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Toxic Site Identification Program in Azerbaijan

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Abstract
The need to protect communities from hazardous waste is an important agenda for any nation. Although pollutant management and policy development are attempted in many developing countries, it is not always successful due to limited funds, project resources, and access to trained experts to conduct toxic site identification projects. For this reason, Pure Earth created the Toxic Site Identification Program (TSIP). The goal of the TSIP program is to provide reliable information and data that identifies location of toxic sites and the level of toxic severity. TSIP is significant because it provides developing countries a database of ranked toxic sites identified as hazardous risk to human health. For example, Azerbaijan is one of the most polluted post-Soviet nations, but has limited resources to address and manage its polluted sites. The Azerbaijani TSIP database is the first reliable data source that identifies hazardous pollutants in the country. Our study is significant because it discusses how the TSIP labels and ranks the level of toxic severity to human health. It is also the first data source in Azerbaijan that identifies which Soviet legacy toxic sites are affecting local communities. Although our study is specific to Azerbaijan, the TSIP method can be applied to nations with similar data limitations and the need for a database that identifies country specific environmental and hazardous locations. The data sampling method and results are mapped and accompanied by tables of the collected pollutant types to identify communities at greatest health-risk to legacy toxic sites.

Keywords Toxic sites · Pollution · Pesticides · Benzene · Metals · Health impacts

Introduction

Over the last 150 years Azerbaijan was one of the principal oil producing and processing countries without adequate environmental management practices (Bickham et al. 1998; Islamzadeh and Khalilova 2003). Azerbaijan was also one of the main producers and users of toxic substances for industrial and agricultural production (Bickham et al. 2003). Estimations and inventories confirmed during the Soviet period, that ~25,000 tons of DDT pesticide were used in Azerbaijan yearly (Aliyeva et al. 2013), which lead to large scale, and unmanageable toxic pollution in the country (Sharov et al. 2016; Swartz et al. 2003). The remaining polluted sites, from the Soviet period, have been found in nearly all parts of Azerbaijan, which include both large and small pollution hotpots (Sharov et al. 2016, 2019).

Pollutants may result from broad-scale anthropogenic activities, which can cause serious health related issues (Albergo 2009). There is an intensive body of literature focused on toxic sites and various contaminants affecting human populations that is based in the United States (Wyzga and Folinsbee 1995; Amin et al. 2018; Elliott and Frickel 2013; Wuana and Okieimen 2011) and on contaminated sites and methods addressing pollutants that threaten human health (e.g., Environmental Protection Agency, EPA) (Boyd 2016; Ho and Hite 2008; Brender et al. 2011; Najem and Cappadona 1991; Soliman et al. 1993; Russi et al. 2008). There is also an extensive body of

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research conducted in Canada that focuses on soil contamination, environmental cleanup projects, and policies addressing hazardous threats (Reyes et al. 2015; Bussières et al. 2004; Health Canada 1995; Goldberg et al. 1999; Fischer 1995). In addition to these studies, there is research that focuses on a specific pollutant-type and its interaction with human health, such as hazardous waste sites (Elliott and Frickel 2013), air pollution (Miettenen 1988; Miraglia et al. 2005; Grimalt 2001; Sun and Zhu 2019; Coker and Kizito 2018), mercury (Bernhoft 2012), sodium azide (Chang and Lamm 2003), lead, and volatile organic compounds (VOCs) (Solomon and Janssen 2010; Reyes et al. 2015).

These studies are significant and identify various methods and pollutant-health related issues of communities impacted by these studied pollutants, however, there are countries that are highly polluted and have been minimally researched due to limited resources and funding. For example, in Azerbaijan, at this point in time, there are no conducted studies linking polluted sites and the impact is has on human health. In 2006, Azerbaijan was identified as having one of the most polluted cities in the world, Sumgait, due to the Soviet legacy and the lack of resources to address its pollutant problem after the Soviet era. For this reason, our study is important because the TSIP identifies the number of people who live near toxic sites and the level of the toxic severity. The TSIP method can be applied to other developing countries that have unidentified or unattended toxic sites, which pose serious impacts on human health.

In Azerbaijan, toxic pollutants have caused a broad range of negative health impacts within the population and have increased the cost of living (WHO Europe 2015). A broad range of studies confirmed that pollution causes negative impacts on the local ecosystems of Azerbaijan. For Example, the discovery of polychlorinated biphenyls, organochlorine pesticides, and organotin compounds found in the blubber and liver of Caspian seals (Phoca caspica), which has been identified to have caused mass mortality of this species (Kajiwara et al. 2002). In addition, there are discovered traces of acute genotoxic effects from pollution in the Russian sturgeon, acipenser gueldenstaedtii (Bickham et al. 1998). There is also evidence of a strong correlation between three-ring PAH pollution and chromosomal damage in aquatic turtles (*E. orbicularis*). Moreover, a study done by Matson et al. (2005) confirmed that the cities, Sumgayit and Neftchala in Azerbaijan, have soils contaminated with genotoxic and PAHs, which have a direct effect on observed genotoxicity.

The Toxic Sites Identification Program (TSIP) was designed to identify toxic pollution in developed countries and to evaluate their current potential impact on human health (Ericson et al. 2012). The implementation of TSIP in Azerbaijan was critical for improving and identifying Azerbaijan's environmental management practices and policies, as well as preventing serious health related risks from hazardous pollutants. The first motivation for the TSIP to be conducted in Azerbaijan is due to the country being one of the most polluted countries in the world (Bickham et al. 2003). The second motivation is the country's forgotten and abandoned legacy polluted sites (e.g., from the Soviet era) that are near residential and industrial areas. The third motivation for this study is to encourage the Azerbaijani national and regional government agencies to implement environmental policies and pollutant management of current and future country remediation projects.

The TSIP in Azerbaijan started 2012 was completed in 2018. Before 2012, there was no comprehensive toxic site inventory that was conducted in Azerbaijan and there was no appropriate and tangible information about the size and scale of toxic pollution in the country (Bickham et al. 2003; Sharov et al. 2016). The goal of the TSIP is to provide governmental agencies guidance, through a reliable database of collected and ranked toxic sites that pose health risks, to prioritize resources management practices, policies, and pollution-cleaning agendas of contaminated sites at the regional scale. Therefore, the TSIP in Azerbaijan is to identify polluted sites and to create a database of toxic sites that can provide reliable and important pollutant information to the Azerbaijani Ministry of Ecology and Natural Resources, in addition to the Ministry of Agriculture and other relevant local governmental institutions.

Our paper is the first to explain how the TSIP is unique in the region because it positions Azerbaijan to be a leading example in Eurasia for the following four reasons: (1) the Azerbaijani TSIP data includes polluted sites that were not recognized previously by the government as toxic sites and hazardous threats to local communities; (2) the TSIP in Azerbaijan is the largest dataset of collected pollutants in the region, which can further advance research focused on the Caspian Sea basin and transboundary pollution studies to help identify main migration routes of pollutants to other countries; (3) this study can aid other studies focused on transboundary pollution in the region, but are limited on the type of pollutant data shared among these bordering countries (e.g., Azerbaijan, Armenia, and Georgia). Former studies have identified there are transboundary pollution issues with heavy metals, pesticides, and radionuclides, but there is a need for more research and data (Zolotovitskaya 2003; Aleksanyan et al. 2008; Suleymanov et al. 2010; Shirneshan et al. 2017; Akhmadiyeva and Abdullaev 2018); and (4) Azerbaijan's TSIP data may further advance and support research focused on regional health outcomes and causes of death in the region, as well as encourage new implementation and improvement of existing environmental management practices and policies.

Materials and Methods

TSIP utilizes a rapid assessment protocol known as the Initial Site Screening (ISS). The ISS has an output index value, known as Pure Earth Index (PI) (formerly known as Blacksmith Index). The detailed development of this method is explained in detail by Ericson et al. (2012) and Caravanos et al. (2014). The PI is an environmental health site ranking system scaled from 1 to 10 (e.g., 10 being of greatest toxic severity and the most dangerous site). The PI formula is based on: (1) addressing legacy and active sites that expose communities to life-threatening pollutants; and (2) requiring less data and financial resources to obtain site pollutant levels (Caravanos et al. 2014). The PI is based on the EPA procedures, but unlike the EPA measure of pollutants at the source and migration of pollutants to and from the site, the PI focuses on past and current contamination without addressing the pollutant migration potential. The PI is a widely accepted model of risk assessment known as the pollutant-pathway-population (Pure Earth 2019a).

The PI focuses solely on current and past contamination by taking samples (e.g., from soils and source wells), without specifically addressing the pollution migration potential. The PI index is generated from data concerning pollutant types, pollutant concentrations, pathways, and populations at risk that the country investigators identified and entered into the Azerbaijani TSIP database. Estimating the exposed population per sector is calculated through the population of people living near or having frequent interaction with the identified contaminated site.

The first stage of the TSIP assessments in Azerbaijan involved identifying potential toxic sites that pose human-health risks. To collect information on the suspected polluted areas, the TSIP Azerbaijani working group interviewed both local enterprises and Azerbaijani governmental agencies, in addition to collecting and reviewing all relevant country conducted studies and reports. The Ministry of Agriculture introduced the list of legacy pesticide distribution locations that were in operation during the Soviet period. The studies included on this list were national and independent reports conducted by Azerbaijan in conjunction with the World Bank (2008), IPEN (2006), and UNIDO-GEF (2004). The identification of some legacy pollution sites in Azerbaijan posed challenges in the collection process due to the remoteness of some locations, as well as the absence of prior information from the Soviet and early post-Soviet years. To obtain the TSIP data for Azerbaijan involved a collection of regional and historical knowledge of previous and current locations of power plants, factories, oil and waste dumping sites, pesticide distributed sites, and detecting all known polluted sites located within remote locations.

The toxic samplings were based on the guidelines developed by Pure Earth (Caravanos et al. 2014). The sampling procedure conducted by Pure Earth largely coincides with procedures of European soil sampling guidelines for soil pollution (Theocharopoulos et al. 2001) and with the US Environmental Protection Agency sampling procedures (EPA 2014). According to Pure Earth guidelines, soil samples were taken from the locations closest to industrial estates or legacy agricultural sites, which have direct pathways to the local residential areas. In some cases, due to underfunded and regional limitations of conducting such site samples, Pure Earth's methodology is focused more on the pathway of pollutant to human health risks, instead of measuring the potential environmental contamination based on predicted pollutant migration patterns (Caravanos et al. 2014). For example, due to high winds, pollution sampling in Sumgait required samples close to the pollution sources, and from remote residential locations. This is due to Azerbaijan's strong winds carrying dust particles of pollutants to neighboring and remote locations.

The target samples are the individual surface soil samples of 25–30 g are taken from suspected hotspots, such as residential areas adjacent to a contamination source. These samples were collected on single place point, which were suspected to be a point that has the highest concentration of pollutants.

To make the composite samples, each site was divided into several parts, called sectors. As a standard procedure in selecting samples, each sector needed to be considered as an agricultural, residential, mixed, or industrial site. For example, when a site is located between residential and agricultural areas, the site was divided into agricultural and residential sectors. Residential sectors included places where most of the areas were occupied by houses, schools, and public buildings, while agricultural places represented places that were used for agricultural purposes. Each sector had its own representative composite sample. The scheme of making target and composite sampling are given in Fig. 1.

The total number of sampled sectors depended on the specific size of the site. Smaller sites, generally had an area up to 2 ha, divided into three sectors, while larger sites consisted of an area that had more than 2 ha, that may have up to ten sectors. Composite samples were taken from various places of each sector and included several 4–5 g mixed samples. These samples were mixed with other soil samples from the same sector. The mixture of these small samples is considered as a composite sample with the weight about 20–30 g. The composite samples were taken

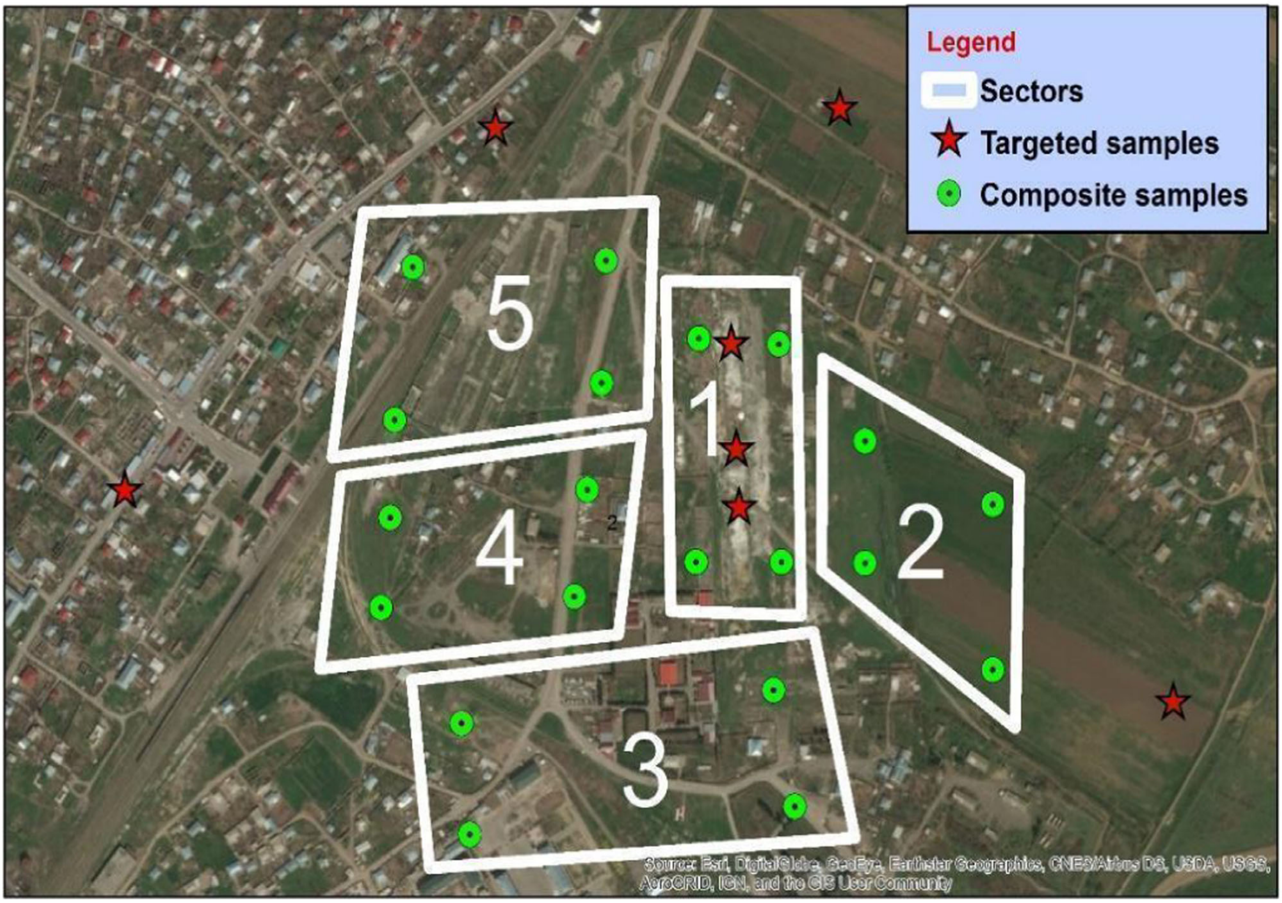

Fig. 1 Scheme of targeted and composite samplings in a DDT polluted Horadiz site (1-hotspot, 2 agricultural, 3-residential, 4 and 5-mixed)

from each sector represented on average, the concentration of the collected pollutant for that specific location. Figure 1 illustrates sectors in each site with the DDT pollutant close to a small town, Horadiz, located in the southern region of Azerbaijan. The sectors were contingently labeled as agricultural, industrial, school, and residential sectors. (Fig. 2). The collected samples were tested to determine the level of pollutant concentration within national, certified environmental laboratories in Azerbaijan (e.g., Azecolab, SOCAR Environmental laboratory, Khazar University laboratory). Table 1 presents a list of the approved scientific methods conducted to identify the specific toxin per identified site.

Estimating exposed population per sector is a most challenging part of ISS. It is the number of people living or working within the relevant sector and meeting the pathway defined for the sector ISS process. This includes interviews conducted with doctors in each region. However, in densely populated urban areas, with many toxic sites, it is challenging to determine the exact number of exposed people to a specific pollutant type and studies focused on health impacts require precise medical samplings (Constantinou et al. 1995).

Results and Discussion

Identified Toxic Sites in Azerbaijan

Within TSIP, 138 toxic pollution sources were identified and included to the Azerbaijani TSIP database. Table 2 shows a list of identified sites within the Azerbaijani TSIP project. Figure 2 shows the geographical distribution of identified pollution sources in Azerbaijan. Most of the toxic hotspots were recognized as legacy sites of abandoned industries from the industrial era of the Soviet period. Due to the absence of regular governmental and environmental monitoring and control of theses pollutants a large portion of the identified toxic sites were not known or identified until the TSIP program was completed (2012–2018) in Azerbaijan.

Although Baku is considered to be the center of oil production in the region it has very minimal environmental standards (Jernelöv 2018). For this reason, current and abandoned oil fields are one of the main sources of pollution in the urbanized regions of the Absheron peninsula. According to TSIP data samples, the pollutants of major

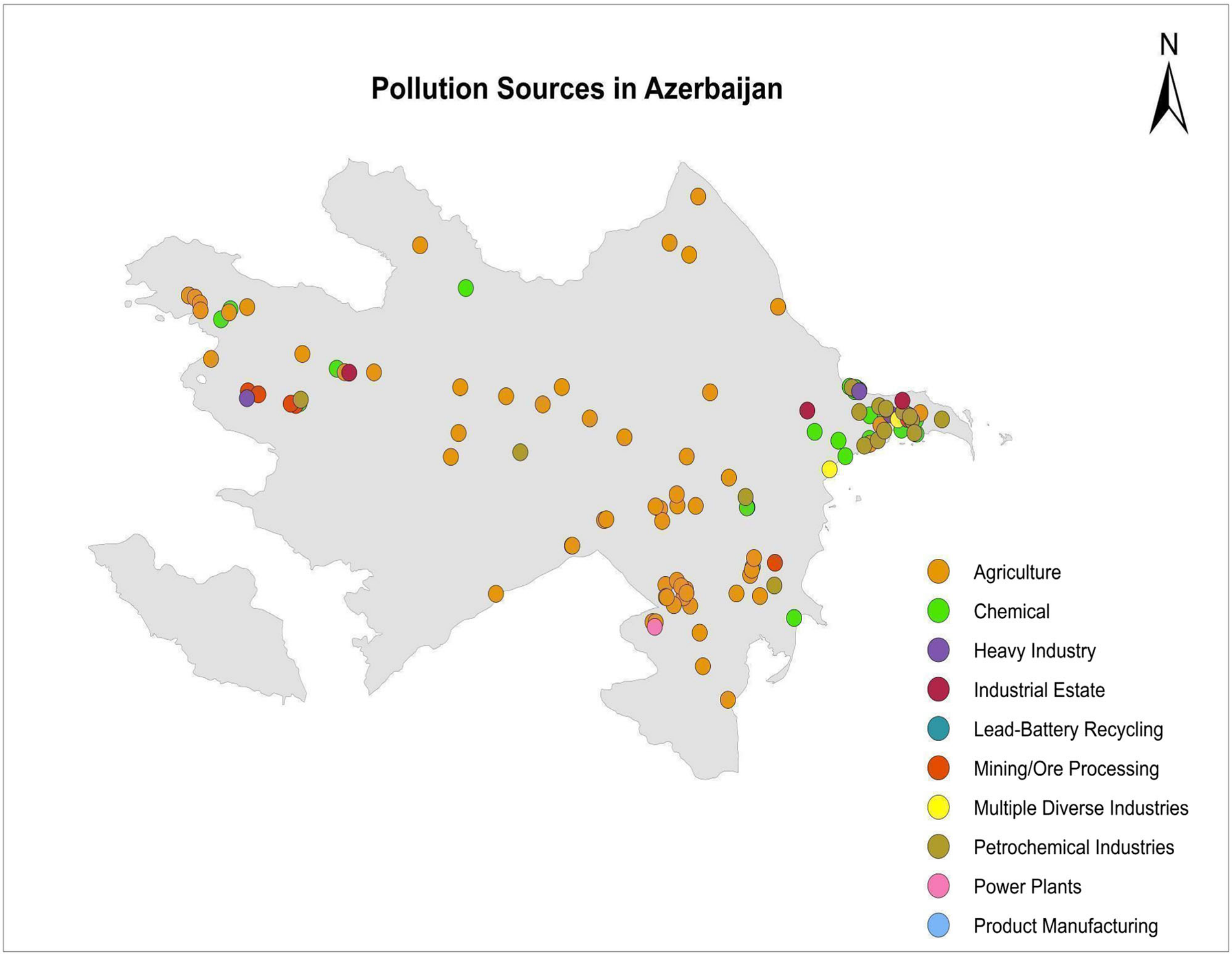

Fig. 2 Geographical distribution of pollution sources in Azerbaijan

concern are located within urban regions of the country. These identified urban toxic sites, from the Soviet era, are still active in the form of operating oil wells, oil processing, petrochemical production, industrial construction, and production industries (Table 2).

The collected results of the TSIP identified that there were no standard environmental procedures in place for the oil rigs located in the Absheron region. In the early 20th century, oil wells had depths no deeper than 10–15 m. In most cases 25–30% of the extracted oil spilled into the land surface (Jernelöv 2018). The Soviet oil industry did not consider environmental standards and quantity of production as a priority and therefore overlooked environmental precautions (Zonn and Kostianoy 2015). In Azerbaijan, the oil fields are one of the main sources of pollution, near the Absheron peninsula's densely populated, residential areas.

According to our TSIP results, the chemical and oil processing industry is the country's second major source of pollution. Nearly all the enterprises of the chemical and oil industry were founded in Sumgait and Baku. During the Soviet period, Sumgait was home to twenty-three large manufacturing chemical factories, which produced a broad range of petroleum and petrochemicals, including chlorinated pesticides, as well as agricultural and industrial chemical products (Bickham et al. 2003). Baku hosts factories of several oil processing and petrochemical industries. These oil refineries, petrochemical factories, and power plants, from the Soviet era, are considered the country's most hazardous locations. Sources of contamination in Baku also include chemical, metallurgy, and energy industries as well as oil extraction and processing (Fig. 2).

Aldrin, chlordane, DDT, dieldrin, dioxins, endrin, furans, heptachlor, hexachlorobenzene (HCB), mirex, and toxaphene were the main agricultural POPs pesticides during the Soviet Union, in Azerbaijan. Specifically, during the 1970–1990s, cotton plantations of 100–300 thousand hectares had intensive applications of POPs pesticides (IPEN 2006). These pesticides have migrated through water and air to the remote areas (Aliyeva et al. 2013; Bennett 1981). These identified sites are considered as legacy pesticide

Table 1 List of methods used in laboratory analyses

#	Analyses	Sample	Method
1	Arsenic As	Water	ASTM D2972 - 08 Atomic absorption spectrophotometer ZEEnit 700P
2	Mercury Hg	Water	ASTM D3223 - 12 Atomic absorption spectrophotometer ZEEnit 700P
3	Cadmium Cd	Water	ASTM D3557 - 12 Atomic absorption spectrophotometer ZEEnit 700P
4	Copper Cu	Water	ASTM D1688 - 12 Atomic absorption spectrophotometer ZEEnit 700P
5	Cobalt Co	Water	ASTM D3558 - 08 Atomic absorption spectrophotometer ZEEnit 700P
6	Lead Pb	Water	ASTM D3559 - 08 Atomic absorption spectrophotometer ZEEnit 700P
7	Nickel Ni	Water	ASTM D1886 - 08 Atomic absorption spectrophotometer ZEEnit 700P
8	Zinc Zn	Water	ASTM D1691 - 12 Atomic absorption spectrophotometer ZEEnit 700P
9	PAH	Water	EPA 8270D
10	TPH	Water	ISO 9377-2
11	VOCs	Water	ISO 11423-2
12	Arsenic As	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
13	Cadmium Cd	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
14	Chromium Cr	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
15	Copper Cu	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
16	Cobalt Co	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
17	Mercury Hg	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
18	Lead Pb	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
19	Nickel Ni	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
20	Zinc Zn	Soil	EPA 3052 Atomic absorption spectrophotometer ZEEnit 700P
21	PAH	Soil	EPA 3541, EPA 3630C, EPA 8270D
22	TPH	Soil	ASTM D5765-05 (2010), ASTM D 3976-92 (2010)
23	VOCs	Soil	EPA 3570

distribution points located in small agricultural villages and provincial towns throughout the country. Our TSIP results identified seventy agricultural pesticide pollution sites in Azerbaijan. Twenty of these identified sites were within residential areas, and fifty locations were actively being used as pastures.

There are 11 large inter-district and 45 village pesticide distribution points. There are five sites that served as a ground for small pesticide sprinkler planes. These sites are in rural areas and are being actively used in the form of roads, pastures, playgrounds, backyards, and agricultural fields. TSIP samplings confirmed that in many sites, winds readily carry dry DDT powder and dust over houses and water sources. In addition, large amounts of pesticide-detected sites were found in remote areas, chemical and product manufacturing plants, petrochemical industries, mining, and in ore processing manufacturing. Most mining sites are currently located in the rural Gedabek and Dashkesan districts of northwestern Azerbaijan, where high rates of birth paralysis and cancer occur. Mining in Gedabek started in 1998 and continues to stay in operation, however the high levels of mercury, arsenic, and cyanide contamination is of serious concern, according to the TSIP sample results. Aluminum factory in Ganja (northwestern region), and a cement factory in the Gardagh region (located on the Absheron peninsula) were the main pollution sources in the region over the last 70 years.

TSIP also included seven lakes located on the Absheron peninsula, which are highly contaminated with industrial and municipal wastewater (Fig. 3). Most of these lakes are primarily located in the areas of oil production and migrate through groundwater into the identified TSIP lakes (Khalilova and Mammadov 2016). The TSIP collected samples identified seven lakes on the Absheron Peninsula (Binagadi, Boyukshor, Masazir, Khojasan, Bulbula, Zabrat, Lokbatan, Girmizi, and Gu), to be serious health-hazards due to the high rates of cancer (e.g., lung, stomach), chronic asthma, and skin diseases, and are now considered by the Azerbaijani government as top priority locations for future remediation project agendas (World Bank 2008).

Identified Pollutants

The results of the TSIP confirmed that despite the efforts of the last twenty years, there was no notable progress in toxic pollution management in Azerbaijan. For example, Azerbaijan's National Implementation Plan (NIP) 2007–2020 under the Stockholm Convention did not produce considerable improvements in accurately identifying and managing POPs pollution, as well as reduction of the toxic

Table 2 Pollution sites, key pollutants, and pollution levels in urban regions

#	Site name	Lat; Long	Pollutant 1	Value	Pollutant 2	Value, mg/kg
1	Ethylene polyethylene plant	40.607;49.622	Cadmium	33.00	Benzopyrene	235.00
2	Surface-active substances plant	40.602; 49.614	Mercury elemental	3250.00	Benzene	305.00
3	Synthetic rubber plant	40.607; 49.616	Benzene	5.27	Benzene	196.00
4	Baku steel company	40.430;49.887	PM 10	2356	Pyrene	11200
5	Technical rubber product plant	40.461;49.935	Benzene	335.60	Benzopyrene	25.50
6	Azerneftyag plant	40.372;49.909	Benzene	98.30	Phenol	451.00
7	Sabunçu town polluted areas	40.453;49.953	Total petroleum hydrocarbon	1925.00	Benzene	195.50
8	Balakhani polluted areas	40.474;49.919	Benzene	323.23	Benzo(a)pyrene	31.00
9	Lokbatan lake	40.321;49.707	Arsenic	42.00	Cadmium	71.00
10	Bulbula lake	40.425;49.976	Arsenic	123.00	Benzene	1245.00
11	Boyukshor lake	40.443;49.876	Cadmium	82.00	Toluene	76.00
12	Khojohasan lake	40.399;49.777	Cadmium	91.00	Phenol	240.50
13	Zig lake	40.354;49.991	Arsenic	194.00	Benzene	151.00
14	Zabrat lake	40.473;49.936	Benzene	156.00	Phenol	190.00
15	Binagadi lake	40.469;49.803	Total petroleum hydrocarbon	1060.00	Arsenic	241.00
16	Gu lake	40.312;49.760	Arsenic	84.00	Cadmium	11.50
17	Masazir lake	40.506;49.759	Cadmium	917.00	Arsenic	78.00
18	Kurdakhani lake	40.536;49.915	Arsenic	1060.00	Benzene	311.00
19	Mirzaladi lake	40.491;49.818	Cadmium	57.80	Benzo(a)pyrene	71.50
20	Gala lake	40.430;50.165	Benzene	134.00	Pyrene	4700.00
21	Ganli-Gel lake	40.368;49.800	Cadmium	561.00	Benzopyrene	35.00
22	Ramana lake	40.447;49.963	Benzene	3790.00	Phenol	191.00
23	Chuxurdara lake	40.466;50.027	Cadmium	34.00	Benzene	181.00
24	Dashagil lake	40.472;49.643	Benzene	121.00	Toluene	123.50
25	Fatmai lake	40.311;49.511	Cadmium	17.00	Toluene	67.00

pollution (NIP 2007). While some small-scale remediation projects had proved to be successful (Sharov et al. 2019), the TSIP assessments conducted within the remediated sites, confirmed that there were no notable reductions in concentrations of the identified pollutants. These areas mainly included remediated oil polluted places in Bail, a suburb outside of Baku, industrial areas of Sumgait and legacy DDT sites in the rural regions. For example, samplings after the remediation in the Boyukshor lake confirmed that the location is still highly polluted with cadmium and toluene. Also, high pollution of mercury was found after the remediation project around the former Sumgait Surface Active Substances (SAS) plant. Moreover, soils around the manufacturing plants and close residential areas in Sumgait remain contaminated with mercury, benzene, benzo(a)pyrene, lead, copper, zinc, and molybdenum, and has been identified to have very high rates of lung and urinary bladder cancer.

Hydrocarbons (TPHs, PAHs), VOCs and heavy metals were detected around oil fields, and plants related to oil and petrochemical industry (Table 2). Also, heavy metals, DDT and other pesticides, PAHs and VOCs were identified as Azerbaijan's regionally, predominant pollutants (Fig. 4). In addition, TPH contamination with predominant concentrations of benzene and toluene were found in oil polluted areas. The TSIP results revealed that concentrations of heavy metals (Cd, Pb, Ni, Cr) were very high in oil polluted areas of Azerbaijan (Table 2).

The areas polluted with benzene included places near Baku, in small villages of the Absheron peninsula, where pollution with crude oil is very high. Benzene is a natural constituent of crude oil and is one of the elementary petrochemicals (Pinedo et al. 2013). The highest benzene concentrations were found in soil of polluted areas near the Balakhani village (545 mg/kg) and Binagadi village (493 mg/l) with high rates of pulmonary cancer, bronchial

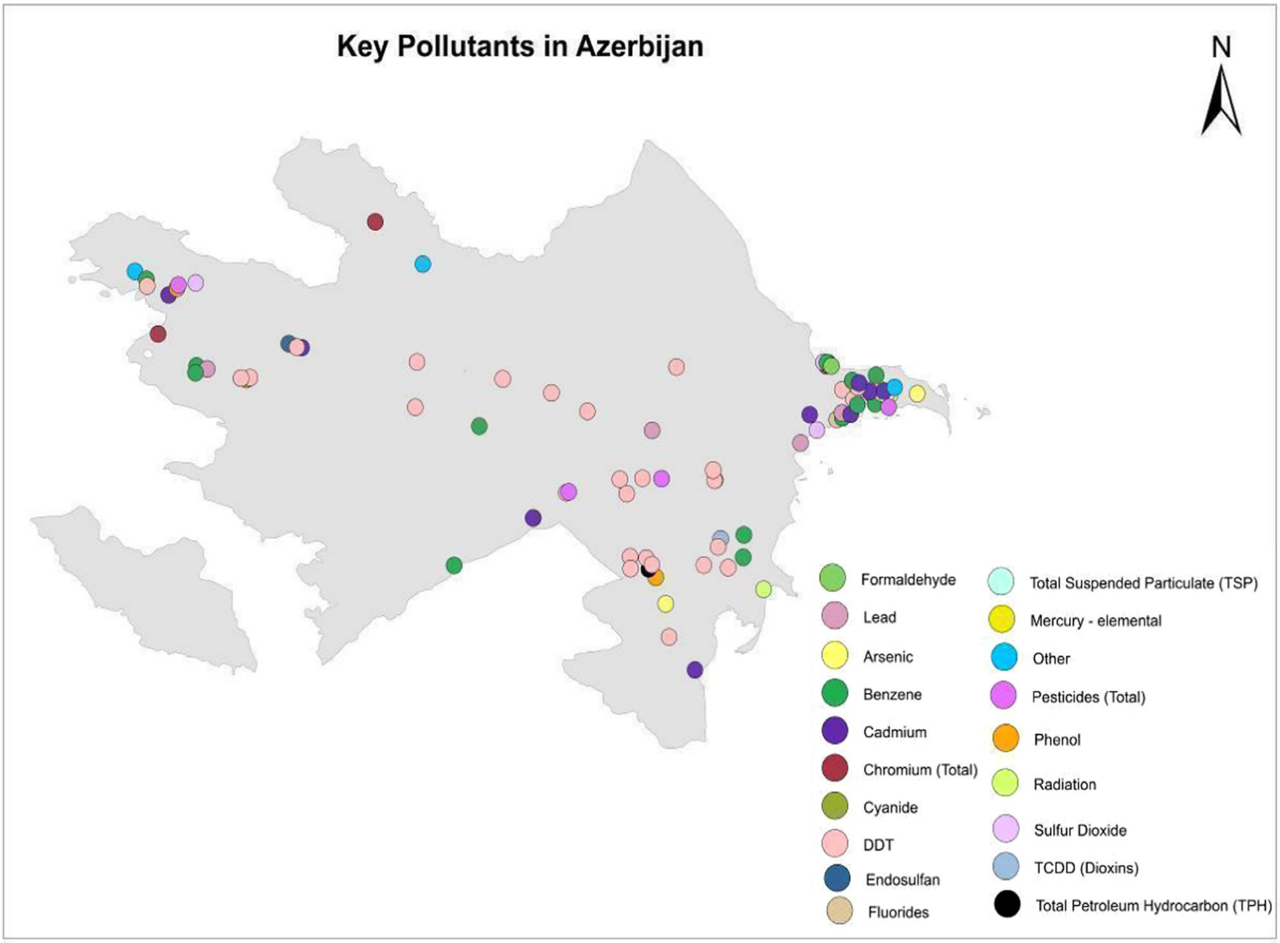

Fig. 3 Geographical distribution of key pollutants in Azerbaijan

asthma, and various skin diseases. In Bail, close to Baku's pollution of benzene was 343 mg/l, in Pirallahi near the shoreline, pollution with benzene was detected to be 645 mg/l. The areas with the highest benzene concentrations were found near the Sumgait shorelines, where benzene concentrations changed from 35 to 74 mg/l.

High concentration levels of PAH were found in Sumgait, Baku, Neftchala, and Salyan. The total PAH levels in polluted areas near the Balakhani village were considered to have high levels of contamination with a 421 mg/kg. In areas close to the studied industrial sites, located in the west of the Balakhani village, PAH levels were 245 mg/kg. The total PAH concentrations in urban areas, close to oil processing industrial units ranged from 216 mg/kg to 32,100 mg/kg. Most common PAH pollutants were pyrene, naphthalene, and fluorene, which had high concentrations in areas close to oil refineries. For example, in samples taken close to shorelines in Sumgait, pyrene sample concentrations ranged between 1122 and 13,500 mg/kg. High fluorene concentrations were also found near the petrochemical enterprises of Sumgait City. High mercury concentrations (3225 mg/kg) were found around the former SAS, even though in 1999 the SAS plant was demolished; a remediation project was conducted, and mercury waste transported into the burial site of toxic chemicals. According to TSIP assessment, currently 100–150 tons of mercury have been accumulated in the soil and, mercury was found within the sludge basins located near the bank of the Sumgait river. High chromium (1440 mg/kg) and aluminum (2976 mg/kg) concentration were also found in areas close to Ganja Aluminum factory (Table 2).

The lakes recorded in the TSIP database have been identified to have contamination with heavy metals, benzene, polycyclic aromatic hydrocarbons (PAHs), total petroleum compounds. The amount of cadmium and arsenic varies from 42 mg/l to 83 mg/l. High arsenic concentrations were found in Gu and Kurdakhani lakes. Other TSIP identified lakes have a large contamination of predominantly benzene, phenols, benzo(a)pyrene and benzopyrene, where concentrations greatly exceed the threshold levels (ESDAT 2018; ATSDR 2009) for residential and human-contact areas. Cadmium contamination were

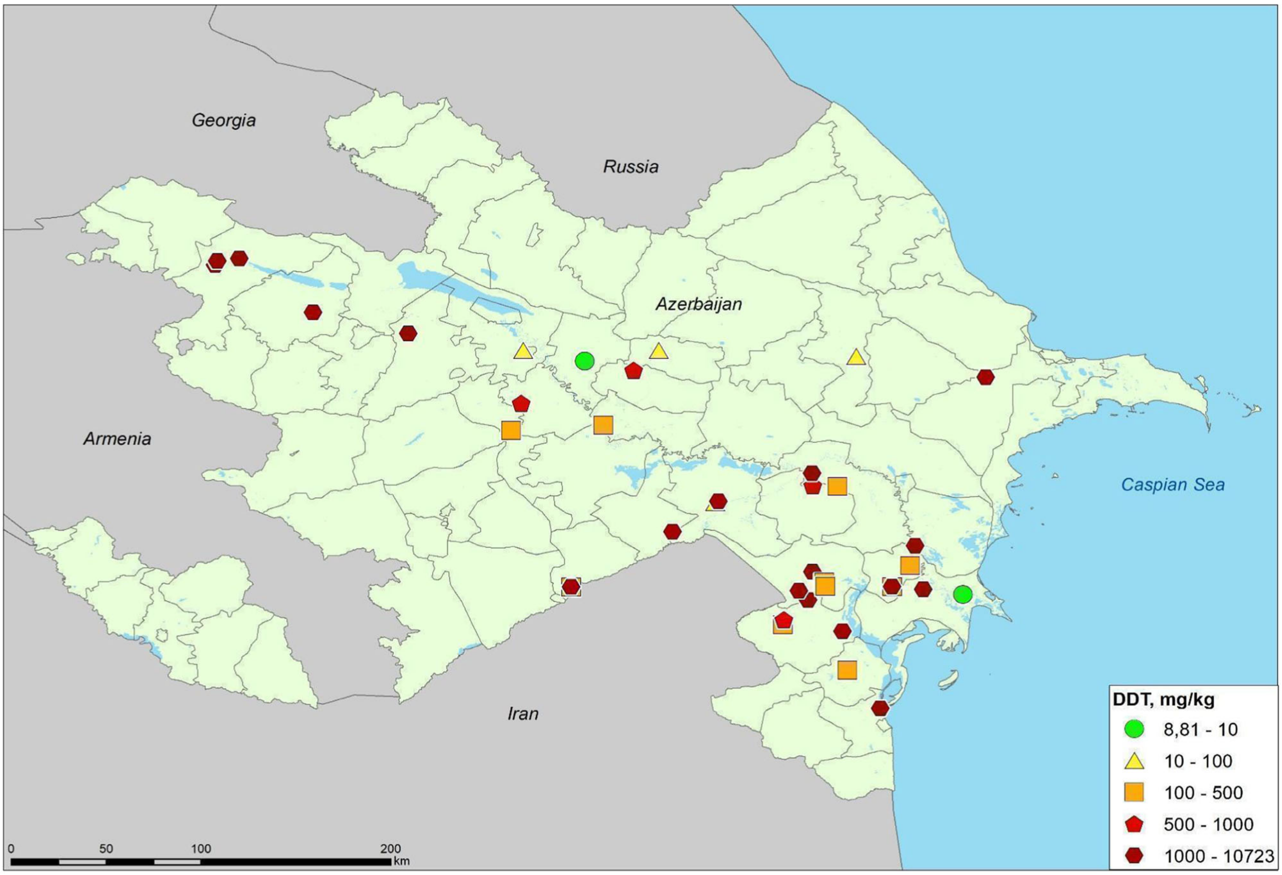

Fig. 4 Location of DDT pollution sites and concentration of DDT

detected within old oil fields near the Binagadi and Ramana lakes. Cadmium concentrations in the Boyukshor and Binagadi lakes range between 70 and 1300 mg/kg. Arsenic pollution was found near the Gu Lake which is 84 mg/kg. Levels of TPH and arsenic in Binagadi lake were 1060 and 241 mg/kg. Detailed information about the sites and pollutants is provided in Table 3. Concentrations of key pollutants within Azerbaijan's lakes (Figs. 3 and 5) contained high concentrations of cadmium found in Masazir lake. This specific lake is of great interest and concern because the extracted salts are used for both industrial use and household consumption in Azerbaijan (Figs. 3 and 5).

TSIP identified DDT to be a major pollutant within the rural sites, while other types of pesticides such as aldrin, dieldrin, toxaphene, chlordane, and endrin were identified to be within both rural and urban locations. The TSIP assessments confirmed that there are high DDT concentrations in all sites, which varies between 1000 and 9500 mg/kg. Also, there are high concentrations of pesticides: aldrin, chlordane, dieldrin, endrin, and toxaphene. More detailed information is explained in Table 3, providing a list of the total number of sites and pollutant type. Figure 6 displays the concentrations of DDT pollution within each collected, sampled site. Field surveys confirmed that the common pathways for pesticides are water, air, and dermal contact.

In northwestern Azerbaijan, arsenic concentrations in residential places near Gadabek gold mines showed various concentration levels that ranged from 1321 and 1970 mg/kg, along with birth paralysis being the main health concern in the region. In the residential places close to the Gosha mine, arsenic concentrations ranged between 1934 and 2360 mg/kg. High rates of cadmium were also observed, which were 66 mg/kg and 108 mg/kg in Chovdar and Gsedabek cold and copper mines. The location of the pollution sources and names of pollutants are shown in the illustrated maps (Figs. 2 and 4).

Exposed Population

The TSIP results identified the number of people residing or working near the identified toxic sites which have been ranked with a high toxic severity. Near oil fields, where population density is rather high, PI values vary from 6 to 9, confirming that human populations are at high risk and exposure to pollution. The highest PI rates are in Binagadi, Sabunchu, and Ramana villages (e.g., PI rates of 7 and 9),

Table 3 Legacy pesticide sites with high PI values in Azerbaijan identified until 2018

#	Site name	Lat	Long	Pollutant	Value, mg/kg	PI value	Number of affected populations, thousands
1	Jangi Pesticide Polygon	40.481	49.314	DDT	1200	7	0.85
2	Horadiz Chemical Supply Facility	39.447	47.348	DDT	1546	8	3.22
3	Shamakhi Chemical Union	40.584	48.701	DDT	66.5	7	25.1
4	Sarijallar Railway Station	39.946	48.494	DDT	521	8	1.22
5	Jalilabad Inter-District Pesticide Union	39.227	48.635	DDT	2664	8	19.3
6	Salyan Pesticide Airdrome	39.449	48.868	DDT	319	7	11.5
7	Masalli Agricultural Union	39.037	48.656	DDT	324	7	9.34
8	Barda Pesticide Storage	40.354	47.112	DDT	584	6	13.2
9	Laki Fertilizers' Storage	40.562	47.412	DDT	9.62	6	6.71
10	Ujar (Mususlu) Pesticide Storage	40.516	47.644	DDT	870	9	13.5
11	Yevlakh Pestiside Storage	40.613	47.122	DDT	12.1	5	17.6
12	Tar-tar Pesticide Storage	40.219	47.063	DDT	195	6	9.21
13	Siyazan Pesticide Department	41.068	49.130	Total pesticides	1420	5	6.71
14	Beyleqan Pesticide Storage	39.719	47.830	DDT	1074	6	8.92
15	Gusar Pesticide Storage	41.430	48.444	Total pesticides	102	5	7.11
16	Quba Pesticide Storage	41.362	48.568	Total pesticides	2456	6	12.1
17	Hajigabul Pesticide Storage	40.102	48.820	Total pesticides	975	6	7.86
18	Garadagh Gas Refining Plant	40.283	49.675	Fluorides	4670	9	87.4
21	Kazakh Pesticide Storage	41.132	45.407	Total pesticides	14.6	5	16.5
22	Kurdamir Pesticide Storage	40.330	48.159	Total pesticides	13.2	6	9.56
23	Goycay Pesticide Storage	40.614	47.765	DDT	19.1	6	3.42
24	Akstafa Pesticide Storage	41.120	45.446	Total pesticides	33.1	6	4.78
25	Qax (Alibayli) Fertilizers' Storage	41.416	46.869	Total pesticides	245	5	0.87
26	Alimardanli Village Pesticide Storage	41.036	45.662	DDT	3217.7	6	1.45
27	Dalmammadli Pesticide Residuals	40.697	46.577	DDT	2077.1	8	2.56
28	Salyan Agricultural Chemical Union	39.553	48.954	DDT	117	8	5.45
29	Nohun Pesticide Site	41.066	45.776	DDT	2537.7	4	0.45
30	Vurgun Pesticide Site	41.087	45.477	Endosulfan	4.254	4	0.54
31	Ganja Alabaster Production Area	40.718	46.342	Lead	1220	7	34.2
32	Lenkaran (Marso) Pesticide Storage	38.848	48.813	DDT	10723	7	0.98
33	Bilasuvar Pesticide Storage	39.379	48.575	Total pesticides	1978	8	9.21
34	Lower Gurali Pesticide Aerodrome	39.427	48.532	DDT	2391	6	0.87
35	Nasimi Pesticide Aerodrome	39.497	48.418	Total pesticides	1150	6	0.45
36	Takla Pesticide Storage	39.260	48.351	DDT	112.3	5	0.34
37	Abazalli Pesticide Aeroground	39.287	48.337	Total pesticides	891	7	1.34
38	Goyceli and Tatli Pesticide Points	41.048	45.481	Total pesticides	4362	7	2.35
39	Qaratapa Pesticide Storage, Sabiradad	39.944	48.610	DDT	129	5	3.42
40	Moldai Aerodrome (Saatli)	39.927	48.385	Total pesticides	1240	6	2.31
41	Sugarishan Aerodrome (Sabirabad)	40.008	48.490	DDT	1876.1	7	1.65
42	Dada Gorgud Pesticide Distribution Point	39.858	48.398	Total pesticides	453	6	1.78
43	Aribatan Aerodrome, Salyan	39.583	48.965	Total pesticides	3070	5	1.32
44	Amankend Pesticide Distribution Point	39.383	48.471	DDT	2021	6	0.89
45	Khirmandali Pesticide Distribution Point	39.429	48.421	Total pesticides	2089	8	1.21
46	Fromer Yuxari Agali Pesticide Point	39.427	48.427	DDT	1891.4	7	0.34
47	Gunashli Pesticide Point (Bilasuvar)	39.521	48.491	DDT	1564.4	7	1.78

Table 3 (continued)

#	Site name	Lat	Long	Pollutant	Value, mg/kg	PI value	Number of affected populations, thousands
48	Chuxanli Aerodrome (Salyan)	39.649	48.978	DDT	1121.2	8	2.39
49	Zahmatabad Pesticide Point (Bilasuvar)	39.471	48.548	DDT	365.2	8	1.76
50	Chayli Pesticide Point (Bilasuvar)	39.489	48.517	Total pesticides	2567.2	8	1.03
51	Fromer Saatli Chemical Union	39.941	48.356	Total pesticides	1765.3	8	6.71
52	Qaraxanli pesticide Estakada	41.054	45.671	DDT	1873.2	8	2.13
53	Mukhatariyat Pesticide Point (Shamkir)	40.801	46.125	DDT	2346.4	7	0.56
54	Halach (Beylagan) Pesticide Storage	39.719	47.828	DDT	4689.34	8	3.02
55	Dayikend (Salyan) Pesticide Storage	39.449	48.868	DDT	1875.2	9	0.78
56	Bilasuvar Agricultural Chemical Union	39.451	48.552	DDT	198.21	8	11.3
57	Neftchala Pesticide Storage	39.434	49.016	DDT	3056.34	7	2.34
58	Imishli Central Pesticide Storage	39.868	48.045	DDT	4652.11	8	4.53
59	Korpukend Pesticide Aero ground	40.245	47.501	DDT	145.3	9	0.34

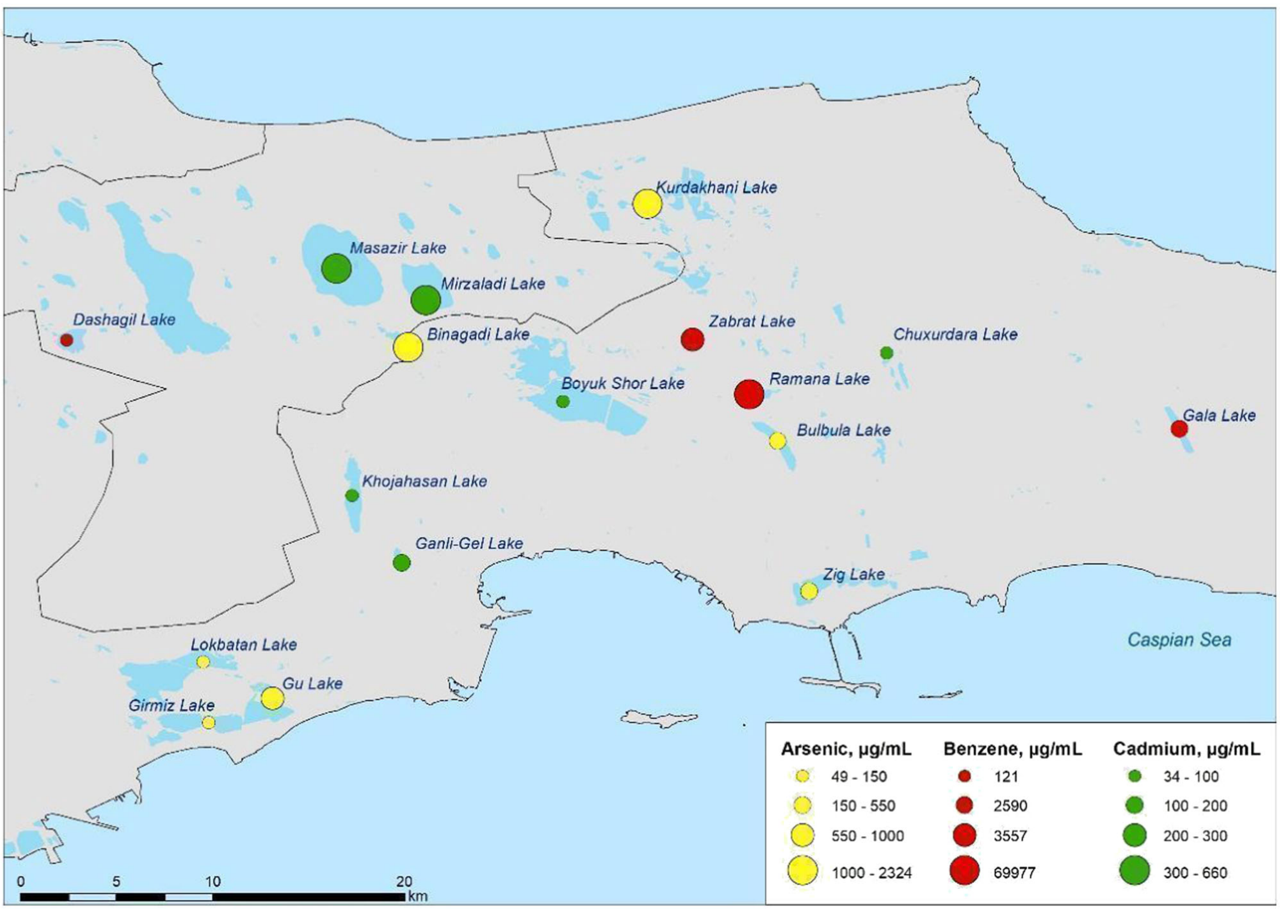

Fig. 5 Concentrations of key pollutants in a water of lakes

and local hospitals confirming that there are high rates of lung cancer and skin diseases. In Sumgait, near the former chemical factories PI values reach 9. There are also high PI values in areas close to legacy pesticide sites (5–8) and old and new metal mines in mountain territories (7–9). Currently, there is a total of 2,300,000 people who live in urban regions (predominately on the Absheron Peninsula: in Baku and Sumgait city) and are at greatest risk of exposure to

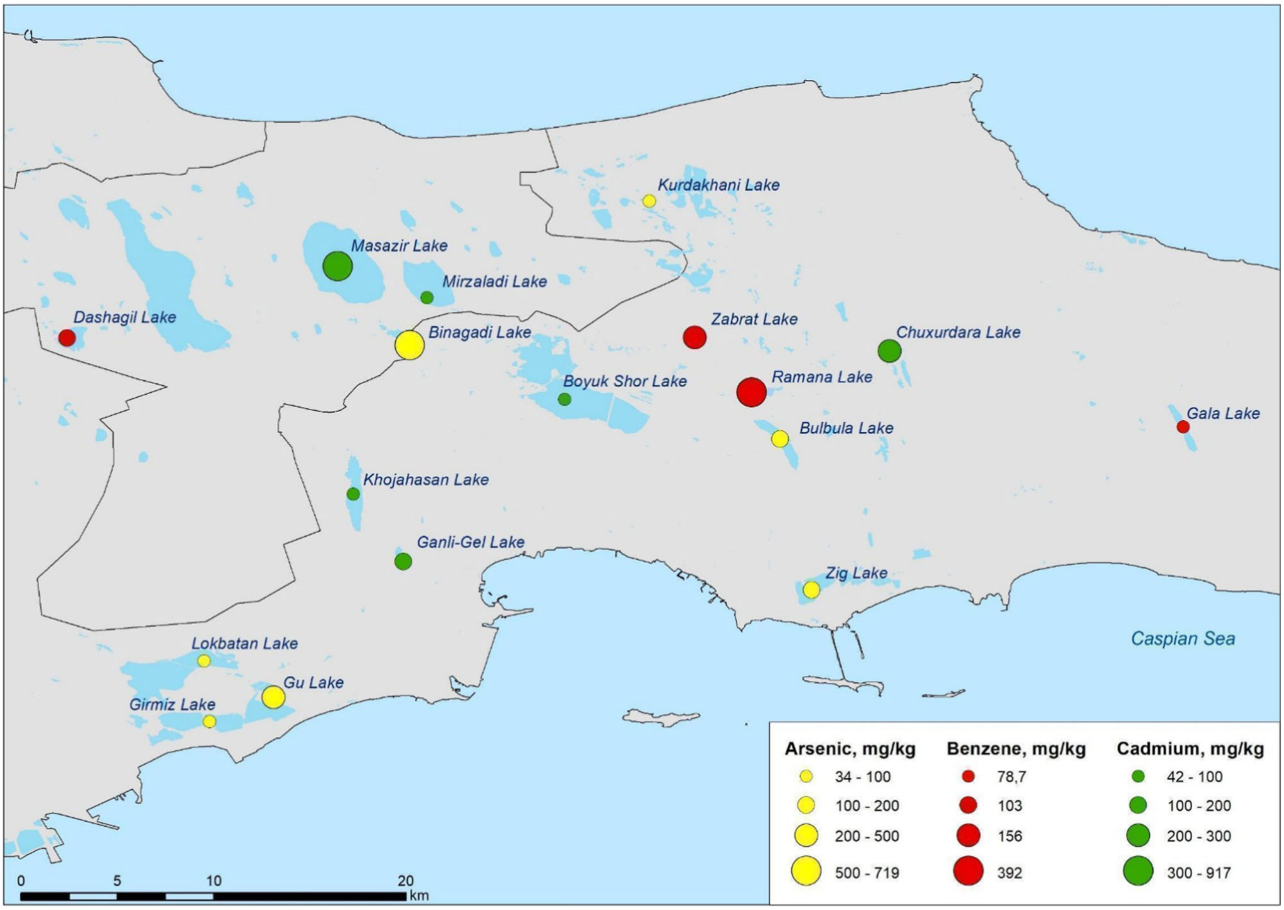

Fig. 6 Concentrations of key pollutants in sediments of lakes

high levels of toxins. The residential areas located near oil mines, polluted lakes and industrial units are the main sites where human health is at greatest risk. In the rural regions of Azerbaijan nearly 250,000 people are under threat of pesticide exposure.

During the data collection and analysis state of the TSIP study (2012–2018), health impacts were recorded and identified as commonly being pulmonary cancer, chronic asthma, birth defects and various skin disease. During the site screenings field investigators met local doctors, municipality representatives, and collected information through interviews regarding health impacts of each identified toxic site. In addition, field notes taken at local hospitals confirm high stomach and skin cancers, asthma in Sumgait. TSIP confirms that nearly 300,000 people in the Sumgait area are subject to the impact of the TSIP identified toxic sites. In Baku, people are at greatest health risks to total petroleum hydrocarbons (TPH) and air pollutants. Baku is one of the most polluted cities in Azerbaijan, because the city and the surrounding suburbs have very highest rates of cancer and bronchial diseases. TSIP field assessments confirmed that nearly 2 million people in Baku are exposed to the different types of pollutions. The majority of health concerns are cancer, bronchial asthma, skin diseases, and other bronchial diseases. In addition, interviews with local hospitals in the small towns and villages, confirmed that residents near soviet legacy pesticide sites, more often suffer from high rates of cancer and bronchial diseases. However, additional research focused on health impacts from the local toxic sites is needed.

Recommendations for Future Research and Concluding Thoughts

Our study identifies Azerbaijan's toxic pollutants of industrial, agricultural, and oil production from both currently active and abandoned sites from the Soviet era (e.g., these sites are known as legacy sites). Generally, high levels of oil and industrial pollutants were identified within urban regions, and in the rural locations there are higher levels of pesticide and heavy-metal contamination. These identified TSIP locations also showed a pattern of people living or working near toxic sites to have a higher rate of cancer, chronic asthma, tuberculosis, skin diseases, or birth defects.

The TSIP data established a reliable dataset that can identify human populations, who are most vulnerable to pollution related health risks in developing countries with minimal or no data available, in addition to limited funds to conduct environmental and health related studies (Pure Earth 2019b). Although there are some studies linking health effects to toxic sites in Azerbaijan, more research is needed to identify the linkages between health effects, from toxic pollutants and place-specific locations, such as air pollution and transboundary pollution in the Caucasus and within the Eurasian nations (Aleksanyan et al. 2008; Sharov et al. 2016; Islamzadeh and Khalilova 2003). The results of the TSIP collected data also confirmed that the lakes on the Absheron peninsula are severely polluted with heavy metals and PAHs, which are located in two of Azerbaijan's largest cities, Sumgait and Baku.

The results of our study demonstrate that the TSIP can better serve developing countries who struggle to collect pollutant and health related data. The TSIP is an excellent database for countries that need to identify hazardous sites that pose serious health risks. For instance, according to the Azerbaijani TSIP assessments, several remediation projects supported by the Azerbaijani government did not produce the expected results. For example, in 2014 a remediation project in Boyukshor lake did not show significant results in the reduction of concentrations of cadmium and toluene. Also, after a remediation project in 2005, around the SAS site in Sumgait, high mercury concentrations still existed. Lastly, in 2009 a remediation project did not eliminate high concentrations of PAHs and TPH that were found to still be at a high level within the Bail area and around Baku. The same situation is observed in White City boroughs in Baku, where after 2006–2010 soil remediation project concentrations of heavy metals, TPH, and PAHs are still very high. It was not until the Azerbaijan TSIP was completed in Azerbaijan that governmental agencies could identify and recognize the urgency of the region's identified pollutants and the high chance of other unidentified sites that pose serious health risk to people interacting or residing in these toxic sites.

Although there are many detected toxic sites recorded within the Azerbaijani TSIP database, there are still many sites that have not been recorded due to financial limitations of TSIP in Azerbaijan. Specifically, many villages have small scale pesticide sites from the Soviet period of agricultural production, but due to financial limitations these small-scale sites were not assessed. Our study's results support the need for continuation and expansion of the TSIP data collection in Azerbaijan and within the neighboring Soviet countries.

We recommend further studies investigate human health risks in relation to hazardous toxic sites. The TSIP is an excellent starting point for nations, such as Azerbaijan and other Eurasian and post-communist nations, by providing a more reliable database for national programs that have not been successful in the past. The results of our study encourage better support and implementation of environmental management and policies, in developing post-communist nations, as well as to provide a database that identifies toxic, hazardous sites in the Caucasus, the Caspian Sea, and in Eurasia.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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