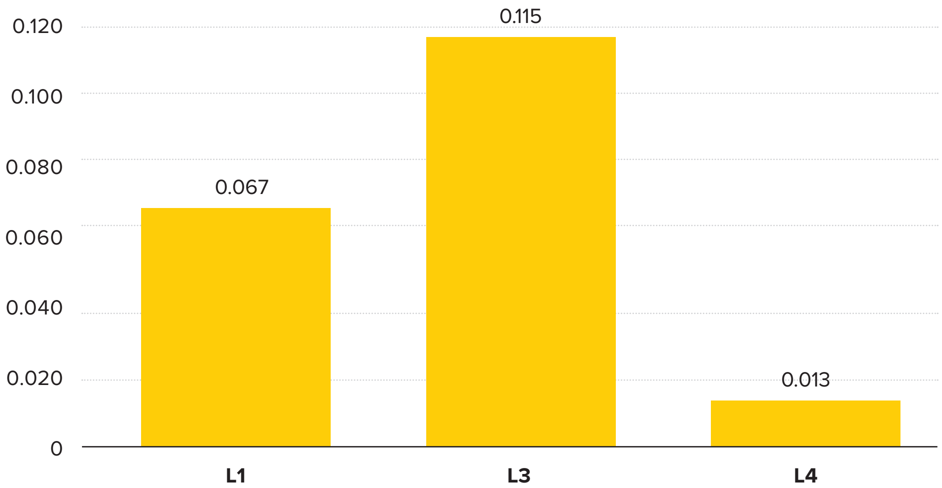

Figure 5.6: Mercury concentrations in wels catfish samples in mg/kg fw.

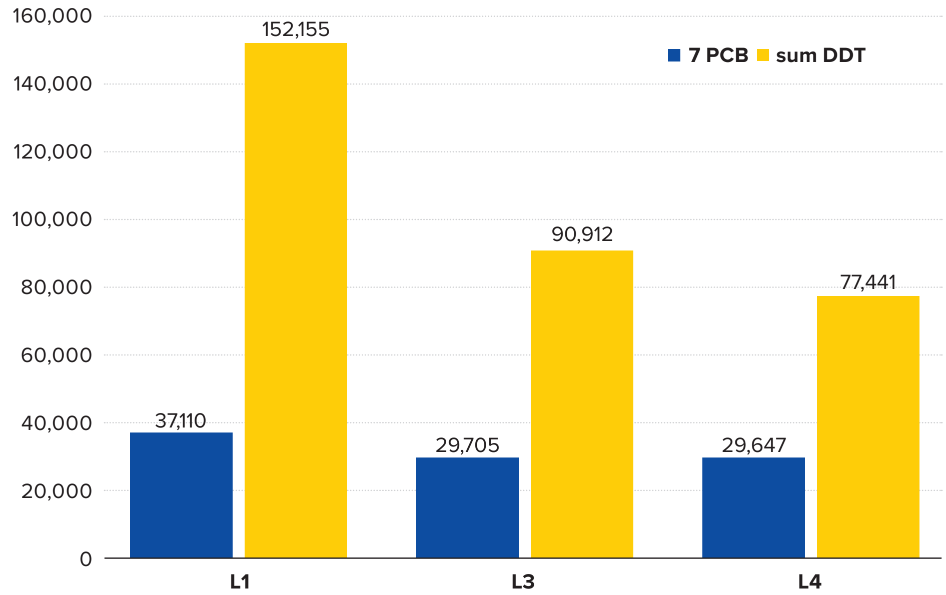

Figure 5.7: Concentration of 7 PCBs and ∑DDTs in mursa by location in ng/g fat.

Wels catfish showed increasing contamination with age. At L6, the older catfish had more than double the PCB and mercury levels than the younger one (see Figure 5.6). At L1, the oldest fish showed the highest levels of PCBs (102,601 ng/g fat) and DDTs (307,305 ng/g fat). This conclusion confirms findings in another study *"that significant heavy metal accumulation in catfish tissues correlates with age and body mass"* (Has-Schon et al. 2015).

A mursa (approx. 1 year old) also showed high levels of POPs. A mursa from L1 contained 37,110 ng/g fat PCBs and 152,155 ng/g fat DDTs. Barbel from L3 and L4 had lower but still concerning levels.

Mercury concentrations in barbel from L3 and L4 were the highest in the study (0.156 and 0.159 mg/kg fw). These findings indicate early-life exposure and support the hypothesis of diffuse pollution downstream of Rustavi, including discharges from the wastewater treatment plant.

Species-specific differences in contamination levels may also be influenced by migratory behavior. The bulatmai barbel (*Luciobarbus capito*) is considered a semi-anadromous species capable of migrating (Ford 2024b) into brackish or even marine waters, such as the Caspian or Black Sea (Coad 2021; Eagderi et al. 2013). This behav-

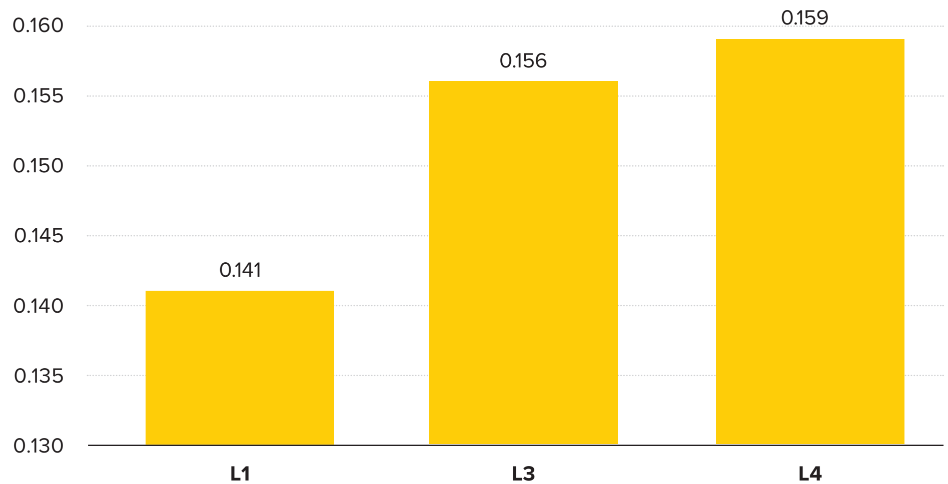

Figure 5.8: Mercury concentrations in Mursa samples in mg/kg fw.

ior potentially exposes it to a broader range of pollution sources, as it moves through waters with varying levels of contamination, including industrial discharges and riverine-marine pollutant transport.

In contrast, the mursa (*Luciobarbus mursa*) is a strictly freshwater species with a limited migratory range (Freyhof 2014; Wikipedia 2025). Its contamination levels are therefore more likely to reflect local pollution in the Mtkvari River in the Rustavi area. This is consistent with our findings, where the mursa showed higher concentrations of POPs and mercury than the bulatmai barbel (see Table 5.2, Annex 2).

The differing life histories and habitat preferences of these two species (see Annex 2) could partly explain the observed variations in contaminant accumulation. A similar pattern was documented in Bangladesh, where the migratory barramundi perch (Lates calcarifer) exhibited lower mercury concentrations compared to non-migratory species inhabiting the same contaminated areas of the Meghna River near Hazaribagh and Gazaria (Hossain and Petrlik 2013).

Similar conclusions were drawn from a study on juvenile Chinook salmon in the Pacific Northwest, where migratory individuals showed distinct POP profiles depending on their movement through differently contaminated sections of the river system (O'Neill et al. 2020). This supports the hypothesis that migratory behavior modulates contaminant exposure even within freshwater and estuarine environments.

These findings underscore the importance of considering species-specific life cycles and migratory behavior in future studies of contaminant bioaccumulation in fish.

5.3. Conclusions and Recommendations

Although most of the fish samples complied with the existing legal limits for individual contaminants, the frequent co-occurrence of multiple hazardous substances—particularly DDTs, PCBs, and mercury—raises concerns about cumulative toxicity. The spatial patterns of contamination strongly suggest industrial pollution in the broader Rustavi area, as well as historical and likely recent or ongoing use of DDT-containing pesticides.

To address these issues, the following measures are recommended:

» Expand biomonitoring of fish (possibly also predatory species), and other aquatic organisms (e.g. invertebrates or shellfish) to track temporal and spatial trends in contamination.

» Conduct targeted investigations of pollution sources, particularly near localities L1 and L4, which showed the highest toxic burdens.

» Develop public health advisories for fish consumption, like those used in the United States, to protect vulnerable groups such as children and pregnant women.

» Undertake ecotoxicological studies to assess potential impacts on fish populations and broader aquatic biodiversity, including sublethal and reproductive effects.

These steps would help to reduce health risks, guide policy responses, and support long-term environmental management of the Mtkvari River ecosystem.

6. HEAVY METALS IN SAMPLES FROM RUSTAVI HOT SPOTS

In total, 14 environmental samples for heavy metal analysis was collected during the fieldwork. These included 8 soil samples from 7 childrens' playgrounds (six in Rustavi and one in the rural village of Udabno) and 6 dust samples (five from Rustavi and one from Udabno).

6.1. Results

Analytical results for heavy metals in soil and dust samples from the Rustavi area, compared with reference samples from Udabno, are summarized in Tables 6.1 and 6.2. The results are discussed by sample type, with specific attention given to children's playgrounds as a sensitive setting.

6.1.1. Heavy Metals in Soil Samples from Children's Playgrounds

This section summarizes the concentrations of selected heavy metals measured in soil samples collected from various children's playgrounds in Rustavi and compares them with the reference site in Udabno (Table 6.1).

The table shows a clear elevation in the concentrations of heavy metals in most playground soil samples in Rustavi compared to the reference site in Udabno (GE-UPG-01). Notable differences include:

- Mercury (Hg): The highest concentration was detected in GE-RPG-1 (0.55 mg/kg), which is 25 times higher than the reference. Other playgrounds had levels closer to or below the reference value.
- Lead (Pb): GE-RPG-2 to GE-RPG-4 all exceed 50 mg/kg, with GE-RPG-4 reaching nearly 100 mg/kg, which is 7.8 times higher than the reference site.
- Cadmium (Cd): GE-RPG-2 showed the highest concentration (1.63 mg/kg), 8.4 times above the reference, indicating possible contamination.
- Copper (Cu): GE-RPG-2 again showed a striking value (138 mg/kg), more than three times higher than the reference. Other elevated values were found in GE-RPG-3 and GE-RPG-4.
- Chromium (Cr): The highest level was found in GE-RPG-2 (105 mg/kg), over 2-times higher than the reference. GE-RPG-6/B also showed elevated values (97.7 mg/kg).

TABLE 6.1: CONCENTRATIONS OF SELECTED HEAVY METALS (MG/KG) IN SOIL SAMPLES FROM CHILDREN'S PLAYGROUNDS COMPARED TO THE REFERENCE SITE (UDABNO)

Element	GE-RPG-1	GE-RPG-2	GE-RPG-3	GE-RPG-4	GE-RPG-5	GE-RPG-6/A	GE-RPG-6/B	GE-UPG-01 (ref.)
Mercury (Hg)	0.55	0.089	0.066	0.074	0.05	0.005	0.009	0.022
Lead (Pb)	25.8	57.7	83	99.8	24.7	4.29	17.3	12.8
Cadmium (Cd)	0.577	1.63	0.925	0.619	0.414	0.027	0.129	0.194
Copper (Cu)	50.5	138	91	60.7	48	6.9	13.9	39
Chromium (Cr)	44.2	105	46.1	58.6	41.8	58.9	97.7	46.3
Zinc (Zn)	387.5	851.6	448	243	178.5	131.2	313	67.6
Arsenic (As)	6.9	8.49	4.49	6.05	5.0	2.26	1.93	7.1

» Zinc (Zn): All Rustavi playgrounds had significantly higher zinc concentrations than the reference, particularly GE-RPG-2 (851.6 mg/kg), which is more than 12 times higher.
» Arsenic (As): Unlike other metals, arsenic levels across all playgrounds—including the reference—were similar and generally low (below 10 mg/kg), with GE-RPG-2 showing a slightly higher level (8.49 mg/kg). This indicates that arsenic may not be a primary concern in this setting.

Several playgrounds—particularly GE-RPG-2, GE-RPG-3, and GE-RPG-4—showed significantly elevated concentrations of heavy metals, likely due to their proximity to industrial facilities, use of contaminated slag in surrounding soil, or their location near busy roads. GE-RPG-3, for example, was situated in an area with visible slag fragments and traces of animal excrement, while GE-RPG-2 and GE-RPG-4 were both near residential zones affected by traffic and past industrial activities.

GE-RPG-6, located within a residential area, was divided into two subsamples: sand from the playground (6A) and surrounding dusty material (6B). While the sand sample showed relatively lower contamination, the surrounding material contained elevated levels, indicating localized hotspots of pollution.

The reference site in Udabno (GEUPG1) consistently showed the lowest concentrations across most analytes, reinforcing its suitability as a baseline. However, for certain elements, such as arsenic and mercury, even lower levels were observed at some other playgrounds. This is likely due to variability in soil composition and longrange pollutant transport, as Udabno is located at a higher elevation in a mountainous area. Overall, these results indicate anthropogenic sources of contamination at several playground sites in Rustavi. The presence of toxic elements in soils frequently used by children raises concerns about longterm health risks and highlights the need for sitespecific remediation and precautionary measures.

Comparison with Kazakhstani playgrounds

To contextualize the results from Rustavi, we compared them with data from a similar study on playground soil contamination conducted in Kazakhstan (Petrlik et al. 2015a), see Table 6.2. That study, which covered several sites including Temirtau, Balkhash, and Stepnogorsk, focused on contamination by heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), zinc (Zn), and mercury (Hg).

The comparison reveals notable differences in the contamination profiles:

» Lead (Pb) concentrations were significantly higher in Kazakhstan (average 392 mg/kg) compared to Rustavi (average 44.7 mg/kg). Some Kazakh sites exceeded 2,000 mg/kg.

TABLE 6.2: CONCENTRATION RANGES AND AVERAGES OF HEAVY METALS IN PLAYGROUND SOILS IN CENTRAL KAZAKHSTAN (PETRLIK ET AL. 2015A) IN COMPARISON WITH RESULTS FROM THIS STUDY

Element	Central Kazakhstan		This study	
	Range (mg/kg)	Average (mg/kg)	Range (mg/kg)	Average (mg/kg)
Lead (Pb)	13.9 – 2,410	392.5	4.29 – 99.8	44.7
Cadmium (Cd)	0–15.3	1.86	0.027 – 1.63	0.62
Copper (Cu)	13.9 – 4,866	465.6	6.9–138	58.4
Chromium (Cr)	0–42.2	17.3	41.8–105	64.6
Zinc (Zn)	43.6 – 1,302	276.8	131.2–851.6	364.7
Arsenic (As)	0–232.2	22.6	1.93 – 8.49	5.0
Mercury (Hg)	0.028 – 0.458	0.10	0.005–0.55	0.12

- Copper (Cu) levels were also substantially elevated in Kazakhstan, with an average of 465.6 mg/kg versus 58.4 mg/kg in Rustavi.
- Cadmium (Cd) showed comparable averages: 1.86 mg/kg in Kazakhstan and 0.62 mg/kg in Rustavi.
- Chromium (Cr) was more prevalent in Rustavi samples (average 64.6 mg/kg) than in Kazakhstan (17.3 mg/kg).
- Zinc (Zn) concentrations were also higher in Rustavi (average 364.7 mg/kg) than in Kazakhstan (276.8 mg/kg).
- Mercury (Hg) levels were comparable, with 0.10 mg/kg in Kazakhstan and 0.12 mg/kg in Rustavi.
- Arsenic levels in Rustavi playground soils were generally low (1.93–8.49 mg/kg). All samples remained well below the levels observed in the Balkhash study (Petrlik et al. 2015a).

These differences reflect varying local pollution sources. In Kazakhstan, extremely high Pb and Cu levels are linked to non-ferrous smelters and legacy pollution, while in Rustavi, the elevated Cr and Zn concentrations likely stem from nearby ferroalloy and cement production facilities. Despite differing profiles, both studies confirm that children's playgrounds in industrial areas may be significantly contaminated and warrant further attention.

Comparison with limit values applied in the Czech Republic

Although the Czech Republic does not establish specific soil contamination limits for playgrounds, the hygienic standards for sandboxes on children's playgrounds (Decree No. 238/2011 Coll., Annex 10) provide a useful point of reference. These limits are defined for dry weight and are intended to ensure the safety of children playing in sand. Table 6.3 below compares the average concentrations of selected elements from Rustavi playground soils with the maximum allowable concentrations in sandboxes.

As the comparison shows, cadmium and zinc exceeded the Czech hygienic limits for sandboxes. While these guidelines are not legally binding for soil, they offer a relevant benchmark considering children's exposure pathways (e.g. hand-to-mouth contact).

Comparison with Other Contaminated Playgrounds and Parks

Measured concentrations of heavy metals in soils from Rustavi playgrounds reveal elevated levels of several contaminants compared to international reference values (Table 6.4). The highest levels were found for zinc (up to 851.6 mg/kg), copper, and lead,

TABLE 6.3: HYGIENIC LIMITS FOR SELECTED CHEMICAL ELEMENTS IN COMPARISON WITH AVERAGE LEVELS IN RUSTAVI
Maximum allowable concentrations in children's playground sandboxes (mg/kg dry weight)

Element	Average in Rustavi (mg/kg)	Czech hygienic limit for sandboxes (mg/kg)	Limit exceeded
Arsenic (As)	5.0	10.0	No
Cadmium (Cd)	0.6	0.5	Yes
Chromium (Cr)	64.6	100.0	No
Copper (Cu)	58.4	100.0	No
Mercury (Hg)	0.12	0.3	No
Lead (Pb)	44.7	60.0	No
Zinc (Zn)	364.7	150.0	Yes

often exceeding values reported in studies from Poland, China, and Colombia (Donado et al. 2021; Li et al. 2023; Peng et al. 2019; Zglobicki et al. 2021). For example, Pb in GE-RPG-4 reached 99.8 mg/kg, compared to 41 mg/kg in Poland and in various locations in China 34.89 (Li et al. 2023) and 23.6–44.2 (Peng et al. 2019) mg/kg respectively.

Mercury concentrations were mostly low (0.005–0.55 mg/kg), though slightly above values from Korea and Poland (Park and Ji 2023; Zglobicki et al. 2021). Cadmium concentration exceeded Czech hygienic limit at four playgrounds in Rustavi (see Table 6.1). Arsenic concentrations were generally moderate but require attention due to their toxicity, especially in child-exposed environments.

The levels of heavy metals in playground soils from Rustavi generally fall within the range of international values, but several trends stand out:

» Lead (Pb): The average concentration in Rustavi (44.7 mg/kg) is higher than in South Korea (7.55 mg/kg), Cape Town (30 mg/kg), and China (34.89 mg/kg), but lower than in Colombia (89 mg/kg) and Poland (41 mg/kg).

» Cadmium (Cd): With an average of 0.62 mg/kg, Rustavi exceeds the levels reported in South Korea (0.21) and is comparable to China (2.52 mg/kg) and Colombia (2.1).

TABLE 6.4 COMPARISON OF HEAVY METAL CONCENTRATIONS (mg/kg) IN SOILS FROM PLAYGROUNDS AND PARKS IN VARIOUS INTERNATIONAL STUDIES

Author, (year)	Parlak et al. (2022)	Park and Ji (2023)	Zglobicki et al. (2021)	Li et al. (2023)	Donado et al. (2021)	Shezi et al. (2022)	Figueiredo et al. (2011)
environment	playgrounds	parks, mean c	playground, mean c	parks	playgrounds	preschool facilities	playground soils
Country	Türkiye	South Korea	Poland	China	Colombia	Cape Town	São Paulo
Hg	na	0.02	0.027	na	0.1	na	na
Pb	3–102	7.55	41	34.89	89	30	na
Cd	na	0.21	4.7	2.52	2.1	na	na
Cu	19–92	5.97	16.3	31.39	39.0	na	na
Cr	8–34	nd	192.4	58.74	27	na	na
Zn	58 (only avg)	34.08	79.8	186.28	204	232	na
As	na	2.40	na	na	26	16	1.2-24

Notes: na = not available; nd = not detected

Maximum level of 1.63 mg/kg was higher than maximum level of 0.96 mg/kg found at children playgrounds in Prague in 2016 (Vavra et al. 2016).

» Copper (Cu): Rustavi (58.4 mg/kg) sits between the lower values in South Korea (5.97 mg/kg) and Poland (16.3 mg/kg), and higher values from Colombia (39.0 mg/kg) and China (31.39 mg/kg).
» Chromium (Cr): The average in Rustavi (64.6 mg/kg) is relatively high, exceeding levels in Colombia (27 mg/kg) (Donado et al. 2021) and Türkiye (8–34 mg/kg) (Parlak et al. 2022), and even surpassing levels in China (58.74 mg/kg) (Li et al. 2023), but still lower than in Poland (192.4 mg/kg) (Zglobicki et al. 2021).
» Zinc (Zn): Rustavi (364.7 mg/kg) has among the highest average Zn levels, exceeding those in all other studies, including Colombia (204 mg/kg) and Cape Town (232 mg/kg).
» Arsenic (As): With 5.0 mg/kg, Rustavi falls below the averages in Donado et al. (2021) (26 mg/kg) and Shezi et al. (2022) (16 mg/kg), but above the low range reported by Figueiredo et al. (2011) (1.2–24 mg/kg).
» Mercury (Hg): The average in Rustavi (0.12 mg/kg) is higher than values reported in South Korea (0.02 mg/kg) and Poland (0.027 mg/kg), but lower than Colombia (0.1 mg/kg).

These comparisons suggest that Rustavi playgrounds exhibit moderate to elevated contamination, particularly for zinc, chromium, and lead, reinforcing the need for local soil quality monitoring and protective policies in recreational areas. It is also important to consider contamination with POPs, described in Chapter 4, which appears to be significant.

6.1.2. Heavy Metals in dust samples

This section presents the concentrations of selected heavy metals measured in dust samples collected from various locations in Rustavi and compares them with the reference site in Udabno (Table 6.5).

The analysis of six dust samples (five from Rustavi and one from the rural reference site Udabno) revealed significantly elevated concentrations of heavy metals in multiple urban samples, especially GE-RD-1 and GE-RD-3.

TABLE 6.5 CONCENTRATION OF HEAVY METALS IN DUST SAMPLES (mg/kg)

Element	GE-RD-1	GE-RD-2	GE-RD-3	GE-RD-4	GE-RD-5	GE-UD-1 (ref.)
Mercury	0.093	0.023	0.021	0.005	0.017	0.020
Lead	344	31	74.6	26.7	24.4	14.2
Cadmium	6.875	1.047	1.77	0.325	0.617	0.262
Copper	300	72.4	170	64.9	93.6	38.5
Chromium	163	152	1,360	696	310	42.9
Zinc	1,566	209.5	758	74.2	150.6	66.9
Arsenic	10.5	9.76	8.94	2.2	6.17	6.98

» Mercury (Hg): The highest value (0.093 mg/kg) was found in GE-RD-1 and is over 4.5 times higher than in the reference site (0.02 mg/kg). Other urban samples were mostly at or below the reference level.
» Lead (Pb): GE-RD-1 again stands out with 344 mg/kg, which is 24 times higher than the reference (14.2 mg/kg). GE-RD-3 also showed elevated levels (74.6 mg/kg), indicating likely industrial influence.
» Cadmium (Cd): The most contaminated sample was GE-RD-1 (6.875 mg/kg), which is over 26 times higher than the reference (0.262 mg/kg). Other samples were also elevated, especially GE-RD-3 and GE-RD-2.
» Copper (Cu): Elevated concentrations were found across most urban sites, with GE-RD-1 (300 mg/kg) and GE-RD-3 (170 mg/kg) showing the highest values. All Rustavi samples exceeded the reference (38.5 mg/kg), in some cases up to 8 times.
» Chromium (Cr): GE-RD-3 showed an extreme value of 1360 mg/kg, more than 30 times higher than the reference site (42.9 mg/kg). GE-RD-4 and GE-RD-5 also revealed substantially elevated levels.
» Zinc (Zn): The most pronounced contamination was again in GE-RD-1 (1566 mg/kg) and GE-RD-3 (758 mg/kg), compared to just 66.9 mg/kg at the reference location.
» Arsenic (As) levels in Rustavi dust samples were moderately elevated compared to the reference site in Udabno (6.98 mg/kg), with the highest value found in GE-RD-1

(10.5 mg/kg). GE-RD-2 and GE-RD-3 also exceeded background levels, indicating diffuse industrial influence.

The contamination levels in Rustavi dust samples closely correlate with land use and proximity to industrial sources, as confirmed by field protocols. GE-RD-1, collected directly within an industrial area, showed the highest levels of nearly all analysed heavy metals, including chromium, zinc, lead, and cadmium. This strongly suggests a direct impact of historical or ongoing industrial activity at the site.

GE-RD-3, located next to a slag dump and a former gravel quarry used for waste disposal, also exhibited extremely high levels of chromium, zinc, and copper, pointing to legacy contamination from slag processing and reuse. GE-RD-4 and GE-RD-5 were taken near metallurgical facilities or roads built using slag material and showed substantial contamination, especially with chromium and zinc. GE-RD-2, sampled in a residential area close to a cement plant, presented moderate levels of contamination, likely reflecting airborne emissions and diffuse urban-industrial sources.

In contrast, the rural reference site GE-UD-1 in Udabno showed uniformly low concentrations of all analysed metals, confirming its suitability as a background location. The spatial distribution of contaminants and field context highlight the strong influence of industrial facilities and secondary use of metallurgical waste in shaping the environmental burden in Rustavi.

Comparison with literature data

The measured concentrations of heavy metals in street dust samples from the study area were compared with average values reported in previous studies from various urban and industrial regions worldwide (Cai and Li 2019; Denny et al. 2022; Jiang et al. 2018; Kianpor et al. 2019; Ordonez et al. 2003; Sun et al. 2017), see Table 6.6.

TABLE 6.6 AVERAGE OR MEAN CONCENTRATIONS OF HEAVY METALS (mg/kg) IN STREET DUST FROM SELECTED URBAN AND INDUSTRIAL AREAS REPORTED IN LITERATURE AND IN THIS STUDY

Author (year)	Cai and Li (2019)	Denny et al. (2022)	Jiang et al. (2018)	Kianpor et al. (2019)	Sun et al. (2017)	Ordonez et al. (2003)	this study
Type of sample and results	street dust, average	road dust in post industrial city, average	street dust, industrial city (mean, min, max)	industrial area, street dust	street dust, mean	street dust, industrial city, mean	Street dust, industrial city - average (min –max)
City, country	Shijiazhuang, China	Michigan, USA	Lanzhou, China	Ahvaz, Iran	Zhuzhou, China	Spain	Rustavi, Georgia
Hg	0.29	0.09	NA	NA	0.92	2.56	0.03 (0.005–0.093)
Pb	154.78	134	34.7 (8.42–61.0)	86	956	NA	100.1 (24.4–344)
Cd	1.86	1.09	0.812 (0.102–3.21)	0.3	41.4	22.3	2.1 (0.325–6.875)
Cu	91.06	91.6	77.4 (33.6–151)	50	139	NA	140.2 (64.9–300)
Cr	131.7	198	96.9 (18.8–135)	57	124.6	NA	536.2 (152–1360)
Zn	496.17	556	56.6 (41.5–109)	999	2,379	4,892	551.7 (74.2–1566)
As	NA	8.0	NA	6	87.8	NA	32.6 (2.2–10.5)

Heavy metal concentrations in Rustavi's street (road) dust generally fall within the range of values reported from other industrial and urban areas. Mercury (0.03 mg/kg) and cadmium (2.1 mg/kg) levels were relatively low, especially compared to highly polluted sites such as Zhuzhou, China (Sun et al. 2017), and Spain (Ordonez et al. 2003). Arsenic (32.6 mg/kg) was moderate, lower than in Zhuzhou but higher than in Iran and the USA (Denny et al. 2022; Kianpor et al. 2019).

Lead (100.1 mg/kg) and copper (140.2 mg/kg) concentrations were in the mid-range, suggesting some industrial influence. Zinc (551.7 mg/kg) was comparable to levels in Michigan, USA and Shijiazhuang, China (Cai and Li 2019; Denny et al. 2022), but well below peak values in Zhuzhou and Spain.

Chromium stood out with an average of 536.2 mg/kg, far exceeding values from all other reviewed cities. This suggests a strong local source of Cr pollution, likely linked to industrial activity.

Overall, the data indicate moderate contamination, with chromium representing the most significant concern for environmental and health risks. Lead levels were also noteworthy: although not the highest compared with other cities globally, lead is a wellknown toxic element in the environment and warrants continued attention and control measures.

6.2. Conclusion

The analysis of environmental samples from Rustavi revealed moderate to high levels of heavy metal contamination, particularly in areas near industrial facilities. Among playground soils, elevated concentrations of zinc, copper, lead, cadmium, and chromium were detected, with GE-RPG-2, GE-RPG-3, and GE-RPG-4 showing the highest values.

Although most elements remained below Czech hygienic limits for children's playground sandboxes, cadmium and zinc exceeded the respective thresholds, indicating potential health risks from direct soil contact.

In comparison to similar sites in Kazakhstan, South Korea, China, and other countries, Rustavi playgrounds exhibited relatively low concentrations of lead and copper, but higher levels of chromium and zinc, reflecting a distinct local pollution pattern, likely shaped by nearby ferroalloy and cement production. Mercury and arsenic levels were generally low to moderate.

In urban street dust, heavy metal concentrations were consistently elevated in samples collected near industrial areas. The most contaminated sites—GE-RD-1, located directly within an industrial zone, and GE-RD-3, adjacent to a slag dump—showed extremely high levels of chromium (up to 1360 mg/kg), zinc (up to 1566 mg/kg), and lead (up to 344 mg/kg). When compared to international data from China, Iran, Spain, and the USA, dust samples from Rustavi displayed equal or higher concentrations of several metals. Chromium, in particular, stood out as the most prominent contaminant, exceeding all values reported in the reviewed studies.

Overall, the findings confirm that industrial emissions in Rustavi contribute significantly to environmental contamination, particularly affecting recreational areas and urban dust. While not all levels exceed healthbased guidelines, the combined exposure risk—especially for children—justifies further monitoring, risk communication, and mitigation efforts, with particular attention to lead and chromium due to their longterm health impacts.

7. EVALUATION OF DIETARY INTAKE

This study does not aim to assess the overall dietary intake of the population living in Rustavi and Tazakendi village. However, we can at least partially evaluate the contribution of two locally sourced food items—free-range chicken eggs and local fish—to dietary intake. For this, we rely on the percentage that eggs, and fish represent in the average food basket in Georgia. The relevant data were taken from data collected by FAO (HelgiLibrary 2025a; HelgiLibrary 2025b). We also base our calculations on the average body weight (bw) of an adult in Georgia, which was 84.4 kg for male and 73.6 for women (Wikipedia 2016).

For our calculations, we use the POPs data obtained from the analyses of free-range chicken eggs and fish presented in the previous Chapters 4 and 5. Due to financial constraints of our project, we are unable to assess dietary exposure for the full spectrum of POPs studied, as, for example, PCDD/Fs and dl-PCBs were analysed in eggs but not in fish. We therefore limit the evaluation to DDT and PCBs for both fish and eggs, and to PCDD/Fs/dl-PCBs in eggs in addition to that. The results of the calculation are summarised in Tables 8.1 and 8.2 in Annex 3. There is also a comparison with Tolerable Daily Intake (TDI) or Reference Dose (RfD) when they are established for PCDD/Fs/dl-PCBs, DDT and its metabolites (∑DDT) or ndl-PCBs.

The European Food Safety Authority (EFSA) had established a new TDI for PCDD/Fs/dl-PCBs at a level of 0.25 pg WHO-TEQ/kg bw/day in 2018 (EFSA CONTAM 2018). This is used mainly within EU countries. However, there is another value for TDI which was suggested by WHO in 2005 at level of 2 pg WHO-TEQ/kg bw/day.

The provisional TDI for ∑DDT is 0.01 mg/kg body weight based on the guideline for drinking water value suggested by WHO (ATSDR 2022; WHO 2017). The US EPA RfD was established at 500 ng/kg bw. No TDI or RfD has been established yet for ndl-PCBs.

7.1. Dietary exposure to PCDD/Fs, dl-PCBs, PCBs and DDT from free-range eggs

The analysis of locally produced free-range chicken eggs collected from Rustavi and Tazakendi village revealed significantly elevated levels of POPs, particularly PCDD/Fs, dl-PCBs, indicator PCBs and DDT. Concentrations of PCDD/Fs and dl-PCBs ranged from 0.73 to 2.37 pg WHO-TEQ/g fresh weight (fw) in free-range eggs, while the commercially produced egg purchased from a supermarket (sample GE-R-EGG-SUP) contained only 0.02 pg WHO-TEQ/g fw.

As a result, estimated daily intakes for adult consumers eating just one local free-range egg per day exceeded the TDI levels recommended by both the European Food Safety Authority (EFSA CONTAM 2018) and the World Health Organisation (WHO 2019). For instance, in females (73.6 kg body weight), the EFSA TDI was exceeded by 280% to 373% depending on the sample, compared to only 3.1% for the supermarket egg. According to WHO's less stringent TDI, most free-range egg samples still represented 14–47% of the threshold, while the supermarket egg contributed just 0.4%.

Furthermore, calculations show that consuming even a fraction of a free-range egg (as little as 0.12–0.4 eggs per day) could result in exceeding the WHO TDI of 14.5 pg WHO-TEQ/day. In stark contrast, it would take over 14 eggs from the supermarket to reach the same level of exposure. These findings highlight a substantial health concern for individuals regularly consuming free-range eggs from the area.

Indicator PCBs (∑6 PCB) were also found at elevated concentrations in free-range eggs, reaching up to 11.6 ng/g fw (GE-R-EGG-4), compared to only 0.47 ng/g fw in the supermarket egg. Estimated intake values showed that, for both males and females, dietary exposure to PCBs from local eggs could be up to 25 times higher than from commercial eggs. We cannot compare it with TDI or RfD levels yet as no such level has been established for the PCBs indicator.

Similarly, ∑DDT concentrations in free-range eggs ranged from 1.6 to 774 ng/g fw, with sample GE-R-EGG-4 showing an exceptionally high level. Intake estimates indicate that the provisional TDI and the US EPA RfD for DDT were not exceeded in any case. However, in samples GE-R-EGG-4, GE-R-EGG-5 and GE-R-EGG-6, intake reached up to 61% of the US RfD, suggesting that long-term consumption may present a non-negligible risk.

7.2. Dietary exposure to PCBs and DDT from consumption of local fish

Although PCDD/Fs and dl-PCBs were not analysed in fish samples from the Mtkvari River, the presence of other persistent organic pollutants (POPs) such as indicator PCBs (∑6 PCB) and DDT suggests a non-negligible toxic burden associated with local fish consumption. Concentrations of ∑6 PCB ranged from 2.6 to 18 ng/g fresh weight (fw), with the highest levels found in samples GE-RF-2 and GE-RF-7 (17.96 and 15.43 ng/g fw, respectively). These values are comparable to or higher than those found in free-range eggs from the same area.

Estimated daily intake values per kilogram of body weight suggest that fish consumption contributes significantly to PCB exposure, especially in females. For example, in female consumers (73.6 kg bw), PCB intake from individual fish samples ranged from 1.26 to 7.08 ng/kg bw, with six out of twelve samples exceeding 3 ng/kg bw. This level of exposure is of concern given the cumulative effects of PCBs and their bioaccumulative nature.

DDT levels in fish samples also varied widely, from 12.8 to 85.6 ng/g fw. Sample GE-RF-2 again exhibited the highest concentration. Estimated intake values for DDT ranged from 5.1 to 33.7 ng/kg bw in females and from 4.4 to 29.4 ng/kg bw in males. When compared to toxicological reference values, these exposures represent up to 0.34% of the provisional TDI and up to 6.75% of the US EPA RfD. While these percentages do not exceed established thresholds, they indicate a substantial intake from a single food group.

7.3. Dietary exposure to DTT and PCBs in comparison with other studies

Although ∑DDT levels in fish were higher (13–86 ng/g fw) than in a study from Bangladesh (3–16 ng/g fw) (Haque et al. 2017), Georgian consumers eat less fish and have a higher average body weight. Still, DDT burden from fish consumption in Rustavi was about twice as high. In that study, researchers recommended reducing DDT intake among women of reproductive age due to fetal exposure risks (Haque et al. 2017).

PCB exposure from fish in Rustavi was 2–3 times higher than in the Bangladesh study (Haque et al. 2017). The average ∑6 PCB concentration in Mtkvari fish (8.3 ng/g fw) matches levels found in European countries during the 1990s to early 2000s (Fattore et al. 2008).

In contrast, the average ∑6 PCB contamination in Rustavi's free-range eggs (46.9 ng/g fat) was much higher than in the European study (6.6 ng/g fat), likely due to the industrial environment and the inclusion of mostly free-range eggs in Rustavi versus commercial ones in Europe.

7.4. Conclusions

Data on ndl-PCBs in Rustavi's eggs and fish show serious local food contamination, likely related to industrial activity, including metal processing. PCBs are common in scrap metal and in older equipment such as transformers.

The Rustavi egg samples point to particularly high exposures. Even in Bangladesh, with lower DDT intake, researchers urged reduced exposure in women of reproductive age.

Compared to commercial eggs, free-range eggs from Rustavi pose a substantially higher dietary exposure to multiple POPs. Although legal limits may not be exceeded individually, the combination of several POPs and long-term exposure—especially in vulnerable groups like children and pregnant women—constitutes a serious public health issue.

Similarly, even moderate fish consumption from the Mtkvari River contributes significantly to PCB and DDT exposure. Considering parallel exposures from local eggs and environmental sources, the cumulative risk for Rustavi residents consuming local food cannot be ignored.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

This study provides the first comprehensive assessment of contamination by POPs and heavy metals in various environmental and food matrices from the Rustavi industrial area and its surroundings. The findings highlight serious environmental and public health concerns stemming from historical and ongoing pollution, particularly from industrial activities and poor hazardous waste management.

Key conclusions:

Widespread contamination of food of animal origin: Free-range chicken eggs and locally caught fish from the Mtkvari River contain significantly elevated levels of legacy POPs, especially PCBs and DDTs. In several egg samples, PCDD/Fs and dl-PCBs exceeded the tolerable daily intake recommended by the EFSA, and in one case even a single egg contained a dose close to the US EPA's reference dose for DDT.

Environmental pollution hotspots identified: Soil samples from playgrounds and other public spaces revealed dangerously high levels of DDT, PCBs and other pollutants, in some cases exceeding reference values by hundreds to thousands of times. Contaminated sites were located in close proximity to residential areas, posing a direct risk to children and the general population.

Evidence of recent or ongoing use of DDT: Elevated p,p'-DDT/p,p'-DDE ratios in both soil and biological samples suggest that illegal or uncontrolled use of DDT may still be occurring in the Rustavi area.

Industrial legacy and current sources impact multiple media: The presence of multiple industrial chemicals in soil, eggs, and fish—including heavy metals (e.g. mercury, lead, cadmium, zinc, and chromium), HCB, PCBs, and PCDD/Fs—confirms that both the industrial legacy and ongoing industrial activities in Rustavi continue to affect the environment and food chain.

Inappropriate use of end-of-life consumer products as a source of contamination: In some cases, local contamination of free-range eggs was linked to the presence of POPs originating from the inappropriate use of discarded consumer products—such as an old mattress—within chicken runs. Some compounds, including PBDEs and HBCD, reached concentrations among the highest ever reported globally, demonstrating that such point sources can significantly contribute to food chain contamination even in small-scale, household settings.

Dietary exposure represents cumulative risk: While individual POP and heavy metals (especially mercury) concentrations in food sometimes remain below regulatory limits, the cumulative dietary exposure to multiple contaminants—especially for sensitive groups such as children or pregnant women—presents a serious long-term health risk.

8.2. Recommendations

Pollution source investigation and control:

» Identify and eliminate ongoing illegal use or releases of banned POPs, particularly DDT.
» Map and remediate legacy stockpiles and contaminated sites, especially near residential areas and public spaces.

Food safety and public health protection:

» Issue official fish consumption advisories for the Mtkvari River and promote public awareness about the risks associated with consuming free-range eggs from Rustavi.
» Improve regulation and monitoring of food of animal origin in contaminated areas, including free-range chicken egg and meat production.

Environmental monitoring and research:

» Establish regular biomonitoring programs for POPs and heavy metals in environmental and biological matrices.
» Expand analytical scope to include PCDD/Fs and dl-PCBs in fish and monitor additional contaminants of concern (e.g. PFAS).

Policy and institutional actions:

» Strengthen the implementation of the Stockholm Convention and relevant EU environmental and food safety regulations.
» Support local and national authorities in building capacity for hazardous waste management, environmental monitoring, and enforcement.

Community engagement and international cooperation:

» Develop appropriate communication strategy on environmental and risk hazards for the communities living within the areas of significant impact of the industrial zones and polluted sites.
» Involve local communities in participatory monitoring, including citizen science projects, and decision-making on environmental permits, EIA and other permits issued for existing as well as newly planned sources of pollution.
» Seek technical and financial support through international mechanisms, including the UNDP/GEF and EU-funded initiatives, to support site remediation and capacity building.

The results of this study should serve as a basis for urgent environmental health interventions and long-term pollution management planning in Georgia.

9. ANNEXES

9.1. Annex 1: A Brief Characterization of Harmful Substances Monitored in This Study

9.1.1. Heavy Metals

Toxic metals: Because of their high degree of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure (Tchounwou et al. 2012).

Arsenic (As), occurring naturally and via mining, metallurgy, and coal burning (Bencko 1984; Bhattacharya et al. 2007; Rasheed et al. 2016), poses acute inhalation risks (gastrointestinal and nervous system effects) (Rahman et al. 2011; Rodriguez et al. 2003). Chronic exposure leads to skin irritation, neurological issues (Chen et al. 2013; Tsai et al. 2003; Tseng et al. 2003). IARC designates arsenic and arsenic trioxide as a human carcinogen, strongly linked to lung and bladder cancer; evidence for other cancers is partial (IARC 2012). Non-carcinogenic risks include fetal development, children's neurodevelopment, nervous system impact, and heart/vessel diseases (EFSA CONTAM 2009).

Cadmium (Cd), a highly toxic element found naturally in soil, is prevalent in the environment due to human activities (Genchi et al. 2020; Kubier et al. 2019; Musilova et al. 2017). Its primary route of human exposure is through the ingestion of contaminated foods (Hellstrom et al. 2007; Hosseini et al. 2013; Perez and Anderson 2009) and water (Genchi et al. 2020). Prolonged exposure leads to cadmium accumulation in the kidneys, causing kidney disease, fragile bones, and lung damage. Chronic exposure is associated with hypertension, arthritis, anemia, cardiovascular disease, diabetes, hypoglycemia, headaches, osteoporosis, and an elevated risk of cancer (Nordberg et al. 2022). Furthermore, cadmium adversely affects the female reproductive system (Chen et al. 2015; Ju et al. 2012; Lin et al. 2015). Mitigating sources of cadmium exposure is crucial for safeguarding human health and preventing associated detrimental effects. Cadmium is frequently detected in urine samples from communities affected by mining (Suta et al. 2020) or metallurgy, and it is also observed in sediments in those areas (Grechko et al. 2021b; Matoušková et al. 2023). IARC classifies cadmium and its compounds as carcinogenic to humans (Group 1); (IARC 2023).

Chromium (Cr) exists naturally in minerals and is widely used in manufacturing, including metallurgy, textiles, papermaking, and various products like dyes and fertilizers. Its environmental presence stems from landfill leaching, ore extraction, and petroleum/coal combustion (Dellantonio et al. 2008; Jin et al. 2014). Chromium (VI) causes skin issues, respiratory problems, weakened immunity, and kidney/liver damage, inducing oxidative stress and DNA/protein damage (Guertin et al. 2004; Song et al. 2012). Inhalation of its compounds leads to nasal membrane ulcers, throat irritation, bronchitis, wheezing, and respiratory distress. Classified as group 1 by IARC. Remarkably, chromium (III) is vital for human nutrition, found naturally in vegetables, fruits, meats, yeasts, and grains (Anderson 1997; Pechova and Pavlata 2007).

Lead (Pb), a major global environmental health hazard, poses serious risks, particularly to young children, with approximately 80–90% of daily exposure occurring through food consumption (Krejpcio et al. 2005; Liu et al. 2010). Elevated blood lead levels are associated with neurodevelopmental issues in children, including attention-deficit disorders and learning disabilities (Flora et al. 2006). Chronic lead exposure disrupts various body functions, causing neurological, cardiovascular, hematologic, and reproductive issues, including central nervous system dysfunction and encephalopathy (Debnath et al. 2019; Pal et al. 2015; Rao et al. 2014). Lead exposure during pregnancy is linked to miscarriage, while prolonged exposure reduces male fertility (Amadi et al. 2017; Vigeh et al. 2011). Environmental impacts include lead binding to airborne dust particles, settling on vegetation, and its presence in soil and water (Nieder et al. 2018). Lead is cumulative and has a long half-life in bones, posing ongoing risks, especially during physiological changes. Lead is classified as a human carcinogen 2B (IARC 2023).

Mercury (Hg) occurs naturally in various forms, spread through erosion (MŽP 2021a), weathering, and anthropogenic sources like combustion processes, coal burning, and mining (Sundseth et al. 2017). Inhaling mercury vapor poses significant risks to the nervous, immune, digestive, respiratory, and renal systems, with symptoms ranging from neurological disorders to potential fatality (Basu 2023; Tchounwou et al. 2003). In aquatic settings, inorganic mercury transforms into highly toxic methylmercury (MeHg), accumulating in fish and shellfish and posing serious health risks upon consumption (Evers et al. 2013; Harris et al. 2003). MeHg adversely affects the nervous, cardiovascular, liver, kidney systems, and disrupts hormones, impacting developing fetuses and inhibiting plant growth (Kumari et al. 2020; Trasande et al. 2016). IARC classifies methylmercury compounds as possibly carcinogenic to humans (Group 2B); (IARC 2023).

Copper (Cu) is a vital element for the human body, crucial for functions such as hormone secretion, nerve conduction, electron transfer, bone and connective tissue growth, and red blood cell synthesis. Despite its small quantity (50–120 mg) in the body, copper plays a critical role in various biochemical processes and its deficiency in adults can lead to blood and nervous system disorders (Ackah et al. 2014; Medeiros et al. 2012; Saracoglu et al. 2009). However, excessive copper intake can lead to health issues such as inflammation in the brain tissues, fatigue, hair loss, allergies, and even serious conditions like kidney dysfunction and cancer (Sobhanardakani et al. 2018). Environmental impacts highlight that copper, while essential for animals and plants, can become toxic to aquatic organisms in higher concentrations (Hossain and Rakkibu 1999).

Zinc (Zn) is essential for living organisms. Humans predominantly acquire it through food. However, excessive intake acutely causes gastrointestinal disorders and chronic damage to blood or the pancreas. While not a significant risk to human health, chronic consumption of large amounts of zinc can increase the risk of heart disease and affect the immune system (MŽP 2021b; Nriagu 2007). The first type of well studied toxic reactions to zinc in human beings was the "metal fume fever" induced by intense inhalations of industrial fumes containing zinc oxide. The most prominent respiratory effects of metal fume fever include fever, chills, gastroenteritis, substernal chest pain, and coughing (Nriagu 2007). Zinc is considerably toxic to fish and other aquatic organisms, particularly sensitive are salmonid fishes. It dissolves minimally in water and typically binds to soil particles (MŽP 2021b; Rainbow and Luoma 2011; Skidmore 1964). As for humans, zinc is essential for plants but too much zinc affects plants' health (Kaur and Garg 2021).

9.1.2. Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants and other organic substances: Due to their high persistence in the environment, potential for long-range transport, bioaccumulation in the food chain, and significant toxic effects, substances such as DDT, HCH, and polychlorinated biphenyls (PCBs) are classified among priority pollutants of global concern.

Organochlorine pesticides (OCPs) in our study represent substances such as DDT, HCH (including lindane), and HCB. All of them were used in large quantities, and many places are still contaminated by them today. These are substances that individually affect human health, but it is also not possible to exclude their synergistic effect. For example, one study has reported OCP to trigger anti-androgenic effects in men and estrogenic effects in women (Freire et al. 2014).

Dichlorodiphenyltrichloroethane (DDT), a globally recognised organochlorine insecticide in use since 1945, has played a significant role in agriculture and the control of vector-borne diseases, particularly malaria since 1955. Its inclusion in the initial list of Persistent Organic Pollutants (POPs) regulated by the Stockholm Convention led to restrictions on its use, with the World Health Organisation permitting its reintroduction solely for vector-borne disease control in select tropical countries in 2006. The physicochemical properties of DDT coupled with its remarkable persistence—characterized by a half-life of up to 30 years—contribute to its association with various health and societal problems. These issues stem from DDT's accumulation in the environment and its biomagnification in living organisms, as highlighted by Mansouri et al. (2017). The Stockholm Convention, listing DDT in Annex B, strictly regulates its production and use (Stockholm Convention 2010).

The term DDT generally refers to the commercial pesticide formulation that includes several related compounds. Consequently, the usage of DDT implies the release of at least six derivatives in the following relative amounts: p,p=-DDT> o,p=-DDT> p,p=-DDE> o,p=-DDE> p,p=-DDD> o,p=-DDD (Haller et al. 1945). Each para, para p,p=-substituted isomer is more abundant than the corresponding ortho, para o,p=-substituted one. The three major components, p,p=-DDT, p,p=-DDE, and p,p=-DDD are generally referred to in the literature as DDT, DDE, and DDD, respectively, and as isomers (or metabolites, although not always correct or the case); (Hellou et al. 2013).[10] Our use of **DDT, DDE, and DDD** without a prefix relates to both p,p=isomers and o,p=isomers.

Initially employed during World War II to safeguard soldiers and civilians from malaria and other insect-borne diseases, DDT continued post-war for disease control and agricultural purposes, notably on crops such as cotton. While its application against mosquitoes persists in certain countries to control malaria, DDT's stability and pervasive use have resulted in residues being found globally. Up to 50% of applied DDT can persist in the soil for 10-15 years, with traces even detected in the Arctic (Stockholm Convention 2019).

One of the most well-known toxic effects of DDT is eggshell thinning in birds, particularly birds of prey, as documented in Rachel Carson's influential work, "Silent Spring" (Carson 1962). This impact led to bans on DDT in numerous countries during the 1970s. [11] Despite these bans, DDT continues to be detected in food globally. Although residues in domestic animals have diminished, food-borne DDT remains a primary exposure source for the general population. Long-term exposure to DDT has been associated with chronic health effects, including its detection in breast milk, raising concerns about infant health (Stockholm Convention 2019). The findings of Carson are echoed in environmental literature such as "Our Stolen Future" (Colborn et al. 1997), emphasising reproductive effects linked to DDT exposure (Hellou et al. 2013).

DDT exposure poses significant risks to human health, manifesting in neurological effects, liver effects, reproductive effects, and immunological effects, including neurodevelopmental impacts (ATSDR 2022; Dallaire et al. 2004). Additionally, DDT and its derivatives are recognised as endocrine-disrupting chemicals (Turusov et al. 2002). Compounds like DDE and DDD, proposed to be more persistent than the parent compound (Teeyapant et al. 2014), exhibit higher toxicity and ecotoxicity (Johnson and Finley 1980; Mansouri et al. 2017). DDT is a probable human carcinogen (2A); (IARC 2023).

Notably, high levels of DDT have been found in free-range chicken eggs, particularly in the vicinity of DDT production sites, obsolete pesticide stockpiles, and waste incinerators and dumpsites where DDT-containing waste was disposed (Dvorska et al. 2009; Dvorská et al. 2007; Hlebarov et al. 2005; Jayakumar et al. 2005; Khwaja et al. 2005; Mng'anya et al. 2005; Petrlik et al. 2022b; Skalsky et al. 2006). Higher concen-

10 The chemical nomenclature for these three prevalent structures is 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane for p,p DDT, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene for p,p DDE, and 1,1-dichloro-2,2-bis (p-chlorophenyl)ethane for p,p DDD

11 Environmental research on organochlorine contaminants (OCs) has been ongoing since the 1940s. One book, Silent Spring by Rachel Carson (1962), is unanimously cited as raising awareness of the dual role of synthetic chemicals, "the good and the bad sides". The book describes the eggshell thinning discovered in birds when the spraying of dichlorodiphenyltrichloroethane (DDT) was initiated to eradicate disease, especially malaria. This book played a major role in generating environmental awareness in the population at large, including scientists, because it was written in an accessible style.

trations of DDT were found in free-range eggs from sites in post-Soviet countries in general (Petrlik et al. 2016; Petrlik et al. 2018).

POPs, including DDT, exhibit a tendency to bind to small particles in the soil, starting to accumulate in sediments shortly after application (Barnhoorn et al. 2009). The fate and transport of DDT in sediment–water systems depend on various site-specific characteristics, environmental conditions, and geo-technical factors, encompassing topography, geology, tidal influences, and sediment composition. DDT in sediments can undergo transformation or partial degradation under suitable environmental conditions. Unfortunately, the resultant degradation products remain as toxic and persistent as the original pesticides. The half-life of DDT in sediments varies between 2 and 25 years (Augustijn-Beckers et al. 1994; Chattopadhyay and Chattopadhyay 2015).

High levels of DDT in sediments have been observed in the vicinity of contaminated sites, legacy production areas, and obsolete pesticide stockpiles stockpiles (Jayakumar et al. 2005; Kohušová et al. 2010; Petrlik et al. 2006). This observation underscores the persistent environmental impact of DDT, necessitating ongoing monitoring and management efforts.

Hexachlorocyclohexanes (HCHs): Lindane (the gamma isomer of HCH) has been used as a broad-spectrum insecticide for seed and soil treatment, foliar applications, tree and wood treatment, and against ectoparasites in both veterinary and human applications (POP RC 2006b). Lindane is persistent, easily bioaccumulates in the food chain, and bioconcentrates rapidly. There is evidence of long-range transport and toxic effects (immunotoxic, reproductive, and developmental effects) in laboratory animals and aquatic organisms. Lindane is classified as human carcinogen (Group 1) by IARC (2023).

High levels of lindane and other HCH isomers were found in free range chicken eggs, in particular from the vicinity of lindane production sites, obsolete pesticide stockpiles, and/or waste incinerators and dumpsites where the waste containing HCHs was disposed of (Agarwal et al. 2005; Blake 2005; Kleger et al. 2006). An extremely high concentrations were found, for example, in the vicinity of the Tintareni landfill in Moldova and abandoned lindane production site in Porto Romano, Albania (Kleger et al. 2006; Petrlik et al. 2022b).

Alpha- and Beta-HCH are highly persistent in water in colder regions and may bioaccumulate and biomagnify in biota and Arctic food webs. These chemicals are subject to long-range transport, classified as probable human carcinogens (2B) to humans (IARC 2023), and have adverse effects on wildlife and human health in contaminated regions (UNEP 2020). Lindane is highly toxic to wildlife, including fish, bees, birds, and mammals (US EPA 2002). The half-life of lindane in humans is less than a day, while the half-life of its major metabolite (beta-HCH) is seven years. Therefore, it is more reliable to measure the latter.

Prenatal exposure to β-HCH has been correlated with altered thyroid hormone levels, which could affect brain development. Studies have shown that all isomers of HCH might reasonably be anticipated to cause cancer in humans (US EPA 2002). Cox et al. (2007) linked β-HCH to increase prevalence of diabetes.

Lindane is listed in Annex A to the Stockholm Convention with specific exemptions for the use of lindane as a human health pharmaceutical for the control of head lice and scabies as a second-line treatment (decision SC-4/15). Alpha- and beta-HCH are listed in Annex A to the Stockholm Convention without specific exemptions (decisions SC-4/10, SC-4/11) (UNEP 2020).

Polychlorinated biphenyls (PCBs) were produced until the 1980s in large volumes and they were used in industry as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics (Stockholm Convention 2019). Approximately 1.3 to 2 million tonnes of PCB were industrially produced in various countries from 1929 to the 1980s (Breivik et al. 2002; Weber et al. 2018). Twelve PCB congeners are considered as dioxin-like PCBs because of their effects and similar properties to PCDD/Fs (European Commission 2012; van den Berg et al. 2006). These congeners are listed as unintentionally produced POPs in Annex C to the Stockholm Convention (Stockholm Convention 2010). Technical mixtures of PCBs are characterised by six,[12] sometimes seven[13] indicator PCB congeners. Maximum levels in food are set for six

12 PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.
13 PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

indicator PCB congeners in food in the EU (European Commission 2012; European Commission 2016).

Polybrominated diphenyl ethers (PBDEs) are a group of **brominated flame retardants (BFRs)** that include substances listed in the Stockholm Convention for global elimination, such as PentaBDE (2009), OctaBDE (2009), and DecaBDE (2017). PBDEs are additives mixed into plastic polymers that are not chemically bound to the material and therefore leach into the environment. They have already been identified in samples from other localities in Thailand (Bystriansky et al. 2018; Petrlik et al. 2017).

PBDEs have adverse effects on reproductive health as well as developmental and neurotoxic effects (POP RC 2006a; POP RC 2007a; POP RC 2014). DecaBDE and/or its degradation products may also act as endocrine disruptors (POP RC 2014).

PentaBDE has been used in polyurethane foam for car and furniture upholstery, and Octa- and DecaBDE have mainly been used in plastic casings for electronics. OctaBDE formed 10%-18% of the weight (Stockholm Convention 2016) of CRT television and computer casings and other office electronics made of acrylonitrile butadiene styrene (ABS) plastic. DecaBDE forms 7%-20% of the weight (POP RC 2014) of many different plastic materials, including high-impact polystyrene (HIPS), polyvinylchloride (PVC), and polypropylene (PP), used in electronic appliances. As this study examines samples from sites affected by the presence of electronic waste and/or by its incineration, all of the above-mentioned PBDEs were part of the main focus of our investigation.

Hexabromocyclododecane (HBCD) is a brominated flame retardant primarily used in polystyrene building insulation. HBCD is an additive mixed into plastic polymers that is not chemically bound to the material and therefore may leach into the environment. HBCD is highly toxic to aquatic organisms and has negative effects on reproduction, development, and behaviour in mammals, including transgenerational effects (POP RC 2010). HBCD is also found in packaging materials, video cassette recorder housings, and electric equipment.

HBCD was listed in Annex A of the Stockholm Convention for global elimination with a five-year specific exemption for use in building insulation that expired for most Parties in 2019 (Stockholm Convention 2013).

Novel brominated flame retardants (nBFRs) are a group of chemicals that in many cases replaced the already restricted BFRs. A group of six novel BFRs was chosen for the analyses in environmental samples from the localities included in this study. Different sources list different chemicals among this group, but only a few of them are measured in the environment. Recent studies also show that nBFRs are becoming widespread in the environment, including in food, particularly in some Asian countries (Shi et al. 2016). A review of the levels of BFRs in soil concluded that: *"Although further research is required to gain baseline data on NBFRs in soil, the current state of scientific literature suggests that NBFRs pose a similar risk to land contamination as PBDEs"* (McGrath et al. 2017).

The scientific panel of the EFSA evaluated 17 "emerging"[14] and 10 "novel"[15] BFRs in 2012 and suggested that: *"There is convincing evidence that tris(2,3-dibromopropyl) phosphate (TDBPP) and dibromoneopentyl glycol (DBNPG) are genotoxic and carcinogenic, warranting further surveillance of their occurrence in the environment and in food. Based on the limited experimental data on environmental behaviour, 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and hexabromobenzene (HBB) were*

14 The group of emerging BFRs included: BEH-TEBP – Bis(2-ethylhexyl) tetrabromophthalate, BTBPE – 1,2-Bis(2,4,6-tribromophenoxy)ethane, DBDPE – Decabromodiphenyl ethane, DBE-DBCH – 4-(1,2-Dibromoethyl)-1,2-dibromocyclohexane, DBHCTD – 5,6-Dibromo-1,10,11,12,13,13-hexachloro-11-tricyclo[8.2.1.02,9]tridecene, EH-TBB – 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate, HBB – 1,2,3,4,5,6-Hexabromobenzene, HCTBPH – 1,2,3,4,7,7-Hexachloro-5-(2,3,4,5-tetra-bromophenyl)- bicyclo[2.2.1]hept-2-ene, OBTMPI – Octabromotrimethylphenyl indane (OBIND in this study), PBB-Acr – Pentabromobenzyl acrylate, PBEB – Pentabromoethylbenzene, PBT – Pentabromotoluene, TBNPA – Tribromoneopentyl alcohol, TDBP-TAZTO – 1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6-trione, TBCO – 1,2,5,6-Tetrabromocyclooctane, TBX – 1,2,4,5-Tetrabromo-3,6-dimethylbenzene, and TDBPP – Tris(2,3-dibromopropyl) phosphate.

15 The group of novel BFRs included: BDBP-TAZTO – 1,3-Bis(2,3-dibromopropyl)-5-allyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBNPG – Dibromoneopentyl glycol, DBP-TAZTO – 1-(2,3-Dibromopropyl)-3,5-diallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, DBS – Dibromostyrene, EBTEBPI – N,N'-Ethylenebis(tetrabromophthalimide), HBCYD – Hexabromocyclododecane (HBCD or HBCDD are more of the abbreviations used for this chemical, already listed in Annex A to the Stockholm Convention), HEEHP-TEBP – 2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate, 4'-PeBPO-BDE208 – Tetradecabromo-1,4-diphenoxybenzene, TTBNPP – Tris(tribromoneopentyl) phosphate, and TTBP-TAZ – Tris(2,4,6-tribromophenoxy)-s-triazine.

identified as compounds that could raise a concern for bioaccumulation" (EFSA CONTAM 2012). EFSA's panel also stated that for most of the BFRs that were evaluated, there was not sufficient data about their presence in the environment for meaningful conclusions to be drawn.

Decabromodiphenyl ethane (DBDPE) was introduced in the early 1990s as an alternative to DecaBDE in plastic and textile applications (Ricklund et al. 2010). It was used mainly in wire coatings and polystyrene, in both cases as a replacement for DecaBDE. This widespread contaminant is a highly hydrophobic compound (with a log Kow of 11.1); (Covaci et al. 2011). DBDPE has been identified in sewage sludge (De la Torre et al. 2012), indoor dust (Ali et al. 2011; Julander et al. 2005) outdoor dust (Anh et al. 2018; Muenhor et al. 2010), chicken eggs (Tlustos et al. 2010), and food in general (Shi et al. 2016; Tlustos et al. 2010).

BTBPE was first produced in the 1970s and is used as a replacement for OctaBDEs (Hoh et al. 2005). It has been identified in various abiotic media (dust, the atmosphere, sediment, water) and biotic media (zooplankton, mussels, fish, aquatic birds' eggs, honey, chicken eggs, or food in general) (Ali et al. 2011; Anh et al. 2018; Hoh et al. 2005; Julander et al. 2005; Mohr et al. 2014; Petrlik 2016; Petrlik et al. 2017; Poma et al. 2014; Wu et al. 2011).

This compound has the ability to bioaccumulate and to biomagnify in aquatic food webs (Law et al. 2006; Wu et al. 2011). Similarly, to DecaBDE, a commercial mixture of BTBPE was found to contain brominated dioxins (PBDD/Fs) and/or to support their formation during the treatment of ABS plastic (Ren et al. 2017; Tlustos et al. 2010; Zhan et al. 2019). BTBPE has been measured in increased concentrations in Indonesia during passive air sampling conducted in 2005–2006 (Lee et al. 2016).

HBB has commonly been used for the manufacture of paper, wood, textiles, plastics, and electronic goods (Watanabe and Sakai 2003; Yamaguchi et al. 1988) and it is *"likely widely distributed, as verified both by chemical analysis and estimated properties"* (Arp et al. 2011).

The laboratory at the Department of Food Chemistry and Analysis of the University of Chemistry and Technology, Prague, routinely measures six nBFRs in environmental samples, including the egg samples for this study: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylpheny-1-indane (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT).

Out of this group, BTBPE, DBDPE, and HBB are monitored more often in environmental samples (Mohr et al. 2014; Munschy et al. 2011; Poma et al. 2014; Vorkamp et al. 2015).

Dechlorane Plus (DP), a flame retardant in use since the 1960s, is prevalent in electrical coatings, plastic roofing, and polymeric systems. Its release during production, use, and recycling increased post the global elimination of PBDEs (Rauert et al. 2018). Persistent and chemically stable, Dechlorane Plus binds to organic carbon, limiting bioavailability and hindering biodegradation. Despite being bioaccumulative, it exhibits adverse effects on mammals and humans, including oxidative damage, neurodevelopmental toxicity, and potential endocrine disruption (POP RC 2021b). Concentrations of Dechlorane Plus are notably high in water and sediments near e-waste recycling areas. However, comprehensive studies across various environmental matrices, especially in these areas, remain limited (Dvorska et al. 2023b; Li et al. 2018). It was listed in the Annex A to the Stockholm Convention in 2023 (Stockholm Convention 2023).

Pentachlorobenzene (PeCB) and hexachlorobenzene (HCB) are primarily produced unintentionally during combustion, as well as during thermal and industrial processes. They also occur as a by-product during the production of chlorinated hydrocarbons such as perchloroethylene, trichloroethylene, carbon tetrachloride, or pesticides. In the past, they were produced intentionally as pesticides or technical substances. Perchloroethylene is widely used in dry cleaning, and trichloroethylene and carbon tetrachloride have been used extensively as degreasing agents and as solvents for other chlorine-containing compounds. PeCB was used as a component in PCB products, in dyestuff carriers, as a fungicide, as a flame retardant, and as a chemical intermediate for the production of the pesticide quintozene (POP RC 2008).

In high doses, HCB is lethal to some animals and, at lower levels, adversely affects their reproductive success. Researchers also found out that HCB, similarly to other organochlorinated compounds, has a transplacental transfer (Sala et al. 2001). HCB has been found in food of all types (BRS 2017).

Although globally, the con ∑ption of HCB-contaminated food is the primary source of HCB exposure, other potential exposure pathways include the inhalation of

HCB-contaminated air, skin contact, in utero exposure, and from breast milk (Reed et al. 2007). The study also found that in addition to cancer, the human health effects associated with HCB exposure encompass systemic impairment (thyroid, liver, bone, skin) and damage to the kidneys and blood cells, as well as the immune and endocrine systems. It also causes a teratogenic effect, and impairs nervous systems.

PeCB is very toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment (POP RC 2007b).

Hexachlorobutadiene (HCBD) occurs as a by-product during the production of the same chlorinated hydrocarbons as PeCB and HCB, as a part of the so-called "hexa-residues". It is also formed unintentionally during the incineration processes of such substances as acetylene and chlorine residues. HCBD is very toxic to aquatic organisms, and has been shown to cause kidney damage and cancer in animal studies as well as chromosomal aberrations in occupationally exposed humans (Balmer et al. 2019; Pohl et al. 2001; POP RC 2012). Systemic toxicity following exposure via oral, inhalation, and dermal routes may include fatty liver degeneration, epithelial necrotising nephritis, potentially causing chronic inflammation, central nervous system depression, and cyanosis (Balmer et al. 2019; BRS 2017).

UV stabilizers We measured seven phenolic benzotriazole UV stabilizers—UV234, UV320, UV326, UV327, UV328, UV329, and UV350—in free-range chicken eggs. These compounds are widely used to enhance the durability of plastics, coatings, textiles, and other materials by absorbing ultraviolet radiation (Karlsson et al. 2021).

Several of these compounds possess endocrine-disrupting potential (Sakuragi et al. 2021). UV 328 may cause damage to human organs through prolonged or repeated exposure and may cause long lasting harmful effects to aquatic life (ECHA 2023). Three other UV stabilizers with similar properties – UV-320, UV-327, and UV-350 – are regulated in Europe alongside UV-328 (Srebny 2021).

Benzotriazole-type UV stabilizers (e.g. UV326, UV327, UV329, UV350) have been widely detected in plastic materials and environmental compartments such as plastic bottle caps, wastewater treatment effluent, sewage sludge, sediments, dust, seawater, and even human breast milk—demonstrating their persistence and potential for human exposure (Castilloux et al. 2022; Sakuragi et al. 2021; Zhang et al. 2011)

In May 2023, UV328 was formally listed under Annex A of the Stockholm Convention with specific exemptions, marking the first nonhalogenated chemical added to the Convention. While UV328 has reached final listing, other stabilizers such as UV320, UV327, and UV350 have also been screened by the Persistent Organic Pollutants Review Committee (POPRC) due to their persistence, bioaccumulation potential, and toxicity; these are under consideration for future regulation (POP RC 2021a; POP RC 2022).

Polychlorinated dibenzo-p-dioxins (PCDD/Fs) Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), commonly known as dioxins, are highly toxic and persistent by-products of industrial processes such as metal smelting, waste incineration, and chlorinated chemical production (UNEP and Stockholm Convention 2013). They are lipophilic and bioaccumulate in the food chain, with over 90% of human exposure occurring via food—primarily meat, dairy, fish, and seafood (WHO 2023).

Short-term exposure to high dioxin levels may cause chloracne, skin discoloration, and liver damage. Long-term exposure is linked to reproductive and developmental toxicity, neurodevelopmental effects in children, immune system suppression, endocrine disruption, and carcinogenicity (Anwer et al. 2016; Carpenter 2013; Eskenazi et al. 2018; Giesy and Kannan 1998). Dioxins have a long biological half-life (7–11 years), with partial excretion via breastfeeding (WHO 2023).

To estimate total dioxin toxicity in a sample, the DR CALUX® (Dioxin Responsive Chemical Activated LUciferase gene eXpression) bioassay is used. This bioanalytical method measures the activation of the aryl hydrocarbon receptor (AhR) in genetically modified cells after sample exposure. The induced gene expression results in luminescence, quantifiable as bioanalytical equivalents (BEQ) relative to the most toxic congener, 2,3,7,8-TCDD (Besselink et al. 2004a; Besselink et al. 2004b). The method is based on US EPA Method 4435 (European Commission 2012). Unlike conventional chemical analysis, DR CALUX captures the cumulative biological activity of all dioxin-like substances present—including PCDD/Fs, dl-PCBs, and even brominated dioxins.

PCDD/Fs are listed as unintentionally produced POPs in Annex C to the Stockholm Convention (Stockholm Convention 2010). Maximum levels in food are set in updated EU Regulation for PCDD/Fs as well as for PCDD/Fs/dl-PCBs (European Commission 2023).

Polybrominated dibenzo-p-dioxins (PBDD/Fs), or brominated dioxins, are structurally similar to chlorinated dioxins (PCDD/Fs) and exhibit comparable toxicity, including immune and thyroid disruption, teratogenicity, and neurodevelopmental effects (van den Berg et al. 2013; WHO 1998). They are unintentionally formed during production and incineration of brominated flame retardants (Soderstrom and Marklund 2002) and have been detected in air, soil, incinerator ash, and poultry eggs near waste facilities (Hsieh et al. 2023; Teebthaisong et al. 2021; Wang et al. 2010). Unlike chlorinated dioxins, PBDD/Fs tend to accumulate more in solid residues such as bottom ash (Bell et al. 2023). European legislation mandates their monitoring in emissions from incinerators burning brominated waste (European Commission 2019). Brominated dioxins are part of a group of polyhalogenated dioxins nominated for listing under the Stockholm Convention (POP RC 2024).

9.2. Annex 2: Profiles of Fish Species Found in This Study

9.2.1. Topmouth gudgeon (Pseudorasbora parva)

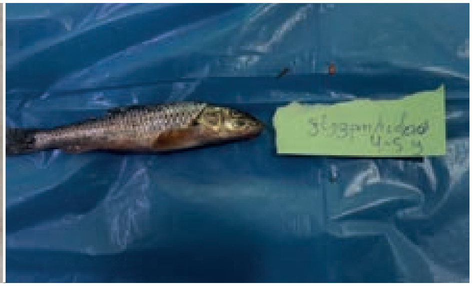

Photo: L. Seebauer (2024)[16]   Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: Also known commonly as the stone moroko (mostly in Asia). First recorded by Temminck & Schlegel, 1846. A small ray-finned, bony fish (teleost), belonging to the family Cyprinidae (carp like fish) in the sub-family Gobionidae (gudgeons). It is a non-native, invasive species originating from East Asia. Elongated and slightly flattened in shape, males and females when not in spawning season are a similar colour - grey back and lighter sides, and belly (yellowish green to silver). During spawning males are darker in colour, females lighter. Short dorsal and anal fins, large deeply incised caudal fin; all fins are rounded. Quite large scales with dark edges. Distinguishing features – Juveniles display a dark coloured stripe along the lateral line on each side. Superior mouth (upturned lower jaw with hard edge), and no barbels present. The fish vary in size commonly from 2 to 8 cm, rarely growing over 8 cm, but can reach a max. length of 11–12 cm. They usually live between 2–4 years but can live to be 5–6 years old, depending on environmental conditions and predation (Bogutskaya 2022; Wikipedia 2008).

Distribution: Native distribution is Asia, including in central and southern Japan, Taiwan, Korea, China and the Amur Basin. It has been introduced into various locations all over Europe and Asia and is also found all over Russia (Bogutskaya 2022). Has been found in Georgia in the Kumis Reservoir since the start of the 1980s and Lake Bazaleti since 1987, (Shoniya et al. 2011).

Environment/habitat: It is a freshwater fish found in a variety of habitats including – small lakes, ponds, ditches, slow-flowing rivers, irrigation channels, canals, reservoirs. It prefers still or slow-flowing waters that are dense with aquatic vegetation. Adults are found in cool running water. Temperature range: 5–22 °C. Highly adaptable and can tolerate low oxygen levels. Its natural predators are pike, perch, zander, catfish and water birds.

Feeding habits: Omnivorous, feeds on small insects, fish and fish eggs, and plant material.

Reproduction/Life cycle: Males and females become dimorphic – males become darker in colour and develop tubercles (pearl organs) on their heads and lower lips, females become paler. Females spawn at 1 year old, spawning takes place from April – June (can be as late as August), in multiple batches, 3–4 times a year. They nest in all sorts of substrates such as on plants, sand or shells, in streams it is under stones, where the male first clears the cavity with his pearl organs, the female then lays hundreds to thousands of eggs. The eggs are adhesive and stick to the substrate. The male then aggressively guards the eggs until they hatch (Copp and Siriwardena 2007).

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 14.04.2020 (Bogutskaya 2022).

Note(s) of interest: Warning – this is a highly invasive and non-native species. It was first recorded in Europe in the 1960s when introduced into ponds in Nucet,

16 https://commons.wikimedia.org/wiki/File:Pseudorasbora_parva_male_and_female.jpg https://creativecommons.org/licenses/by-sa/4.0/

Romania then making its way into the Danube and then rapidly spreading across Europe. Due to its high adaptability and tolerance of environmental conditions and rapid reproduction rate. It is spread via the ornamental fish and aquarium trade, from fish farm ponds, because of its small size it is hard to notice. It is a pest/nuisance fish for anglers. More serious, it out out-competes local valuable species, by eating their eggs and juvenile fish and out-competes them for food due to their aggressive behaviour, stunting native species growth. It also causes eutrophication by feeding on and removing zoo and phytoplankton from waters it inhabits. It carries a range of dangerous parasites and diseases. In the EU it is listed on the List of Alien Species of Union Concern (European Commission 2017), banning its import, transport, breeding, intentional release within the whole of the EU.

9.2.2. Mursa (Luciobarbus mursa)

Photo: Alazani, A (2010)[17]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Güldenstädt, 1773. A ray-finned bony fish (teleost) of the family Cyprinidae (carps), of the sub-family Barbinae (barbels). Long, slender, elongated body adapted to living on the bottom of riverbeds. The mouth is moderate in size, inferior (pointing downward), horseshoe-shaped, with moderate to thick fleshy lips and an undeveloped to strongly developed median lower lip lobe. Scales are small, horizontally elongated, and almost rectangular. The Barbels are thick, the anterior one not extending back beyond the nostril level and the posterior one not exceeding the middle or posterior eye margin. Distinguishing features are high lateral line scale counts and the usual presence of a fleshy, three-lobed lower lip. Overall, colour can be pale grey to olive-grey to brownish, slightly darker over the back and the belly is white to yellowish brown. The side of the head and flanks can have golden tints. The dorsal and caudal fins are pale to dark reddish-brown. The caudal fin has several series of small dark spots. The pectoral and pelvic fins have pale brown rays with transparent membranes but may be pink. The anal fin may be colourless except for a little grey pigment to an overall reddish-brown. The margins of the pelvic and anal fins are well-developed and white, while the pectoral fin has a very narrow white margin. Juveniles may have numerous dark spots on the back and upper flank, lost in adults. Can grow to 39.5–43 cm and can live to 6 years old and become mature at 2–3 years old, (Coad 2021; Wikipedia 2025).

Distribution: Central Asia, namely Armenia, Azerbaijan, Georgia, Türk and Iran.

Environment/habitat: A non-migratory freshwater fish. Avoids muddy bottoms, it prefers fast-flowing streams and rivers with a gravel or sand substrate and a rich benthos. Also, it inhabits lakes and reservoirs, from which it migrates to streams and rivers to spawn if possible. Temperature range unknown but, could prefer cooler water. Benthopelagic (bottom dwelling) temperate climate. Predators include carnivorous fish such as zander and water birds (Wikipedia 2025).

Feeding habits: Food items include chironomids, as much as 70–100% of the diet at times, mayflies, crustaceans such as copepods and ostracods, insects, worms, plankton, vegetation and detritus (Coad 2021). Feeds on the bottom.

Reproduction/Life cycle: Not well recorded, mature at 2–3 years, spawning season is probably in May and June as noted for Georgian fish, but may extend from April to August depending on locality. Reproduce in freshwater streams and rivers possibly preferring gravel bottoms (Coad 2021).

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 18.3.2013 (Freyhof 2014).

Note(s) of interest: No economical interest, apparently tastes better than trout to eat.

17 https://en.wikipedia.org/wiki/Luciobarbus_mursa#/media/File:Luciobarbus_mursa.jpg https://creativecommons.org/licenses/by/3.0/

9.2.3. Bulatmai barbel (Luciobarbus capito)

Photo: Nouripanah, S. (2014)[18]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Güldenstädt, 1773. A ray-finned bony fish (teleost) of the family Cyprinidae (carps), of the sub-family Barbinae (barbels). Slender to slightly rounder, elongated body. There is a rounded keel on the back in front of the dorsal fin. The mouth is moderate in size, inferior and horseshoe-shaped. Lips are fleshy and well-developed with tubercles, but there is no free median lobe on the lower lip. Barbels can be the most developed in thickness in this species, but this can vary. The anterior barbel extends back between the anterior eye margin level and its middle and the posterior barbel extends to the posterior eye margin level or almost to the preopercle in young and some adults. The upper flank and head are steel grey, and the lower flank and belly are a strongly contrasting pale yellow or pearly-white. Occasionally fish with a uniform coloration are found and preserved material may be uniform. The steel-grey upper flank may be comprised of dark scale margins surrounding a silvery-grey scale centre. The lateral line may be darkly pigmented. Spots may occur individually on the body. Barbels are white with grey on the inner surface. The dorsal fin is greyish and may have some dark grey spots. The caudal fin has a greyish or yellowish or slightly orange upper lobe, sometimes with faint dark grey spots, a more strongly coloured and larger yellow-orange to canary-yellow lower lobe and pink margins. The pectoral fin is whitish with a little or considerable amount of pink or yellow. The pelvic and anal fins are canary yellow to orange with a white margin. Young fish may be darkly speckled and mottled on the mid and upper flank, (Coad 2021). They have a lifespan of 4–6 years but can live to 8 years old. They commonly grow to 65 cm in length, to a max. of 1.05 m a max. weight of 15 kg has been recorded.

Distribution: Armenia, Azerbaijan, Georgia, Türkiye, Iran and Southern Russia. It is endemic to the Caspian Sea basin, where it inhabits the majority of inflowing rivers, plus the sea itself. Its range extends southwards around the Caspian coastline, from the Volga River in southern Russia to the Atrek River at the border between Iran and Turkmenistan. Also found in the Black Sea.

Environment/habitat: This relatively large benthic species has two distinct life histories. Some sub-populations are semi-anadromous (migrate from marine or brackish water to freshwater to spawn), inhabiting the Caspian Sea itself and swimming up the inflowing rivers to spawn. This is while others stay resident in these rivers all year round and don't migrate at all. Migratory individuals tend to forage in coastal areas of the Caspian, including estuaries. Their spawning grounds comprise fast-flowing reaches of lowland rivers and streams with substrates of gravel or sand. They avoid muddy bottoms. It has also colonised some reservoirs created by artificial dams or lakes leaving these sub-populations completely landlocked. It occurs in temperate environments (Ford 2024b; Wikipedia 2025).

Feeding habits: Generally, benthopelagic (bottom feeding), feeding on insects, crustaceans and worms, filamentous algae and other plant material, aquatic invertebrates, detritus small fish and even frogs.

Reproduction/Life cycle: Sexual maturity is attained at 3–7 years of age at a body length of 35–50 cm (SL), with females maturing later than males. There is limited evidence to suggest that males spawn on an annual basis, whereas females do so only every 2–3 years. Reproduction occurs from April to August. In semi-anadromous subpopulations, some individuals migrate to rivers during early spring while others do so from late summer to autumn and overwinter there before spawning the following spring. It is a highly fecund, fractional (i.e., females release batches of eggs at intervals during the reproductive period) spawner, and fully-mature females can release as many as 125,000 eggs per year. Landlocked sub-populations breed in upstream tribu-

18 https://fishbase.se/photos/UploadedBy.php?autoctr=25346&win=uploaded

taries and migrate just prior to spawning, although some have successfully adapted to utilise the shallows of artificial reservoirs (Ford 2024b).

Conservation Status: According to the IUCN Red List, it is rated as Vulnerable (VL, A2acd), assessed on 2.8.2022 (Ford 2024b).

Note(s) of interest: Can be semi-anadromous, migratory, living in marine and brackish water, returning to freshwater to spawn. It is rapidly declining in numbers due to threats such as overfishing for food and sport, pollution from industry, agriculture, domestic and urban wastewater. No conservation, monitoring, or action plans for its protection exist!

9.2.4. European chub (Squalius cephalus)

Photo: Jakubec, K. (2011)[19]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Linneaus, 1758. Formerly called Leuciscus cephalus, more recently S. cephalus. A ray-finned bony fish (teleost) of the family Leucisidae (daces), of the sub-family Leucisinae. It is a stocky fish with a large, rounded head. Its body is long and cylindrical in shape and is covered in large greenish-brown scales which are edged with narrow bands of black across the back, paling to golden on the flanks and even paler on the belly. The tail is dark brown or black, the dorsal fin is a greyish-green in colour and all the other fins are orange-red. It commonly grows to 30 cm (TL), but has been recorded to a max. of 60 cm. Max. weight has been recorded of 8 kg, it can live up to 22 years. Females live longer than males (Wikipedia 2002).

Distribution: This species is native to the North, Baltic, White, northern Black, Azov and Caspian Sea basins, Atlantic basin southward to Adour drainage (France), Great Britain north to 56°N, Scandinavia: southern Finland, Sweden north to about Stockholm. Mediterranean basin from Var to Hérault (Aude in France) drainages. Introduced elsewhere, it has been introduced to Ireland, Croatia, and reportedly Spain and Italy (Freyhof 2024c; Wikipedia 2002).

Environment/habitat: This species is most abundant in small rivers and large streams of the so called 'barbel zone' with riffles and pools. Also, along the banks and shores of slow-flowing lowland rivers, even in very small mountain streams. Also in large lakes, undertaking spawning migrations to inflowing streams. Spawns in fast-flowing water above gravel bottom, rarely among submerged vegetation. It has a temperature range of 4–20 °C, and can also be found in benthic regions, although a freshwater species it can also be found in brackish waters. The adult fish are solitary but the juvenile fish are sociable and occur in shoals. The larvae and juveniles prefer rather shallow habitats along shorelines and banks of rivers.

Feeding habits: Feeds on a wide variety of aquatic and terrestrial animals and plant material. Large individuals prey predominantly on small fishes. Chub have been recorded feeding on worms, molluscs, crustaceans, and various insect larvae, even known to eat frogs, crayfish, voles and the young of small water birds. It has also been known to eat berries falling into the water from trees overhanging the water. It feeds all year round even in the coldest days of winter.

Reproduction/Life cycle: Males reproduce for the first time at 2–4 years old, females at 4–6. Maturity is influenced by environmental factors and individuals may mature much later. Spawns in May-August, when the water temperature rises above 12–14°C. Females spawn more than once during a season. Individual females spawn with several males. Males assemble at spawning grounds and follow ripe females, often with much splashing, to shallow riffles. Females deposit sticky pale-yellow eggs into the gravel, that stick to the gravel, weed and stones (Wikipedia 2002).

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 29.5.2022 (Freyhof 2024c).

19 Jakubec, Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=14941862

Note(s) of interest: A very popular and favourite sport fish with anglers. Hybridizes with the common bleak (Alburnus alburnus). Apparently has poor meat quality and does not taste good to eat.

9.2.5. Common bleak (Alburnus alburnus)

Photo: Kagor (2009)[20]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Linneaus, 1758. A ray-finned bony fish (teleost) of the family Leucisidae (bleaks), of the sub-family Leucisinae. The body of the bleak is elongated and flat. The head is pointed and the relatively small mouth is slightly superior (turned upwards). The anal fin is long and has 18–23 fin rays. The lateral line is faint or absent. The bleak has a shiny silvery colour, and the fins are pointed and colourless. It can grow to a max. weight of around 100 g, but commonly between 10–60 g and a max. length of 25 cm (TL), although commonly 12–15 cm (TL). Max. recorded lifespan is 8–9 years, commonly 3–5 years. Individuals mature at age 2–3+ at a size of 8.5–12.0 cm (SL). Can be confused with other species such as common bream, silver bream, roach and rudd.

Distribution: occurs in Europe and Western Asia: north of the Caucasus, Pyrenees and Alps, and eastward toward the Volga basin and in northern Iran and north-western Türkiye. It is absent from the Iberian and Apennine peninsulas, from the rivers of the Adriatic watershed, in the Balkans and most of the British Isles except southeast England. It is locally introduced in Spain, Portugal and Italy (Ford 2024a; Wikipedia 2005a).

Environment/habitat: Inhabits open waters of lakes and medium to large rivers. Forms large groups in backwaters and other still waters during winter. Adults occur in shoals near the surface. The larvae live in the littoral zone of rivers and lakes while juveniles leave shores and occupy a pelagic habitat. It has a wide oxygen and temperature tolerance, as well as colonising rivers it can also colonise heavily-modified habitats and tends to be particularly abundant in eutrophic and mesotrophic waters. Can inhabit low-velocity stretches of both natural and regulated river channels, including floodplains, side-channels and canals, while some populations are found in lakes, marshlands, and artificial reservoirs. Preferred temperature range is from 10–20°C. Natural predators are carnivourous fish such as pike, perch or zander and water birds.

Feeding habits: Feeds mainly on plankton, crustaceans, and insects. Juveniles feed on the surface eating plankton, drifting insects or invertebrates that have fallen on the water surface. It is an omnivorous, opportunistic forager which typically feeds in open water close to the surface. The composition of the diet can shift depending on habitat and food availability, however, and can also include benthic macroinvertebrates, organic detritus, plant material, and the eggs of other fish species.

Reproduction/Life cycle: Its spawning period takes place from April to June when the water temperature ranges between 14 and 15 °C. In larger rivers, spawning occurs in small tributaries or temporally-inundated areas such as floodplains, including ditches that become connected to nearby river channels during periods of high flow. The eggs are scattered over submerged plants, woody debris or fine-grained sediment, and are sometimes transported downstream before settling in nursery zones which tend to be located along channel banks. The larvae initially remain in shallow, still, often vegetated habitats, while juveniles aggregate in slow-moving environments such as side-channels. Males undergo changes during the spawning season, developing tubercles on their backs and flanks, while their fins take on an orange hue. The incubation period for the eggs lasts about 2 to 3 weeks. The growth rate of fry is relatively slow (Ford 2024a; Wikipedia 2005a).

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 5.12.2023 (Ford 2024a).

20 https://commons.wikimedia.org/wiki/File:Alburnus.jpg https://creativecommons.org/licenses/by-sa/3.0/deed.en

Note(s) of interest: Very popular as a bait fish in sport fishing because of its small size. Can be a pest or invasive species where it is non-native, because of its rapid reproduction and eating other fishes' eggs. Hybridizes with other similar species such as rudd, roach, chub and dace (Ford 2024a).

9.2.6. Wels catfish (Silurus glanis)

Photo: Nikkolo (2010)[21]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Linneaus, 1758. A large, ray-finned bony fish (teleost) of the order Siluriformes (catfishes), of the family Siluridae (sheatfishes). Wels or European catfish have numerous lines of small teeth in their mouths. Distinguished from all other freshwater fish in Europe by the following unique characters: two large, long barbels on the upper jaw and four smaller barbels on the lower jaw; and a long anal fin with 83–91 rays extending to the caudal fin. Differs further by the following combination of features: naked body (tiny scales), large, depressed head, a small sharp dorsal fin set relatively far forward, caudal fin rounded or truncate, no adipose fin and the anal rays almost touching the caudal. The body-shape is elongated, it can swim backwards like eels, only a few fish can do this! The skin is very slimy. Skin colour varies with the environment. Clear water will give the fish a black colour, while muddy water will often tend to produce green-brown coloured individuals. The underside is always pale yellow to white in colour. Albino specimens are known to exist. The wels is one of the largest freshwater fish in Europe and Western Asia, only exceeded by the Atlantic and beluga sturgeon. Most adult wels catfish are about 1.3–1.6 m long; fish longer than 2 m are a rarity. At 1.5 m they can weigh 15–20 kg and at 2.2 m they can weigh 65 kg. Only under exceptionally good living circumstances can the wels catfish reach lengths of more than about 2 m. The max. length of the species has been recorded as 3–5 m for a long time and the max. weight as 306 kg. It has been demonstrated that misidentifications and problems of measurement units have led to confusing numbers. The recorded max. size with evidence is 2.73 m and 130 kg. There are many records and stories of monster-sized fish. It is a long living species with a max. recorded age of 80 years (Wikipedia 2006).

Distribution: Europe and Asia. North, Baltic, Black, Caspian and Aral Sea basins, as far north as southern Sweden and Finland; Aegean Sea basin in Maritza and from the Struma to the Sperchios drainages; Türkiye. Absent from the rest of the Mediterranean basin. Now widely introduced and translocated throughout Europe and the Lake Balkhash basin in Kazakhstan (Freyhof 2024b; Wikipedia 2006).

Environment/Habitat: It is a benthopelagic species inhabiting fresh and brackish waters of depths of up to 30 m and a temperature range of 4–20 °C. They are non-migratory. Inhabits large and medium size lowland rivers, backwaters and well vegetated lakes. It occurs mainly in large lakes and rivers, though occasionally enters brackish water in the Baltic and Black Seas. Found in deep waters of dams constructed on the lower reaches of rivers (Freyhof 2024b; Wikipedia 2006).

Feeding habits: A nocturnal predator, feeding near the bottom and in the water column. Very sensitive to extra-aquatic sounds. Head sensory canal system allows it to track the wakes (a trail of hydrodynamic and chemical signatures left by a swimming fish) of prey up to 10 seconds old over distances up to 55 times the length of the prey. Larvae and juveniles are benthic feeding on a wide variety of invertebrates and fish. Adults feed on fish and other aquatic vertebrates. Like most freshwater bottom feeders, the wels catfish lives on annelid worms, gastropods, insects, crustaceans and fish. Larger specimens have also been observed to eat frogs, snakes, rats, voles, coypu and aquatic birds such as ducks, even cannibalising on other catfish. It has been known to attack humans! Although nocturnal has been known to be highly adaptable in new

21 https://commons.wikimedia.org/wiki/File:Silurus_glanis_from_the_Dnieper_River.jpg https://creativecommons.org/licenses/by-sa/1.0/deed.en

environments changing its feeding habitats accordingly by eating during the day and feeding on different prey (Freyhof 2024b; Wikipedia 2006).

Reproduction/Lifecycle: Spawns for the first time at 2–3 years old at 1–2 kg in size. Spawns in April–June, in northern areas until August, when the water temperature reaches about 20°C. In spawning grounds, males defend small territories and build nests of plant material, dig shallow depressions or clean spawning substrate such as willow (Salix) roots. Nests are defended by males until larvae emerge. Spawns in pairs. During spawning act, the male embraces the female. Eggs hatch in 2–3 days and larvae remain in nest until yolk sack is absorbed (2-4 days).

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 29.5.2022 (Freyhof 2024b).

Note(s) of interest: As an introduced species can have adverse effects on the indigenous population, like in the River Ebro in Spain where it has predated and nearly killed off the resident native species of barbel, have grown huge, made the water eutrophic due to algal growth, but has become a huge sport fish tourist destination for anglers. Albinos may appear, one of the only fishes that can swim backwards and can even attack humans and their pets! Can live for a very long time. Readily eaten as a popular food source (Wikipedia 2006).

9.2.7. Crucian carp (Carassius carassius)

Photo: Terver, D.[22]

Photo: Ondřej Petrlík, Arnika (2024)

Description & Identification: First recorded by Linneaus, 1758. A ray-finned bony fish (teleost) of the family Cyprinidae (carps). It is medium sized, commonly growing to 15 cm in length (TL), but a max. length of 64 cm has been recorded. It rarely exceeds 2 kg, a max. weight of 3 kg is recorded, max. reported age is 10 years. It is usually shining golden-green in colour, juveniles can be a golden-bronze colour but then darken as they mature, until they have a dark green back, deep bronze upper flanks and gold on the lower flanks and reddish or orange fins. Other colour variations exist. One distinguishing feature is the free edge of the dorsal fin is convex; it also has no barbels. The crucian carp is easily confused with the prussian carp (C. gibelio) and its close relative the common goldfish (C. auratus), especially the brown goldfish variety and their hybrids, they appear very similar looking. The variation in the shape of crucian carp is very high. More rounded for individuals living in waters where predators are present, because it is harder for the fish to fit in the jaws of the predator. In waters with little or no predators individuals are more slender in shape (Freyhof 2024a; Wikipedia 2005b).

Distribution: Eurasia: North, Baltic, White, Barents, Black and Caspian Sea basins; Aegean Sea basin only in the Maritza drainage; eastward to the Kolyma drainage (Siberia); westward to the Rhine and eastern drainages of England. Absent from the North Sea basin in Sweden and Norway. In the Baltic Sea basin north to about 66°N. Widely introduced to Italy, England and France (Freyhof 2024a; Wikipedia 2005b).

Environment/Habitat: Freshwater species with a water temperature range of 2–22°C, can be found in brackish water. They occur in lakes rich in vegetation, ponds, slow-moving rivers and may inhabit the densely vegetated backwaters of lowland rivers and floodplains. Crucian carp can survive for long periods of time in the winter when the water surface is frozen over and oxygen levels deplete, and the water becomes anoxic. Remarkably it then switches to anaerobic respiration, with ethanol as the major metabolic end product, rarely seen among vertebrates. It tolerates very high summer temperatures and low oxygen levels; it can survive in almost dry habitats by burying itself in wet mud. It is a weak competitor and is usually absent from waters with rich ichthyofauna and abundant predatory species but can be very abundant in the absence of other fish species. Can also tolerate organic pollutants.

22 https://www.fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=270&what=species https://creativecommons.org/licenses/by-nc/4.0/?ref=chooser-v1

Feeding habits: It is omnivorous and feeds all day but mostly at night on plankton, benthic invertebrates, plant material and detritus (Freyhof 2024a; Wikipedia 2005b).

Reproduction/Lifecycle: Spawning takes place in shallow water amongst dense submerged vegetation from May-July at water temperatures above 18 °C. Individual females spawn with several males. Males follow ripe females, often with much splashing. Females spawn 3–5 times during a season. The eggs are sticky and are attached to water plants, and hatch after 4–8 days.

Conservation status: According to the IUCN Red List it is rated as Least Concern (LC), assessed 27.1.2023 (Freyhof 2024a).

Note(s) of interest: Very popular sport fish with anglers and widely eaten and farmed commercially. Hard to identify due to hybridization and similar species looking very similar. Rare metabolic adaptation for life in low oxygen level environments. Considered a pest fish in some areas (Freyhof 2024a).

9.3. Annex 3: Dietary Intakes Estimation – Tables

TABLE 9.1:

Sample ID	GE-R-EGG-1	GE-R-EGG-2	GE-R-EGG-3	GE-R-EGG-4	GE-R-EGG-5	GE-R-EGG-6	GE-R-EGG-7	GE-R-EGG-SUP
POPs in egg samples								
PCDD/F/dl-PCBs (pg TEQ/g fw)	1.78	1.14	1.13	0.73	1.29	2.37	1.46	0.02
Σ6 PCB ng/g fw	3.47	1.85	1.65	11.6	3.19	6.8	1.23	0.47
ΣDDT ng/g fw	5.8	7.9	25.5	774	36.6	44.5	1.61	0.18
Calculation of intake per kg bw for females (73.6 kg bw)								
PCDD/F/dl-PCBs (pg TEQ/kg bw)	0.70	0.45	0.44	0.29	0.51	0.93	0.58	0.008
Σ6 PCB (ng/kg bw)	1.37	0.73	0.65	4.57	1.26	2.68	0.49	0.18
ΣDDT ng g-1 fw	2.29	3.12	10.1	305	14.4	17.6	0.64	0.07
% of tolerable intakes and/or reference doses								
Percentage of PCDD/Fs/dl-PCBs EFSA 2018 TDI level	280%	179%	178%	115%	203%	373%	230%	3.13%
Percentage of PCDD/Fs/dl-PCBs WHO 2005 TDI level	35%	22.4%	22.2%	14.4%	25.4%	46.6%	28.8%	0.39%
Percentage of provisional TDI for DDT	0.023%	0.031%	0.10%	3.05%	0.14%	0.18%	0.0064%	0.0007%
Percentage of US RfD for DDT	0.46%	0.62%	2.01%	61%	2.89%	3.51%	0.13%	0.014%
Calculation of intake per kg bw for males (84.4 kg bw)								
PCDD/F/dl-PCBs (pg TEQ/kg bw)	0.61	0.39	0.39	0.25	0.44	0.81	0.50	0.007
Σ6 PCB (ng/kg bw)	1.19	0.64	0.57	3.98	1.10	2.33	0.42	0.16
ΣDDT ng g-1 fw	2.00	2.72	8.77	266	12.6	15.307	0.553	0.061

Continuation of **TABLE 9.1:**								
% of tolerable intakes and/or reference doses								
Percentage of PCDD/Fs/dl-PCBs EFSA 2018 TDI level	244%	156%	155%	100%	177%	325%	201%	2.73%
Percentage of PCDD/Fs/dl-PCBs WHO 2005 TDI level	30.5%	19.5%	19.4%	12.5%	22.1%	40.6%	25.1%	0.34%
Percentage of provisional TDI for DDT	0.020%	0.027%	0.088%	2.66%	0.13%	0.15%	0.006%	0.0006%
Percentage of US RfD for DDT	0.40%	0.54%	1.75%	53%	2.52%	3.06%	0.11%	0.012%
Level of contamination of eggs with PCDD/Fs/dl-PCBs								
PCDD/Fs + DL PCBs (pg WHO-TEQ in one egg)	89	57	56	36	64	118	73	0.99
Number of eggs to reach 116 pg WHO-TEQ per day	1.31	2.04	2.06	3.18	1.80	0.98	1.59	117
Number of eggs to reach 14.5 pg WHO-TEQ per day	0.16	0.26	0.26	0.40	0.22	0.12	0.20	14.6

TABLE 9.2:

Sample ID	**GE-RF-1**	**GE-RF-2/1-2**	**GE-RF-3/1-3**	**GE-RF-4/1-2**	**GE-RF-5**	**GE-RF-6**	**GE-RF-7/1-2**	**GE-RF-8**	**GE-RF-9/1**	**GE-RF-9/2-3**	**GE-RF-10/1-2**	**GE-RF-11/1-4**
Σ6 PCB ng/g fw	13.004	17.958	11.551	3.868	3.206	5.867	15.433	5.525	4.873	2.646	7.715	7.661
ΣDDT ng/g fw	46.917	85.640	41.533	12.834	13.853	25.869	47.575	19.271	16.942	29.546	21.846	28.102
Calculation of intake per kg body weight for females (73.6 kg body weight)												
Σ6 PCB (ng/kg bw)	5.12	7.08	4.55	1.52	1.26	2.31	6.08	2.18	1.92	1.04	3.04	3.02
ΣDDT ng g-1 fw	18.49	33.74	16.36	5.06	5.46	10.19	18.75	7.59	6.68	11.64	8.61	11.07
% of tolerable intakes and/or reference doses												
Percentage of provisional TDI for DDT	0.185%	0.337%	0.164%	0.051%	0.055%	0.102%	0.187%	0.076%	0.067%	0.116%	0.086%	0.111%
Percentage of US RfD for DDT	3.697%	6.749%	3.273%	1.011%	1.092%	2.039%	3.749%	1.519%	1.335%	2.328%	1.722%	2.215%
Calculation of intake per kg body weight for males (84.4 kg body weight)												
Σ6 PCB (ng/kg bw)	4.47	6.17	3.97	1.33	1.10	2.02	5.30	1.90	1.67	0.91	2.65	2.63
ΣDDT ng g-1 fw	16.12	29.43	14.27	4.41	4.76	8.89	16.35	6.62	5.82	10.15	7.51	9.66
% of tolerable intakes and/or reference doses												
Percentage of provisional TDI for DDT	0.161%	0.294%	0.143%	0.044%	0.048%	0.089%	0.163%	0.066%	0.058%	0.102%	0.075%	0.097%
Percentage of US RfD for DDT	3.224%	5.885%	2.854%	0.882%	0.952%	1.778%	3.269%	1.324%	1.164%	2.030%	1.501%	1.931%

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PHOTOS

Industrial Area in Rustavi, in close vicinity of residential area. Photo: Ondřej Petrlík

Anti-pollution mural close to the Rustavi City Hall. Photo: Ondřej Petrlík

LLC Rusalloys, ferroalloys plant. Photo: Ondřej Petrlík

Cement Plant in Rustavi. Photo: Majda Slámová

Constitution Street in Rustavi. Photo: Ondřej Petrlík

Metallurgical Plant Geosteel. Photo: Ondřej Petrlík

Metallurgical Plant Geosteel. Photo: Majda Slámová

Industrial area in Rustavi. Photo: Majda Slámová

Mtkvari Energy Plant. Photo: Majda Slámová


Industrial area in Rustavi. Photo: Ondřej Petrlík


Chemical plants in Rustavi. Photo: Ondřej Petrlík

Nikola Jelinek collecting dust from one of the roads in the industrial part of Rustavi. Photo: Ondřej Petrlík

Soil sample collection next to free-range chicken site in Rustavi. Photo: Ondřej Petrlík

Tazakendi village – soil sampling. Photo: Ondřej Petrlík

Marcela Cernochova showing a dust sample from the road between the metallurgical plants. Photo: Ondřej Petrlík

Homogenization of the soil sample from a children's playground in Rustavi. Photo: Ondřej Petrlík

Sediment sampling in Rustavi Lake, city park. Photo: Ondřej Petrlík

Discharge of wastewater treatment plant effluent into the Mtkvari River. Photo: Ondřej Petrlík

Sediment sampling in Mtkvari River near Rustavi. Photo: Ondřej Petrlík

Sediment sampling in the Mtkvari River downstream from the wastewater treatment effluent discharge. Photo: Ondřej Petrlík

Arnika brings together people who strive for a healthier environment. We believe that natural wealth is not only a gift, but also a responsibility to preserve for future generations. Since its founding in 2001, Arnika has grown into one of the leading environmental organisations in the Czech Republic. Its work rests on three pillars: public engagement, expertise-based arguments, and effective communication. From the very beginning, Arnika has led public campaigns both in the Czech Republic and internationally. The organisation's main areas of focus are nature conservation, toxic pollution and waste, and environmental democracy.

Gavigudet (We are Suffocating) is a civic movement established in 2018 to address air pollution in Rustavi, Georgia. The movement works to improve environmental legislation, reduce industrial emissions, create a healthier urban environment, and raise public awareness. Its activities include advocacy, public campaigns, and cooperation with decision-makers, resulting in the inclusion of air pollution on the national agenda and contributing to legislative changes.

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