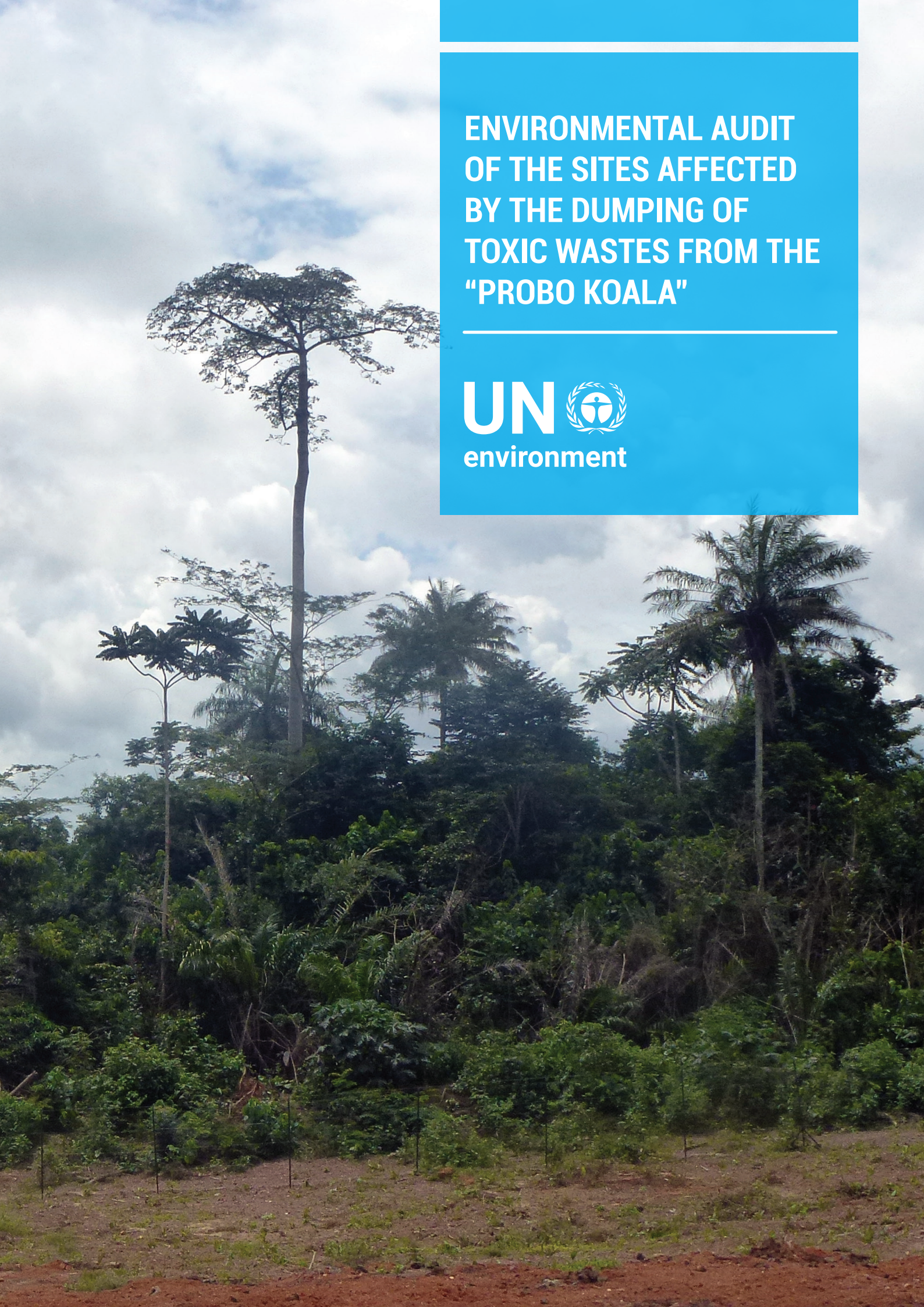
ENVIRONMENTAL AUDIT OF THE SITES AFFECTED BY THE DUMPING OF TOXIC WASTES FROM THE "PROBO KOALA"

UN environment



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Acronyms, Symbols and Abbreviations

Institutions

ALS	Australian Laboratory Services
BNEDT	Bureau National d'Études Techniques et de Développement (National Office of Technical and Development Studies, Côte d'Ivoire)
CIAPOL	Centre Ivoirien Antipollution (Ivorian Anti-Pollution Center, Côte d'Ivoire)
EC	European Commission
MACA	Maison d'Arrêt et de Correction d'Abidjan (Abidjan prison)
MINSEDD	Ministère de la Salubrité, de l'Environnement et du Développement Durable (Ministry of Sanitation, Environment and Sustainable Development, Côte d'Ivoire)
NFI	Netherlands Forensic Institute
ONEP	Office National de l'Eau Potable (National Drinking Water Authority, Côte d'Ivoire)
PETROCI	Société Nationale d'Opérations Pétrolières de la Côte d'Ivoire (National Petroleum Operations Company of Côte d'Ivoire)
SIR	Société Ivoirienne de Raffinage (Ivorian Refining Society)
TPH CWG	Total Petroleum Hydrocarbons Criteria Working Group
UK	United Kingdom
UN Environment	United Nations Environment Programme
UNEP-DHI	United Nations Environment Programme – Danish Hydraulic Institute
USEPA	United States Environmental Protection Agency

Chemicals

As	Arsenic
BTEX	Benzene, toluene, xylene isomers
C	Carbon
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
HCl	Hydrochloric acid
Hg	Mercury
HNO3	Nitric acid
NaOH	Sodium hydroxide
Ni	Nickel
PAH	Poly-aromatic Hydrocarbons
Pb	Lead
PE	Polyethylene
pH	Potential of hydrogen

PP	Polypropylene
Sr	Strontium
Se	Selenium
TPH	Total petroleum hydrocarbons
VOC	Volatile organic compounds
VPH	Volatile petroleum hydrocarbon
Zn	Zinc

Scientific protocols

AAS	Atomic absorption spectroscopy
GC-FID	Gas chromatography – flame ionization detector
GC-MS	Gas chromatography – mass spectrometry
HPLC	High performance liquid chromatography
ICP-MS	Inductively coupled plasma – mass spectrometry
ICP-OES	Inductively coupled plasma – optical emission spectrometry

Weights and measures

°C	Degree Celsius
cm	Centimetre
g	Gramme
hddd°mm.mmm	Hemisphere, degrees, minutes, decimal minutes
kg	Kilogramme
km	Kilometer
l	Litre
m	Metre
m^3	Cubic metre
mg	Milligramme
mm	Millimetre
ppm v/v	Parts per million volume of volume
t	Tonne
µg	Microgramme

Other

Approx.	Approximately
GPS	Geographical Positioning Systems
NF	Norme française (French standard)
WGS	World Geodetic System

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Executive Summary

Background

On 19 August 2006, the Probo Koala, a Panamanian-registered ship chartered by the shipping company Trafigura, off-loaded 528 cubic meters of liquid wastes in the port of Abidjan, Côte d'Ivoire. The wastes were reportedly generated as the by-product of an industrial process known as "caustic washing" of coker naphtha, an unrefined gasoline typically containing high levels of sulfur. The material was transferred onto tanker trucks operated by a local contractor, and dumped in twelve different locations around the city.

Within hours of the dumping, local residents, alerted by an overwhelmingly strong smell, reported experiencing a series of detrimental health effects, such as respiratory difficulties and eye and skin irritations. In the following weeks, over 100,000 people sought medical assistance from public health facilities for similar issues, as well as nosebleeds, digestive problems, nausea and vomiting, and other symptoms.

As a precautionary measure, the Government ordered schools in the affected areas to be closed, and for fruit and vegetables crops grown on or near dumping areas to be destroyed. Livestock raised in proximity to some dumping sites was culled, and fishing was banned in the bays of Ébrié Lagoon. Furthermore, anxiety and anger over the situation generated protests, road-blocks and violent demonstrations in various parts of the city.

A first phase of clean-up – during which the dumping sites were excavated and the excavated material was shipped to France to be incinerated – was carried out by the French company Trédi, starting in September 2006. In the ten years that followed the dumping, a number of additional clean-up and remediation activities were carried out by various actors, including by the Government of Côte d'Ivoire, which was still performing environmental monitoring of the sites at the time of writing. In spite of these initiatives, however, local populations have continued to express concern over the potential health and environmental impacts of the toxic waste dumping.

It is in this context that in June 2012, UN Environment received a formal request from the Government of Côte d'Ivoire to undertake an independent and scientific environmental audit of the sites that were impacted by the dumping of wastes from the Probo Koala. The Government wished for UN Environment to determine whether the sites continued to pose risks for the environment or for public health, and to make recommendations about additional or corrective clean-up measures that would need to be carried out in case contamination was detected.

The UN Environment Audit

Following several scoping missions to gather background information and examine the practicalities of undertaking such an audit, a UN Environment team of four international experts was deployed to Abidjan in July 2016 to undertake sampling of soil, water, air, sediment, molluscs, fruit and vegetables at 18 sites considered to have been affected by the dumping of toxic wastes, as well as at three control sites. The samples were meticulously prepared, packed and shipped to three internationally accredited European laboratories for analysis.

A second mission was conducted in January 2017 to identify additional control sites, and carry out complementary sampling to fill specific analytical gaps and corroborate initial findings from the laboratory analysis. In both cases, the international experts were joined in the field by three experts from the Ivoirian Anti-Pollution Center (CIAPOL), who had first-hand knowledge of the original dumping event and the subsequent clean-up and environmental monitoring initiatives.

Based on the different analyses of the chemical composition of the wastes carried out in 2006, UN Environment considered the following groups as the key contaminants of interest for the audit: (i) petroleum hydrocarbons; (ii) sulfur compounds; and (iii) heavy metals. In addition, the impact of high levels of sodium hydroxide was measured through the pH value of the soil.

Conclusions

The results of the laboratory analysis that was undertaken on the 130 samples of soil, water, air, sediment, molluscs, fruit and vegetables that were collected by UN Environment clearly indicate the following for the different types of sites affected by the dumping of toxic wastes from the Probo Koala:

Toxic wastes dumping sites

- None of the sites where wastes from the Probo Koala were actually dumped show contamination exceeding the limits set by the Government of Côte d'Ivoire for remediation. As a result, none of these sites require additional intervention, even when gauged against Dutch intervention values, which are among the most commonly used guidelines for contaminated site management and remediation worldwide.

Dumping sites presenting other types of pollution

- Elevated levels of air and groundwater pollution parameters are found at Site 4 (Koumassi) as compared to the control sites. This reflects the lack of adequate environmental monitoring of the numerous small to medium-scale industrial plants in the area. While concentrations do not reach levels requiring emergency intervention, the results show Koumassi to be something of an "environmental hotspot" requiring Government attention and follow-up.

- As compared to the control sites, the municipal waste disposal site at Akouédo unsurprisingly shows elevated levels of several pollutants, including slightly elevated levels of cadmium in some vegetables grown on Site 12 (Akouédo 2).

Other sites of interest

- The silos that stored the suspected contaminated maize within the autonomous port of Abidjan are free of any of the pollutants linked to the Probo Koala wastes.

- Site 8 (Agboville), where maize that was potentially indirectly impacted by Probo Koala wastes was composted, shows elevated levels of chromium. These levels are above both the standards used to monitor the composting process, and Dutch intervention values.

Recommendations

Based on the conclusions above, the following specific recommendations can be made to the Government of Côte d'Ivoire:

- **Remediation of the Agboville maize composting site:** As two rounds of sampling have indicated that the site has elevated levels of chromium and that chromium is leaching into the drainage collection system, this site should be closely monitored. Access to the site should continue to be restricted, and sign boards should be put up warning people not to enter or harvest grass or vegetables from the site. Leachate from this site should be appropriately disposed of in a dedicated facility following comprehensive chemical analyses. Furthermore, the Government should review its contract and address the situation with the contractor. Additional sampling and risk assessment using a "source-pathway-receptor" model will be needed to determine what interventions are required at the site.

- **Due diligence needed for decommissioning of Akouédo municipal waste disposal site:** The Government has informed UN Environment that the municipal waste disposal site at Akouédo has been earmarked for closure for a long time. Once a closure date is selected, a comprehensive environmental due diligence survey should be conducted, including establishing systems for leachate collection and landfill gas monitoring. Land use restrictions, including on farming on the site, may also have to be put in place.

- **Environmental assessment of the Koumassi area:** Based on the contamination levels found in air and groundwater samples taken at Site 4, it is strongly recommended that the Government: (i) ensure that workers are provided with personal protection equipment and training on occupational health; (ii) establish guidelines on emissions controls and waste management for small and medium-scale industries; and (iii) undertake a comprehensive environmental assessment of the Koumassi area, comprising soil, water and air quality, as a basis for developing an action plan for mitigating impacts on public health.

More generally, while the environmental audit concludes that none of the sites where wastes from the Probo Koala were dumped show contamination exceeding the limits set by the Government or acceptable international standards, the following issues should be highlighted:

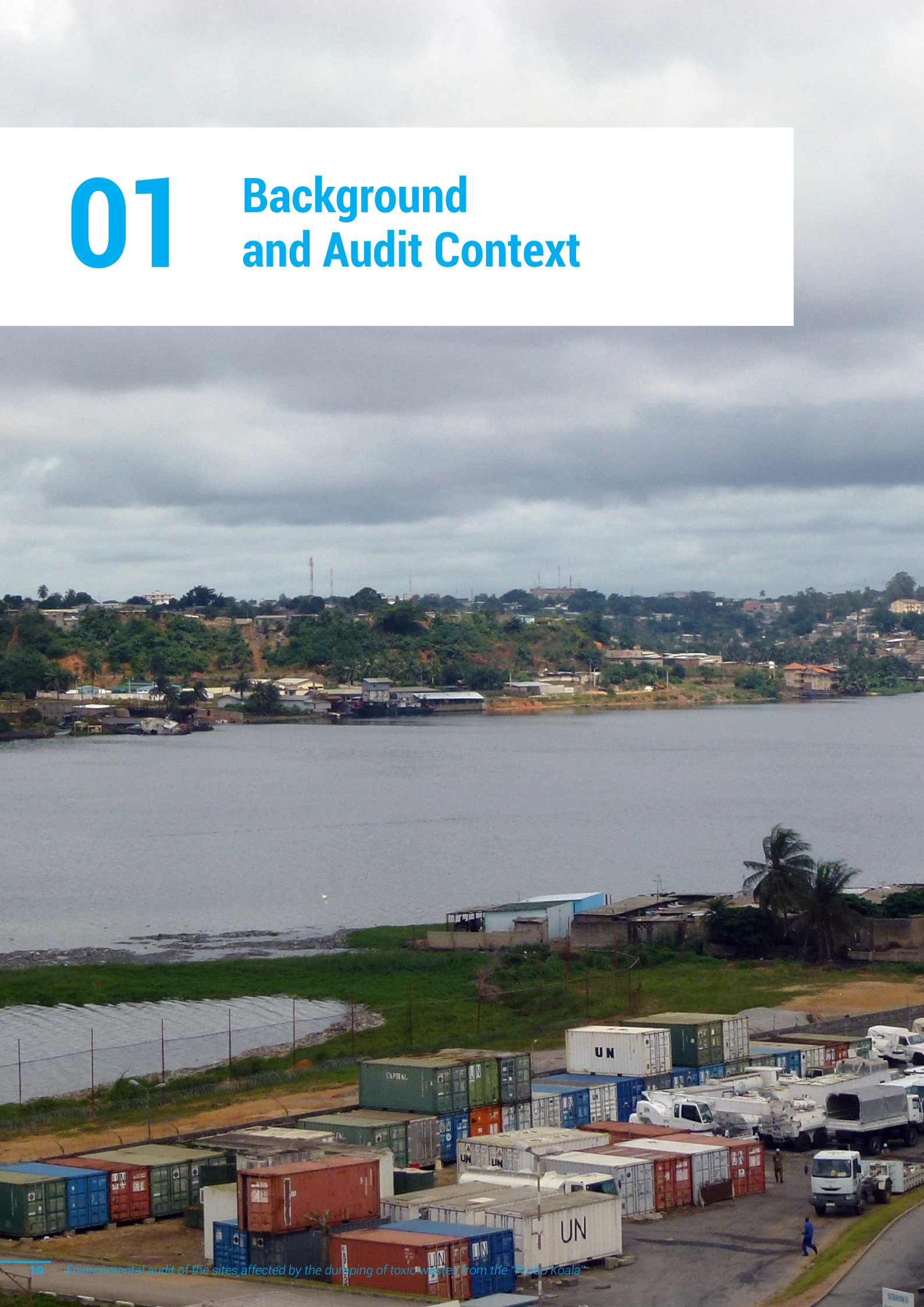
- Tens of thousands of people were impacted by the dumping of the toxic wastes from the Probo Koala in 2006. UN Environment's study focuses on whether the dumping sites continue to pose environmental and health risks to the populations living on or near them, and its conclusions on this count are reassuring. The findings, however, do not preclude that health impacts from their original exposure to the wastes in 2006 are still affecting communities. While it cannot be addressed through an environmental survey, the question of whether those who were impacted at the time of the dumping continue to suffer physiological or psychosomatic impacts is a critical one, particularly as systematic monitoring of affected populations has not taken place over the last decade. It is strongly recommended that the Government of Côte d'Ivoire undertake to review a representative selection of original cases and consider the need to establish a monitoring programme of the health of these communities.

- Although a number of measures have been taken by the Government to improve the monitoring and management of liquid wastes from ships in the ports, access controls to the municipal waste disposal site at Akouédo, which was the original target of the waste dumping, remain somewhat weak. The Government should undertake to further review its operating procedures for hazardous waste management and to ensure that adequate chain of custody procedures are enforced to prevent such events from occurring again.

- Moreover, the environmental monitoring systems and capacity built by UN Environment within CIAPOL in the aftermath of the toxic waste dumping event – which included the provision of state-of-the-art laboratory equipment – were lost during the post-electoral violence of 2010-2011, which devastated the institution. As a result, CIAPOL is no longer able to execute its mandate to its full extent. An assessment of CIAPOL was conducted in 2012 by the UNEP-DHI Centre on Water and Environment. The Government should draw on the recommendations of this assessment to restructure CIAPOL and provide it with additional resources to ensure that it can respond to current environmental challenges.

As evidenced in Koumassi, environmental "hotspots" are developing in Abidjan in the absence of effective surveillance. While these may not yet have major environmental and public health impacts, the consequences of this pollution may be rapidly felt in a fast-growing metropolis such as Abidjan.

01 Background and Audit Context



In June 2012, the Government of Côte d'Ivoire made a formal request to UN Environment to undertake an independent and scientific environmental audit of the sites that were impacted by the dumping of toxic wastes from the Probo Koala ship in 2006. This chapter provides an overview of the background to the audit, including the geographical context, an account of the dumping itself and clean-up efforts undertaken since then, as well as an explanation of the scope and limitations of UN Environment's mandate.

1.1 Geographical and Environmental Context

The Republic of Côte d'Ivoire is located in West Africa and shares borders with Liberia and Guinea to the west, Ghana to the east, and Mali and Burkina Faso to the north. The Atlantic Ocean lies to the south. The country covers an area of 322,463 km^2 and in 2014 had a population of 22.7 million inhabitants.[1]

The country's capital is Yamoussoukro. However, Abidjan, located on the south-eastern coast, is Côte d'Ivoire's largest city and remains the de facto administrative and economic capital of the country. The city and its immediate surroundings are grouped into the Autonomous District of Abidjan, which is comprised of ten urban municipalities (each with its own mayor and municipal council) as well as the sub-prefectures of Anyama, Songon and Bingerville.

Abidjan has an equatorial climate, with two rainy seasons separated by two dry seasons. The District has a high annual rainfall of 1600 mm, with June and July being the rainiest months, and an annual average temperature of 26°C. Geologically, Abidjan is situated in the coastal sedimentary basin, which is composed of clay, sandy clay, sandstone, sand, conglomerate, glauconitic sand and marl.[2]

The city lies adjacent to the Ébrié Lagoon, which extends for approximately 150 km in an east-west direction, averaging some 4 km in width and 5 m in depth. It is separated from the Gulf of Guinea for almost its entire length by a narrow, mostly sandy, strip of land, and connected to it only through the Vridi Canal, a man-made channel 185 m wide. Fresh water flows into the lagoon from a number of small creeks and rivers, the most significant being the Comoé and Mé in the east, and the Agnéby and Ira in the central part.

The population of Abidjan experienced very rapid growth in the second half of the 20th century: the city was home to fewer than 50,000 people in 1948; by 1998, the population had grown to 2.9 million inhabitants.[3] The conflict period of 2002-2011 dramatically intensified the influx of people into the city, due largely to large-scale migration of people from rural villages and towns in the north of the country seeking safety, as well as economic opportunities and social services such as education and health care. In the last census conducted in 2014, the district of Abidjan had a population of 4.7 million, representing approximately 20% of the country's total.[4]

UN Environment's Post-Conflict Environmental Assessment of Côte d'Ivoire, published in 2015, found that this rapid and unplanned growth – coupled with a reduction in investment in urban infrastructure during the conflict period – radically increased pressure on all of Abidjan's services and infrastructure. This has resulted in a range of environmental challenges across the city, including issues related to the disposal of hazardous and municipal waste, water pollution and severe land degradation.[5]

1.2 The Toxic Waste Dumping

On 19 August 2006, the Probo Koala, a Panamanian-registered ship chartered by the shipping company Trafigura, off-loaded 528 cubic meters of liquid wastes in the port of Abidjan. The material was transferred onto tanker trucks operated by a local contractor, Compagnie Tommy, and dumped, in twelve (12) different locations around the city, including the municipal waste disposal site at Akouédo, roadside drains, ditches and vacant plots of land. The liquid also leaked from stationary trucks, flowed from actual dumping locations or migrated from roadside drainage channels in four (4) additional locations. The details of these sites are given in Table 1.

According to several reports,[6] the wastes were generated as the by-product of an industrial process known as "caustic washing" of coker naphtha, an unrefined gasoline typically containing high levels of sulfur, which had been, at least partially, carried out onboard the Probo Koala between April and June 2006. The ship had previously attempted to dispose of the wastes in various ports around Europe, including Amsterdam, and in West Africa. The likely composition of the wastes is discussed in Box 1.

Table 1. Dumping and overflow sites for the Probo Koala wastes

UN Env. site n°	UN Env. site name	How the site was impacted
2	Vridi Canal 1	Wastes were dumped into a roadside drain and overflowed onto the adjacent grounds of a warehouse complex
3	Vridi Canal 2	Wastes dumped at Vridi Canal 1 flowed along an underground pipe and discharged into an open concrete channel at this location
4	Koumassi	Wastes were dumped into an open roadside drainage canal, next to commercial properties and adjacent to a public weighbridge
5	MACA 1	Wastes leaked into a ditch and adjacent fields from a tanker truck parked on the roadside for 3 days
6	MACA 2	Wastes were dumped on the road surface, flowing down the roadside slope into thick vegetation at the edge of the Banco National Forest
7	MACA 3	Wastes were dumped onto the roadside slope into thick vegetation at the edge of the Banco National Forest
9	Alépé 1	Wastes were dumped onto the roadside verge, flowing down into an open field
10	Alépé 2	Wastes were dumped onto a steep roadside slope covered in dense vegetation; wastes also flowed across the road through a culvert
11	Akouédo 1	Wastes were dumped into a roadside ditch running adjacent to the central dirt road through the municipal waste disposal site
12	Akouédo 2	Wastes leaked from a tanker truck parked onto a sloped concrete slab inside the municipal waste disposal, and into the adjacent drainage ditch
13	Akouédo 3	Wastes dumped at Akouédo 1 flowed approximately 200 m downstream and pooled in this low-lying portion of the municipal waste disposal site
14	Coco-Service	Wastes were dumped into a roadside drain connecting to an open concrete channel that discharges into a deep ditch along which runs a stream
15	Abobo Sagbé	Wastes were dumped onto the ground in an open area surrounded by informal workshops
n/a	Abobo Plaque	Wastes were dumped into an fuel tank belonging to an adjacent bakery[7]
16	Plateau Dokoui 1	Wastes were dumped down the side of a rainwater/storm overflow basin into which all surface water flows
17	Plateau Dokoui 2	Wastes were dumped into a roadside sewage disposal tank. During the cleaning of the tank, small quantities of sewage overflowed and ran down the adjacent slope towards a culvert downhill

In addition to emitting a powerful foul odor, the combination of high concentrations of sodium hydroxide with odorous sulfur compounds could potentially cause a range of health impacts. Within hours of the dumping, local residents, alerted by an overwhelmingly strong smell, reported experiencing a series of detrimental health effects, such as respiratory difficulties and eye and skin irritations. In the following weeks, as the Government opened the hospitals and offered free health care to affected residents, over 100,000 people sought medical assistance from public health facilities for similar issues, as well as nosebleeds, digestive problems, nausea and vomiting, and other symptoms.[8]

In the early part of the crisis, lack of information about the composition of the wastes and their potential effects contributed to heightened anxiety among the population, including fears that food and water might be contaminated. At the request of the Government, fruit and vegetables crops grown on or near dumping areas, as well as livestock raised in proximity to some dumping sites, were destroyed, and fishing was banned in the bays of Ébrié Lagoon.[9] Government officials also reported population displacement and school closures in the affected areas. The Akouédo site, Abidjan's only official waste disposal site, where some of the toxic waste was dumped, was closed for two months.[10]

On 6 September 2006, faced with an increasingly tense situation, Prime Minister Charles Konan Banny announced the resignation of his Cabinet.[11] However, anxiety and anger over the handling of the events continued to generate protests, road-blocks and violent demonstrations in various parts of the city over the next weeks.[12]

Following the creation of a new Government, the Prime Minister announced the establishment of a national commission of inquiry on 17 September, as well as the start of clean-up operations to be coordinated by a dedicated entity known as the Cellule Opérationnelle de Coordination du Plan National de Lutte contre les Déchets Toxiques, which was also responsible for regular communication to the public about the measures being taken to address the crisis.

In the ten years since the dumping, a number of clean-up and remediation activities have been carried out by various actors, including by the Government of Côte d'Ivoire, which continues to perform environmental monitoring of the sites at the time of writing (see below). In spite of these initiatives, however, local populations continue to express concern over the potential health and environmental impacts of the toxic waste dumping.

Box 1. What was in the wastes from the Probo Koala?

Although the exact chemical composition of the wastes that were dumped in Abidjan in August 2006 is not definitively known, the strong and foul smell that triggered panic across Abidjan following the dumping provides some measure of certainty that hydrogen sulfide and mercaptans were present in the wastes.

Three analyses mandated by the State of Côte d'Ivoire at different stages of the crisis helped establish their general chemical characteristics. Samples were taken from the Probo Koala by the Ivorian Anti-Pollution Center (CIAPOL) on the Probo Koala at the very beginning of the crisis, and were analyzed by the Société Ivoirienne de Raffinage (SIR, or Ivorian Refining Society) on 24 August 2006. Other samples were taken on the dumping sites, including those analyzed by the French Civil Security, which provided support to the Government in September 2006, or those examined at the Government's request by the european laboratory Wessling, whose report was delivered in March 2007.

Table 2. Characterization of the wastes according to the NFI analysis (carried out in July 2006)

AQUEOUS PHASE		
Chemical	**% of slops**	**Weight in slops**
Sodium hydroxide (NaOH)	10 %	37.9 t
Total sulfur (S)	6.8 %	25.7 t
Mercaptan sulfur (Ethyl and Methyl Sodium mercaptides as S)	3.34 %	12.7 t
Thiophenols	0.16 %	0.6 t
Phenols, including cresols	4.8 %	18.2 t
Inorganic sulfur (Sulfide and Bi-Sulfide as S)	0.5 %	1.9 t
Cobalt phthalocyanine sulfonate	4 ppm added	1516 g
Catalysts (as Co)	1.3 ppm measured	492 g
Mercury (Hg)	0.91 ppm	345 g
Zinc (Zn)	2.7 ppm	1023 g
Copper (Cu)	1.8 ppm	682 g
Strontium (Sr)	0.42 ppm	159 g
HYDROCARBON PHASE		
Chemical	**% of slops**	**Weight in slops**
Hydrocarbons C5 to C11	Approx. 98 %	Approx. 135 t
Heavy hydrocarbons C14 to C40, estimated from Trédi analyses	0.45 %	0.62 t
Normal alkanes	29.1 %	39.9 t
Branched alkanes	17.2 %	23.6 t
Unsaturated compounds	36.2 %	49.6 t
Cyclic alkanes	10.9 %	14.9 t
Aromatics, of which	6.2 %	8.5 t
C2 Alkyl benzenes	1.7 %	2.3 t
C3 Alkyl benzenes	0.9 %	1.2 t
C4 Alkyl benzenes	0.1 %	0.14 t
Total sulfur mainly as diethyl and methyl propyl disulfides (measured as S)	1.3 %	1.8 t
Mercaptan sulfur (S)	0.095 %	0.13 t
Organo chlorine (ex Main VII)	2 ppm	274 g

The most detailed characterization of the chemical composition of the wastes, however, is that resulting from analyses carried out in July 2006 by the Netherlands Forensic Institute (NFI), from samples taken when the Probo Koala was docked in Amsterdam, which described the wastes as "a combination of an oily liquid and water, with a whole range of impurities."[13] This analysis was used as the basis for the only document provided by Trafigura, in 2008, regarding the "likely" composition of the wastes. The chemical composition, as accepted by Trafigura, is shown in Table 2 above.[14] However, the respective concentrations of each chemical at the time the wastes were dumped in Abidjan are not known.

1.3 Clean-Up Operations[15]

Several clean-up operations involving both international and national actors were conducted in the years following the dumping. The key aspects of each operation are summarized below, while specific details of the work conducted on each dumping site are provided in Chapter 3.

A first phase of clean-up – consisting of excavation of the dumping sites, followed by shipment and incineration of the excavated material in France – was carried out by the French company Trédi, starting in September 2006. Trédi was initially contracted for the treatment of 2,500 tons of waste and contaminated soils, but by early 2007, had removed in excess of 9,000 tons.

In February 2007, an agreement was reached between the Government of Côte d'Ivoire and Trafigura, in which Trafigura agreed to cover the costs of these clean-up efforts, as well as to identify and remediate any remaining contamination.

In May 2007, Trafigura contracted another French company, Burgéap, to conduct an audit of the clean-up completed by Trédi and to identify additional remediation needs. The first phase of Burgéap's audit was concluded in November 2007.

Differences that emerged with the Government on Burgéap's approach and methodology led to the end of the collaboration. However, Ivorian parties identified four sites requiring further clean-up – Alépé 1, Alépé 2, Vridi Cap Logistics and MACA 2 bis. Trafigura then contracted Biogénie, a Canadian company, to undertake remediation of the Alépé sites.

In April 2008, following an amendment to the agreement with Trafigura that gave control of clean-up operations to the Government, a project was created under the auspices of the Ministry of Environment to undertake additional clean-up and environmental monitoring, the implementation of which was entrusted to the specialized Ivorian Anti-Pollution Center (CIAPOL) and the National Office for Technical and Development Studies (BNEDT).

A new contract between the Government and Biogénie was signed in 2009 to continue the remediation work that had been initiated in 2007. In March 2010, excavation and treatment, through bio-remediation, of the Alépé 1 and 2 sites resumed. The MACA site was also excavated and the collected soil was transferred to Alépé 1 for treatment. Further clean-up of the Vridi Cap-Logistics site was contracted to another company named EMEB-CI, which replaced the internal sanitation network on the site and carried out additional cleaning of the manholes and pipes connected to the main network between October 2010 and June 2011. Following some delays due to the post-electoral violence in 2010-2011, the bio-remediation process at Alépé was considered as completed by end 2014. The treated soil was then redistributed across the site in 2015.

The project also included treatment of a stock of dry maize destined for the production of baby food, which was considered to have been potentially contaminated through airborne pollution while it was stored in a silo in proximity of the Vridi Canal 1 and 2 sites at the time of the dumping. A contract for the removal, transport and treatment of the maize stock was awarded to the Ivorian company Envipur in 2010.[16] Overseen by BNEDT, this involved the composting, starting in 2012, of the maize on a dedicated site located in the township of Agboville, north of Abidjan. While a draft completion report has been provided by Envipur, it has not yet been accepted by the Government and hence the site is still under observation.

In parallel to these clean-up operations, CIAPOL undertook a programme of environmental monitoring of all the dumping sites starting in November 2012, involving periodic assessment of the quality of soils, air, underground water and surface water to identify lingering issues and make recommendations to address them.

The various phases of the clean-up operations are fairly well documented: a number of contractual documents, progress reports and laboratory analysis reports were provided to UN Environment by the Government during this assessment. While these documents present valuable information and make broad conclusions about the status of different operations, the reports do not provide a clear conclusion to each phase of the clean-up, including for example a comparison, presented in a simple format, of the clean-up levels that were achieved to the standards that were agreed.

Given the lack of clear communication on the results obtained from clean-up operations to date, it is perhaps unsurprising that communities near the dumping sites remain concerned about the potential for persisting negative impacts on their health and environment. Moreover, the combination of domestic politics and legal implications related to compensation for the victims has contributed to the issue remaining visible in Côte d'Ivoire, as well as internationally.

1.4 The UN Environment Audit

UN Environment has conducted independent scientific assessments of the environmental impacts of conflicts, disasters and industrial accidents for nearly two decades. In 2011, UN Environment published a landmark report on the environmental contamination of Ogoniland, Nigeria. The report was commissioned by the Government of Nigeria following decades of conflict between local communities and the oil industry that resulted in the suspension of oil exploration and production activities in the area. This report assisted the Ogoni community to work with the oil industry on a remediation process and received international attention.

It is in this context that in June 2012, UN Environment received a formal request from the Government of Côte d'Ivoire to undertake an independent and scientific environmental audit of the sites that were impacted by the dumping of wastes from the Probo Koala, in order to determine whether the sites, which had undergone clean-up and remediation in the years since the dumping event, continued to pose risks for the environment or for public health; and make recommendations about additional or corrective clean-up measures that would need to be carried out in case contamination was detected.

In September 2012, UN Environment undertook a scoping mission to Côte d'Ivoire to discuss the request, visit the locations where dumping took place and gather the required logistical information needed to conduct an audit. During the mission, the team highlighted the following key challenges for carrying out such an assessment:

- By then, six years had passed since the toxic waste dumping, and multiple clean-up activities had taken place in the intervening period. This meant that the probability that contamination from the original dumping event would be found in any of the environmental media was very low.

- The locations where the dumping had occurred had multiple land uses (as ports, warehouses, informal workshops), which were mostly industrial or semi-industrial in nature. After clean-up activities were undertaken, these sites were returned to their uses and a majority of them was still in operation.

- The sites affected by the dumping were impacted by multiple other sources of pollutants both prior to the dumping and after the clean-up. The most extreme case was the Akouédo municipal waste disposal site, where wastes of all kinds continued to be disposed of on a daily basis. Other sites were affected by pollution from heavy traffic, workshops and uncontrolled tipping of household waste, for example.

- Likewise, Ébrié Lagoon, into which some of the contamination would have been washed off through roadside drains and rivers, received municipal and industrial effluents from the entire city of Abidjan on a daily basis and was visibly polluted.

Both the Government and UN Environment understood that it would be scientifically impossible to attribute any detected contamination to a specific

event in 2006. However, it was deemed important to evaluate the degree to which the sites affected by the toxic waste dumping posed any health risk, regardless of the source of contamination. It was therefore agreed that the environmental audit, which was to be financed by the Government of Côte d'Ivoire, would have the following objectives:

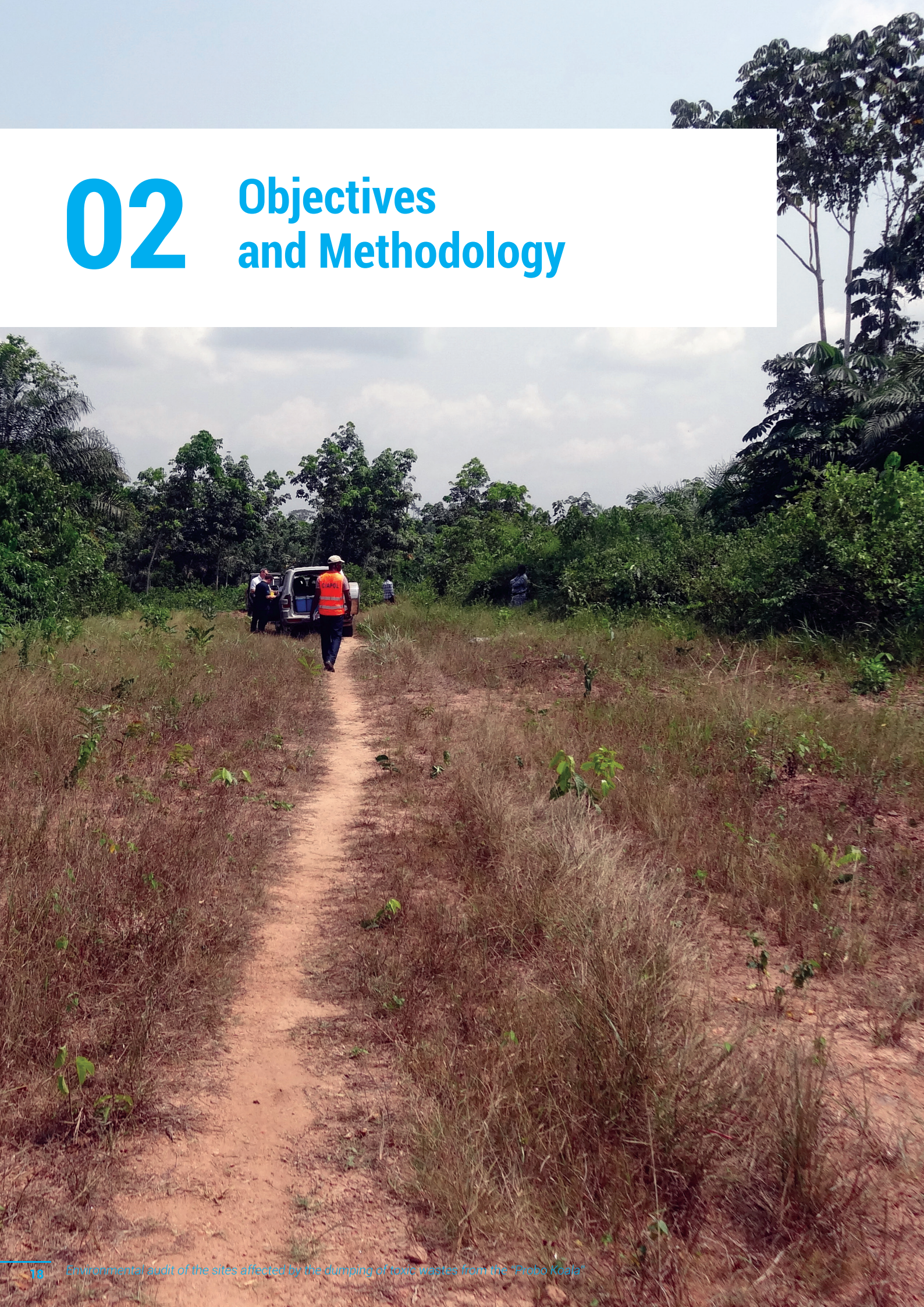
1. To verify if the sites that had already undergone remediation continued to pose any environmental or public health risks; and if so, to provide recommendations on additional clean-up measures needed; and

2. To verify if the clean-up operations that were still ongoing were being carried out in a manner that would achieve the required reduction in environmental contamination; and if not, to make corrective recommendations.

In addition, the Government requested that in parallel to the audit itself, UN Environment review the public health studies conducted in Côte d'Ivoire to date and – in light of the audit's findings – suggest complementary follow-up studies.

A formal agreement to this effect between UN Environment and the Government of Côte d'Ivoire was reached in 2014, and signed in February 2015.

02 Objectives and Methodology



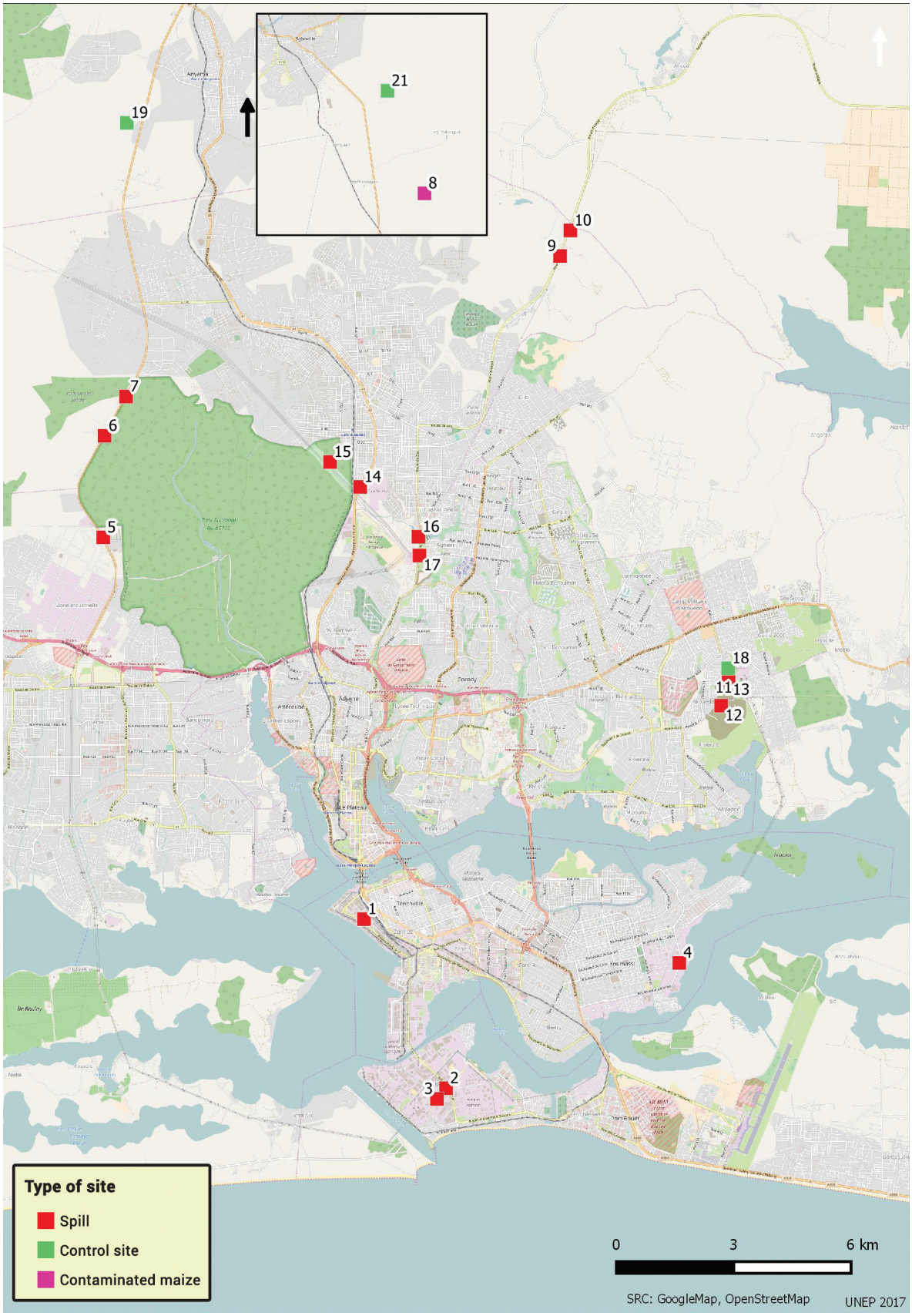
2.1 Objectives and Scope of the Environmental Audit

Although UN Environment reached a formal agreement with the Government of Côte d'Ivoire in 2014, the fieldwork for the environmental audit only started in 2016 – ten years after the toxic waste dumping – due to number of factors including the 2015 presidential election. By the time the work commenced, all but one of the clean-up activities had been concluded, with the result that the objectives of the audit were narrowed down to verifying if the sites that had already undergone remediation continued to pose any environmental or public health risks; and if such risks were found, to provide recommendations on additional clean-up measures needed.

It must be emphasized at the outset that it was not the audit's main objective to determine if any identified pollution could be attributed to the toxic waste dumping from the Probo Koala. Indeed, for reasons explained in the previous chapter, it would not have been scientifically possible to correctly attribute any identified chemical contamination to a single event that took place ten years prior to the audit, particularly as the sites were not secured after the dumping and had been exposed to multiple sources of pollution since that time. From an environmental and public health perspective, what was key was to determine if any of these sites showed contamination – whatever the source of that contamination may be – beyond agreed environmental standards and to ensure that any detected pollution could be adequately and rapidly cleaned up.

As noted in Chapter 1, the Government also requested that UN Environment oversee a review of public health studies related to the toxic waste dumping from the Probo Koala, and facilitate a discussion about complementary studies that should be conducted on the basis of the audit's findings. The review and further recommendations will be documented in a separate paper following a dedicated event in Abidjan in 2017.

Map 1. The District of Abidjan and Ébrié Lagoon



Scope of the audit

The geographical scope of the audit covered twenty-one (21) sites within and around the District of Abidjan, Côte d'Ivoire, including:

- Eleven (11) actual dumping locations;[17]
- Four (4) locations where liquid waste leaked from stationary tanker trucks or flowed from actual dumping locations;
- Two (2) locations where potentially contaminated maize was stored and treated;
- Three (3) control sites that were unaffected by the toxic waste dumping of 2006; and
- The Ébrié lagoon, where run-off from the dumping sites could have flowed.

The list of these sites, along with their current land uses, are given in Table 3; while their location is shown in Map 1. A full description of the specific context and physical properties of each site, as well as a succinct history of how each site was affected by the toxic waste dumping of 2006 and subsequent clean-up activities, are provided in Chapter 3.

Table 3. List of UN Environment sampling sites

UN Env. site n°	UN Env. site name	Land use around the site	Clean-up status
1	Treichville (silos)	Industrial	Potentially contaminated maize moved from silos here to Site 8 for composting
2	Vridi Canal 1 (Cap-Logistics)	Industrial	Drainage structures removed within the Cap-Logistics company site and along the roadside, and replaced with new structures; surrounding soil excavated and treated elsewhere
3	Vridi Canal 2 (Petroci)	Industrial	Canal and immediate vicinity remediated
4	Koumassi	Industrial	Drainage canal removed, surrounding soil excavated and treated elsewhere
5	MACA 1	Roadside; agricultural	Soil excavated and treated elsewhere
6	MACA 2	Roadside; forest	Soil excavated and treated elsewhere
7	MACA 3	Roadside; forest	Soil excavated and treated elsewhere
8	Agboville	Agricultural	Composting of maize (2012-2016) completed ; site still under observation
9	Alépé 1	Agricultural	Soil excavated, treated on site through bio-remediation (2010-2014) and redistributed across site
10	Alépé 2	Agricultural	Soil excavated and treated at Alépé 1
11	Akouédo 1	Waste disposal site	Soil excavated and treated elsewhere
12	Akouédo 2	Waste disposal site	Soil and part of concrete structure excavated and treated elsewhere
13	Akouédo 3	Waste disposal site	Soil excavated and treated on site
14	Coco-Service	Roadside; urban	Soil excavated and treated elsewhere; drainage canal remediated
15	Abobo Sagbé	Industrial	Soil excavated and treated elsewhere
16	Plateau Dokoui 1	Urban; drain and rainwater collection basin	Contaminated water pumped and sediment excavated
17	Plateau Dokoui 2	Roadside; urban	Roadside sewage disposal tank cleaned; adjacent soil excavated and treated elsewhere
18	Control site at Akouédo	Waste disposal site (formerly active area)	N/A
19	Control site at Anyama	Agricultural	N/A
20	Ébrié Lagoon	Lagoon	N/A
21	Control site at Agboville	Agricultural	N/A

It should be noted that the Abobo Plaque dumping site (see Table 1) was not included because the fuel tank into which the wastes were dumped was removed soon after the event and treated in France by Trédi, and its location was paved over. It was therefore not possible to take samples on this dumping site.

Contaminants of interest

Based on the different analyses of the chemical composition of the samples taken onboard the Probo Koala in 2006, as well as those undertaken on samples collected on the dumping sites (see Box 1), UN Environment considered the following groups as the key contaminants of interest for the audit:

- Petroleum hydrocarbons;
- Sulfur compounds; and
- Heavy metals.

The speciation of contaminants to be analyzed within the above three groups was primarily determined by what was present in the Probo Koala wastes as well as the environmental standards set by the Government of Côte d'Ivoire for clean-up. In addition, the impact of high levels of sodium hydroxide was measured through the pH value of the soil (see Table 26). The full list of analytes is presented in Appendix 2.

Environmental media analyzed

The main focus of this audit was on soil, as this was the primary medium within which the wastes were dumped and clean-up activities were undertaken. Samples of air, water, sediment, molluscs, fruit and vegetables were also taken, based on the following criteria:

- **Soil:** Soil samples were collected from all locations where the toxic wastes had been dumped and/or contaminated materials had been stored or treated, so long as it was feasible to take samples.[18]

- **Groundwater:** The original objective of collecting groundwater samples from all of the sites of investigation could not be met, as a change in drilling methodology – suggested by UN Environment – caused a delay in the installation of the groundwater monitoring wells needed, which could not be drilled in time for the sampling campaign. As an alternative, the audit team relied on existing water wells in the vicinity of the dumping sites, including private drinking water wells and monitoring wells managed by the national drinking water authority (ONEP).

- **Surface water:** Surface water samples were taken on or near the sites of investigation, where relevant water bodies could be found. These included roadside drains, ponds, streams and rivulets, as well as Ébrié Lagoon.

- **Air:** Samples of air were taken on or near the various sites of investigation. In some cases, such as when sites were located in close proximity to one another, a single air sample was collected as representative of air quality in the area.

- **Comestible vegetation:** Vegetable and fruit that were grown on or around the impacted sites were analyzed to verify if their consumption posed any public health risks. Samples were taken on an opportunistic basis, as not every site of investigation was used for cultivation.

- **Molluscs:** Shellfish are an important bio-monitoring "tool" for measuring the health of an ecosystem as they accumulate pollutants over time and hence magnify even trace elements. Samples of oysters were therefore collected near the locations where Probo Koala wastes may have migrated into the lagoon.

- **Sediment:** Samples of sediment were collected from the sites of investigation, wherever possible, to serve as potential records of earlier contamination.

2.2 Fieldwork

Following several scoping missions to gather background information and examine the practicalities of undertaking such an audit, a UN Environment team of four international experts was deployed to Abidjan from 1-16 July 2016 to undertake sampling at all the above-mentioned sites. The team included experts with specializations in solid and hazardous waste management, soil and land-based contamination, water and environmental sampling techniques. In addition, two specialists – in atmospheric pollution

and public health, and in marine pollution, respectively – provided their expertise remotely, advising on sampling strategy and technique, and analyzing the laboratory results.

A second mission, involving two international experts, was conducted from 16-20 January 2017 to identify additional control sites, and carry out complementary sampling to fill specific analytical gaps and corroborate initial findings from the laboratory analysis.

In both cases, the international experts were joined in the field by three experts from the Ivoirian Anti-Pollution Center (CIAPOL), who had first-hand knowledge of the original dumping event and the subsequent clean-up and environmental monitoring initiatives.

Sample collection

The sampling approach for each environmental medium is provided in Table 4.

Table 5 details the sampling regimen that was possible at each site, which was largely a factor of the prevailing site conditions and characteristics.

Table 4. Sampling approach

Medium	Details
Soil	• Soil sampling was undertaken at all sites where waste was dumped, stored or treated, with the exception of Site 1 (Treichville) and Site 3 (Vridi Canal 2) where these could not be obtained due concrete surfacing. • Hand-auguring was used to collect samples down to an average depth of 1 m. • Shallow surface soil samples were also collected as relevant, using small hand augers to enable a comparison to be made of potential contamination at the surface and sub-surface. • A total of 53 soil samples were collected from 15 impacted sites, as well as from the 3 control sites.
Air	• Air sampling was conducted using stainless steel passivated canisters. • A total of 16 air samples were collected.
Groundwater	• Sampling could only be undertaken at selected locations based on the presence, and access to existing drinking water boreholes and monitoring wells operated by the local drinking water authority (Office National de l'Eau Potable or ONEP), or shallow wells dug by local residents. • A total of 12 groundwater samples were collected from 8 different sites, including 8 from ONEP wells and 4 from locally dug shallow wells. • Water samples from private wells were collected in the same fashion that householders access their drinking water, whether mechanically or manually pumped or using buckets. • The team also used hand-bailers to assist with sample collection, where necessary.
Surface water	• Surface water samples were collected where relevant from rivers, surface drains and channels. • A total of 21 surface water samples were collected from 9 different locations, including 8 impacted sites and a series of samples from various depths across the Ébrié Lagoon.
Comestible vegetation	• To check all possible contamination pathways, vegetable matter from comestible crops, such as cassava, corn, sweet potato and fruit was collected where relevant. • A total of 16 samples of comestible vegetable matter were collected, including 15 from impacted sites and 1 from the control site at Agboville.
Sediment	• Where possible, sediment was collected from culverts, surface water bodies and rivers. • A total of 8 sediment samples were collected, including 3 samples from impacted sites and a further 5 samples from the Ébrié Lagoon.
Molluscs	• A total of 4 samples of oysters were collected from around the shoreline of the Ébrié Lagoon. • Sampling was attempted in other locations but was unsuccessful for a combination of reasons including: an absence of any oysters as they had been locally harvested; high tides; inaccessibility due to steep banks or dangerous/ loose rocks.

Table 5. Sampling regimen per site

UN Env. site n°	UN Env. site name	Environmental medium						
		Soil	Sediment	Surface water	Groundwater	Air	Comestible vegetation	Molluscs
1	Treichville	×	×	×	×	✓	×	×
2	Vridi Canal 1	✓	×	✓	×	✓	×	×
3	Vridi Canal 2	×	×	✓	✓	✓	×	×
4	Koumassi	✓	×	×	✓	✓	×	×
5	MACA 1	✓	×	×	✓	✓	✓	×
6	MACA 2	✓	×	×	×	×	×	×
7	MACA 3	✓	✓	×	✓	✓	✓	×
8	Agboville	✓	×	✓	✓	✓	✓	×
9	Alépé 1	✓	×	×	×	✓	✓	×
10	Alépé 2	✓	✓	✓	✓	✓	✓	×
11	Akouédo 1	✓	×	×	×	✓	✓	×
12	Akouédo 2	✓	×	✓	×	✓	✓	×
13	Akouédo 3	✓	×	✓	×	×	✓	×
14	Coco-Service	✓	✓	✓	✓	✓	✓	×
15	Abobo Sagbé	✓	×	×	×	✓	✓	×
16	Plateau Dokoui 1	✓	×	✓	×	✓	×	×
17	Plateau Dokoui 2	✓	×	×	×	✓	✓	×
18	Control site at Akouédo	✓	×	×	×	×	×	×
19	Control site at Anyama	✓	×	×	✓	×	×	×
20	Ébrié Lagoon	×	✓	✓	×	×	×	✓
21	Control site at Agboville	✓	×	×	×	✓	✓	×

Control samples

As the sites where the toxic wastes from the Probo Koala were dumped are also impacted by multiple other sources of pollution on a daily basis, it was important to be able to assess the degree of potential contaminatio in these locations from natural as well as anthropogenic sources, outside of any contact with the Probo Koala wastes. As shown in Table 5, three control sites were selected for this purpose:

- **Site 18 – Control site at Akouédo:** This control site is located within the municipal waste disposal site's perimeter walls, near the entrance gate and weighbridge, in an area that was not impacted by the Probo Koala toxic wastes dumping of 2006. Situated in a part of the waste disposal site that had not received any significant volume of new waste in recent years, it was selected to serve as a control site illustrating prevailing conditions in an environment that was significantly contaminated from long-term routine disposal of urban solid wastes as well as industrial wastes. One surface (0-20 cm) soil sample was collected on this site. It was not possible to collect a deeper sample as the ground underfoot was still comprised essentially of undegraded waste materials.

Map 2. Site 18: Control site at Akouédo

Site 19: Control site at Anyama

- **Site 19 – Control site at Anyama:** This control site is located near the town of Anyama, 15 km to the north of Abidjan, in a rural area of grassland, forest and small agricultural plots. It is accessible by vehicle but located some 320 m from the Abobo highway coming from Abidjan. Considered to be completely non-impacted by the Probo Koala wastes, this site was selected to serve as a control site illustrating the prevailing environmental conditions within a rural setting that was expected to have similar soil characteristics as Abidjan, but not to be severely impacted by urban activities or waste disposal. One surface (0-20 cm) and one 1 m-depth soil sample were collected from within the control site, as well as one sample of groundwater and one sample of air.

Map 3. Site 19: Control site at Anyama

- **Site 21 – Control site at Agboville:** This control site is located some 65 km from Abidjan, near the town of Agboville. It is located within a forested area interspersed with small agricultural plots. Approximately one kilometer from the main road, it is accessible by vehicle along a small dirt track. Considered to be completely non-impacted by the Probo Koala wastes, this site was selected to serve as a control site illustrating the prevailing environmental conditions within a rural setting, with a specific focus on air quality, as the Anyama site (Site 19) was close enough to Abidjan to potentially be impacted by the urban air pollutants of the city and the main road nearby. This site could also act as a control site for soil characteristics in the Agboville area. This was important because the chemical analyses – for heavy metals in particular – could differ widely between different types of soil. As the audit analyzed heavy metal concentrations for Site 8, also located near Agboville, it was important to ensure that findings be compared to accurate background values. In addition to an air sample, one surface (0-20 cm) soil sample and one vegetation sample were therefore collected from within the control site. It was not possible to collect a 1 m-depth sample as the hard, stony soil prevented augering to any significant depth.

Map 4. Site 21: Control site at Agboville

Table 6. Laboratory analysis results for the control sites

Soil	Site 18	Site 19	Site 21	
	Akouédo	Anyama	Agboville	
Parameters (mg/kg)	0-20 cm	0-20 cm	1 m	0-20 cm
Total Hy C5-C44	215	7.16	0.829	11.4
Benzene	< 0.009	< 0.009	< 0.009	< 0.009
Ethylbenzene	< 0.004	< 0.003	< 0.003	< 0.004
Toluene	< 0.007	< 0.002	< 0.002	< 0.007
Xylene	< 0.02	< 0.009	< 0.009	< 0.02
Total sulfur (%)	0.0287	0.0248	< 0.02	0.0456
Pb	339	5.5	5.9	8.09
Cd	2.22	< 0.1	< 0.1	0.0722
As	11.3	1.3	1.5	2.38
Cr	45.7	19	21	38.7
Ni	23.6	2.7	3	2.25
Co	5.47	0.5	0.53	0.268
Hg	< 0.14	0.03	0.02	< 0.14
Cu	130	4.3	4.5	1.74
Zn	1.880	7.5	6.8	6.14

Air		Site 21
Parameters/units		Agboville
Dimethyl sulfide	ppm v/v	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1
Methyl tert-butyl ether	µg/m3	ND
Benzene	µg/m3	ND
Toluene	µg/m3	ND
Ethylbenzene	µg/m3	ND
m,p-Xylene	µg/m3	ND
0-Xylene	µg/m3	ND
Naphthalene	µg/m3	ND
TPH (C4-C6)	µg/m3	10
TPH (C6-C8)	µg/m3	20
TPH (C8-C10)	µg/m3	35
TPH (C10-C12)	µg/m3	53
TPH (C4-C12)	µg/m3	120
Aliphatic (C4-C6)	µg/m3	ND
Aliphatic (C6-C8)	µg/m3	17
Aliphatic (C8-C10)	µg/m3	31
Aliphatic (C10-C12)	µg/m3	53
Aromatic (EC5-EC7)	µg/m3	ND
Aromatic (EC7-EC8)	µg/m3	ND
Aromatic (EC8-EC10)	µg/m3	ND
Aromatic (EC10-EC12)	µg/m3	ND

Comestible vegetation	Site 21 Agboville
Parameters (mg/kg)	Pomegranate
Total Hy C5-44	270
Benzene	< 0.009
Ethylbenzene	< 0.004
Toluene	< 0.007
Xylene	< 0.02
Total sulfur (%)	0.0547
Pb	< 0.7
Cd	< 0.02
As	< 0.6
Cr	1.62
Ni	0.82
Co	0.149
Hg	< 0.14
Cu	3.85
Zn	22.9

Groundwater	Site 19 Anyama
Parameters (µg/l)	Borehole
Total Hy C5-35	< 10
Benzene	< 7
Ethylbenzene	< 5
Toluene	< 4
Xylene	< 11
Free sulfur	< 50
Pb	< 0.25
Cd	< 0.25
As	< 0.25
Cr	0.41
Ni	1.5
Co	1.4
Hg	< 0.25
Cu	1.8
Zn	5.4

The laboratory analysis results for the three control sites, which are presented in Table 6, confirm expectations for the various contaminants of concern. Site 18 (control site at Akouédo) shows elevated levels of hydrocarbons in soil as compared with Site 19 (control site at Anyama), whereas the concentration of contaminants between the two unpolluted control sites (Sites 19 and 21) are comparable. Air pollution levels (for hydrocarbons) at site 18 are only marginally elevated as compared to Site 21.

In the following chapters, concentrations of pollutants that are found to exceed the standards set by the Government or international guidelines are compared against the control sites to verify if these pollutants were also present in the background.

Field equipment

Soil sampling

Manually operated soil augurs were used to collect soil samples down to an average depth of 1 m, as well as shallow soil samples (0-20 cm).

Air sampling

Stainless steel passivated canisters with a GC-grade silonite inner coating providing an extremely inert and stable collection medium were used for air sampling.

Water sampling

A multi-parameter field analyzer (model Hach Lange HQ40d) was used to measure water quality parameters. Permanent sensors available in the analyzer were used to measure temperature, electrical conductivity and pH.

Geographical positioning system

In order to corroborate data compiled from scoping missions and to obtain accurate coordinates of various sampling points, the field team used hand-held Geographical Positioning Systems (GPS) devices (GARMIN etrex 30; positioning format: hddd°mm. mmm'; WGS 84).

Sample management

Sample handling and containers

The laboratories selected to carry out the analyses provided a range of glass and plastic containers for the storage and transportation of soil, sediment, water, comestible vegetation and mollusc samples. Each sample vessel was filled to capacity and securely sealed with screw caps to reduce the loss of volatile components.

In the case of water samples, particular attention was given to fill each bottle in a slow and steady manner to reduce interaction with the gaseous phase, and minimize agitation of the sample during transport. This was particularly the case for volatile vials – from which BTEX and the volatile petroleum hydrocarbon (VPH) component of the TPH CWG analysis were undertaken – which were filled until a meniscus was formed, and then slowly sealed with a cap. The vial was then inverted to inspect for air bubbles that may have occurred during the sampling process, as this would have indicated a risk that volatile compounds could migrate into the headspace.

Each sample was then individually wrapped to prevent contact with others. Any samples presenting visible and/or olfactory evidence of contamination were packed separately in their own cool box, and marked as such in the chain of custody to be communicated directly to the laboratory. Disposable gloves were changed between each sampling location in order to keep cross-contamination to a minimum when handling different sets of bottles.

Sample storage and transportation

Sample containers were transported back to UN Environment's base after each site visit, securely packaged with clear labelling to minimize damage during transit through improper handling. Extra bubble wrap was included to prevent movement of samples and contact between fragile containers.

All containers were refrigerated upon arrival at the UN Environment base, in order to retain their field composition and properties, and minimize any chemical and biological changes. Light-sensitive constituents were stored in darkness in colored containers: dark-colored glass containers were used to store soil samples for analysis of organic

parameters, while green-colored glass was used to prevent photo-degradation of water samples.

Samples for the analyses of metals were stored in appropriate bottles – PE for the solids and PP (Nalgene©) for the water samples. This ensured that no analytes could be absorbed by the containers. Liquid samples were stabilized with nitric acid, citric acid and gold, ensuring the stability of all metals (including mercury), during storage under cool conditions and transport.

Samples were then couriered to the laboratories using cool boxes filled with frozen ice packs.

2.3 Laboratory Analysis

Analytical parameters and techniques

UN Environment distributed samples for analysis to three internationally accredited laboratories in Europe: Spiez Laboratory in Switzerland, ALS (formerly Alcontrol) Laboratory in the UK and ALS Scandinavia Laboratory in Sweden. The specialized analysis undertaken by each laboratory is detailed in Table 7 below.

Assessment criteria

As mentioned above, the main focus of this audit was on soil, as this was the primary medium within which the wastes were dumped and clean-up activities were undertaken. The results obtained from the analyses of soil samples were, therefore, screened using three different analytical frames (see Table 8):

1. According to normal scientific practice, findings were first compared with relevant national standards. In this case, results for soil from all the sites where Probo Koala wastes were dumped and which had undergone remediation were compared with the environmental standards set by the Government of Côte d'Ivoire for clean-up operations conducted by Biogénie at Alépé.[19] If the values obtained were lower than the standards set by the Government, UN Environment considered that no additional clean-up intervention was necessary on the site.

2. In the case of Site 8 (Agboville), where maize that had been potentially contaminated by the Probo Koala wastes was composted, and for which the Government did not provide clean-up standards, laboratory results were compared against French standard NF U 44-095 for trace metal

Table 7. Overview of the laboratory analysis undertaken

Laboratory	Analysis undertaken	Methodology
Spiez Laboratory (Switzerland)	**Solids (soil, sediment, comestible vegetation)**	
	• Vanadium, chromium, manganese, cobalt, nickel, copper, zinc, arsenic, molybdenum, cadmium, antimony, thallium, lead, thorium, uranium	Leaching according to EPA 3051 (HNO3 + HCl), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) according to EPA 200.8
	• Mercury	EPA 7473: Mercury in solids by thermal decomposition, amalgamation and atomic absorption (AAS)
	• pH	pH meter

Laboratory	Analysis undertaken	Methodology
	Water	
	• Vanadium, chromium, manganese, cobalt, nickel, copper, zinc, arsenic, molybdenum, cadmium, antimony, thallium, lead, mercury, thorium, uranium	Leaching according to EPA 3015 (HNO_3), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) according to EPA 200.8
	• pH	pH meter
ALS Laboratory (UK)	**Solids (soil, sediment, comestible vegetation) and water**	
	• BTEX	Gas Chromatography-Flame Ionisation Detector (GC-FID)
	• Poly-aromatic hydrocarbons (PAH)	Gas Chromatography-Mass Spectrometry (GC-MS)
	• Elemental sulfur	Gas Chromatography-Mass Spectrometry (GC-MS) & Selective Ion Monitoring
	• Dissolved sulfur	High Performance Liquid Chromatography (HPLC)
	• Total sulfur	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)
	• Phenols	High Performance Liquid Chromatography (HPLC) and Gas Chromatography – Mass Spectrometry (GC-MS)
	Air	
	• Total petroleum hydrocarbons (TPH)	Gas Chromatography using a mass selec-tive detector
	• Volatile organic compounds (VOC)	Gas Chromatography using a mass selec-tive detector
	• Odorants	Pulsed flame photometric detector
ALS Scandinavia, Sweden	**Molluscs**	
	• PAH in biota	Solvent extraction and Gas Chromatography-Mass Spectrometry (GC-MS)
	• BTEX in biota	Headspace technique and Gas Chromatography-Mass Spectrometry (GC-MS)

elements in composted materials used as fertilizer, which the contractor, Envipur, is using to evaluate the status of the maize pile.[20]

3. If laboratory results for a given parameter showed values exceeding the clean-up standards set by the Government or contractor, results were then compared with the internationally recognized Dutch soil remediation standards (intervention values) to see if further immediate action was needed from an environmental point of view. Dutch standards have been in existence for over 30 years and are used as a basis for contaminated site assessment and clean-up in many parts of the world, when local standards are not available. For most parameters of analysis, however, the Government's clean-up standard was more stringent than the Dutch values.
4. Results were also compared with the control sites to see if the observed pollution was also present in the background.

It should be noted that the Government included sulfur as a standard to be met in its contract with Biogénie in 2009.[23] This is presumably because the wastes from the Probo Koala comprised sulfur compounds (mostly volatile). Sulfur is present in soil from natural sources and is not in itself considered a contaminant. In fact, sulfur is often added as a soil conditioner, so its presence per se is not a matter of concern. In 2013, after initial analyses of samples from the Alépé clean-up site showed higher levels of sulfur than the standard that was set, the Government adapted the standard to account for the natural presence of sulfur in samples from background locations,[24] before finally excluding sulfur from the final analysis leading to the conclusion of Biogénie's clean-up operations at Alépé.[25] UN Environment

Table 8. Remediation standards used in this report

Parameter	Government standards for clean-up at Alépé site (2009)	French norm NF U 44-095 used by Envipur at Site 8[21]	Dutch intervention values for soil (2013)[22]	Dutch intervention values for groundwater (2013)
Concentration	**mg/kg**	**mg/kg**	**mg/kg**	**µg/l**
Sulfur (organic extractable)	10			
Total sulfur	10			
Total hydrocarbons	1,000		5,000	600,000
Benzene	1		1.1	30
Ethylbenzene	25		110	150
Toluene	05		32	1,000
Xylenes	05		17	70
Co	240		190	100
Cu	190	300	190	75
Hg	7	2	36	0.3
Pb	400	180	530	75
Zn	9,000		720	800
Cd	20	3	13	6
As	37	18	76	60
Cr	130	120	180	30
Ni	140	60	100	75

analyses of control samples also showed sulfur levels an order of magnitude above the initial standard set, so the Government's decision to exclude it was fully appropriate.

As the primary medium of receipt of the wastes was soil, the Government of Côte d'Ivoire did not carry out any clean-up of groundwater or sediment. Consequently remediation standards were not set by the Government for these environmental media.

For sediment samples, soil remediation standards are often used, although a decision as to whether to initiate clean-up if standards are exceeded is typically based on several additional criteria. In the case of groundwater, the values found were compared against Dutch intervention values for groundwater (see Table 8) to determine if the pollution warranted further action. In the case of air, concentrations observed were compared against control site values. As no local standards existed

Box 2. Soil Contamination and Clean-up Standards

Contamination of soil by chemicals is a major problem across the globe, posing significant risks for human health and ecosystems. Land contamination can be managed by restricting the land use of a contaminated area, and/or by cleaning up the contaminant of concern. In both cases, it is critical that a specific and measurable concentration of the chemical be defined, above which an intervention – be it clean-up or land use restriction – is needed. This can be a guideline (recommendation) or a standard (mandated by law).

Setting standards, however, is scientifically complex. On the one hand, the damage that a specific chemical can cause to human health depends on a number of factors (including toxicity, dose, duration, media of intake, and the body's defense and excretion mechanisms) in addition to the age and health of the individuals themselves. On the other hand, the way in which specific chemicals migrate from the soil into the human body also varies widely depending on the nature of the chemical, the type of location, and environmental and climatic factors.

Internationally, many countries have set standards for soil remediation. While the fundamental chemistry of how a chemical can harm human beings is universal, the standards for clean-up often are not. This is because in addition to science, standard setting needs to factor in social and economic reasons. The Dutch Government was one of the earliest actors to establish a set of comprehensive standards for soil clean-up. As the landmass in the Netherlands is very limited and almost fully utilized, the Government also has significant experience in monitoring soil quality and undertaking clean-up. As such, the Dutch Standards have been used as the basis for a number of other soil remediation standards that have since been adopted, for example by the European Union, the United Kingdom and the United States of America.

The Dutch soil remediation standard sets two limits, the Intervention Value and the Target Value. The Intervention Values indicate when the functional properties of the soil for humans, plant and animal life are seriously impaired or threatened. They are representative of the level of pollution above which there is a serious case of soil contamination. The Target Values indicate the level at which there is sustainable soil quality, or in other words, a benchmark for environmental quality in the long term on the assumption of negligible risks to the ecosystem.

From a practical point of view, if the concentration of chemical contamination is above the Intervention Value, it is clear that the site needs to be remediated. Conversely, if concentrations are below the Target Values, no additional action is required to ensure environmental health and no restriction of land use is needed. In the situation where the contamination is below the Intervention Value but above the Target Value, a site-based risk assessment is needed to identify the specific land use restrictions or clean-up measures needed to address the identified issues.

This report uses the Dutch soil remediation values as indicated in the Soil Remediation Circular of 2013.[26]

for this type of pollution and no comparable international standards could be applied, no further comparison was made. Finally, samples of fruit and vegetable were compared against control site values – and, for some parameters for which these were available, against European Commission Regulation No. 1881/2006, which sets limits for certain contaminants in foodstuffs, including some heavy metals and hydrocarbons. Samples of oysters were compared against the same European Commission Regulation for available parameters, as no control sample of molluscs was obtained.

2.4 Key Challenges and Constraints

In carrying out a project of this scope and complexity, some challenges are inevitable. The following were the key challenges encountered during the audit:

1. The main cause of concern for the communities at the time of the toxic wastes dumping in 2006 was severe air pollution resulting from the presence of odorous substances, including mercaptans and hydrogen sulfide. However, not only is air pollution from any single event very transient in nature, but the substances of concern are also very volatile, with the result that even if a proportion of them had dissolved in the aqueous phase, these would have been liberated long ago. As such it would have been scientifically impossible to detect air contamination from the 2006 dumping ten years after the event. In the context of the audit, air pollution measurements were therefore intended to assess the overall environmental quality rather than detect any remnants of the 2006 event.

2. The Government and UN Environment had originally agreed that the Government would have groundwater monitoring wells drilled for each impacted site following specifications provided by UN Environment. For various reasons, however, the Government was not able to undertake the drilling of the wells within the project's timeframe. Consequently, it was agreed that groundwater samples would be collected from existing wells around the impacted sites, where these could be found. While this would not provide assurances that the contamination from the 2006 toxic wastes dumping had not leached into the groundwater, it would provide an indication of whether the existing water supply for the communities was contaminated. This is an important distinction to keep in mind.

3. Some of the wastes were dumped into roadside drains that eventually run off into the Ébrié Lagoon. However, the lagoon is heavily polluted by domestic and industrial wastes from all the human activities around the lagoon (which include the city of Abidjan), and is flushed daily by tidal influx through the Vridi canal. It would therefore not have been possible to attribute any contamination in the lagoon to the 2006 dumping event.

4. Samples of comestible vegetation (vegetables and fruit of various kinds) were collected from different sampling sites on an opportunistic basis. As Abidjan is a crowded city with limited free land available for formal agriculture, communities informally grow vegetables in every possible location, including on the waste disposal site at Akouédo. The samples taken for this study were meant to obtain an overall indication of the presence of contamination in vegetation grown in urban areas, as specific attribution to a dumping incident would not have been possible.

5. In order to understand the full extent of the clean-up operations that had taken place, and to be able to interpret the results as accurately as possible, UN Environment requested the following information from the Government of Côte d'Ivoire:

    - Copies of the original contracts between the Government and the different operators, including details on the objectives of the clean-up project and the environmental standards that were to be met;
    - The baseline concentrations of the various parameters at the start of the different clean-up projects;
    - The interim reports showing the evolution of the concentration of these parameters over time;
    - The final closure reports indicating how the objectives had been met; and

- Any reports of sampling or analyses conducted by the Government prior to accepting the contractors' requests for site closure and final payment.

While a number of documents were made available, some gaps remained, including most notably reports on the results of the clean-up works undertaken by Trédi, or the environmental standards established by the Government for the remediation of the suspected contaminated maize at Site 8 (Agboville).

03 Assessment of Site Clean-up Activities

This chapter presents the findings of UN Environment's audit of the clean-up activities that were undertaken between 2006 and 2016 on the sites affected by the dumping of toxic wastes from the Probo Koala, with a focus on determining whether these remediation efforts have resulted in the various sites meeting the environmental quality standards set by the Government. In this chapter, each site[27] is discussed individually, starting with a site description and information on the spill and clean-up history, followed by a discussion of the sampling approach and the laboratory results.

As mentioned in Chapter 2, the main focus of this audit was on soil quality, as this was the primary medium within which the wastes were dumped and clean-up activities were undertaken. In order to verify whether the site continued to pose risks for public health and the environment, the laboratory results were analysed using the following approach:

1. According to normal scientific practice, findings were first compared with relevant national standards. In this case, results for soil from all the sites where Probo Koala wastes were dumped and which had undergone remediation were compared with the environmental standards set by the Government of Côte d'Ivoire for clean-up operations conducted by Biogénie at Alépé.[28] If the values obtained were lower than the standards set by the Government, UN Environment considered that no additional clean-up intervention was necessary on the site.

2. In the case of Site 8 (Agboville), where maize that had been potentially contaminated by the Probo Koala wastes was composted, and for which the Government did not provide clean-up standards, laboratory results were compared against French standard NF U 44-095 for trace metal elements in composted materials used as fertilizer, which the contractor, Envipur, is using to evaluate the status of the maize pile.[29]

3. If laboratory results for a given parameter showed values exceeding the clean-up standards set by the Government or contractor, results were then compared with the Dutch soil remediation standards (intervention values) to see if further immediate action was needed from an environmental point of view.

4. Results were also compared with the control sites to verify whether the observed pollution was also present in the background. The values found in samples from control sites were used as a reference to determine if concentrations from remediated sites were typical for a given environment.

Site 1: Treichville

Spill history

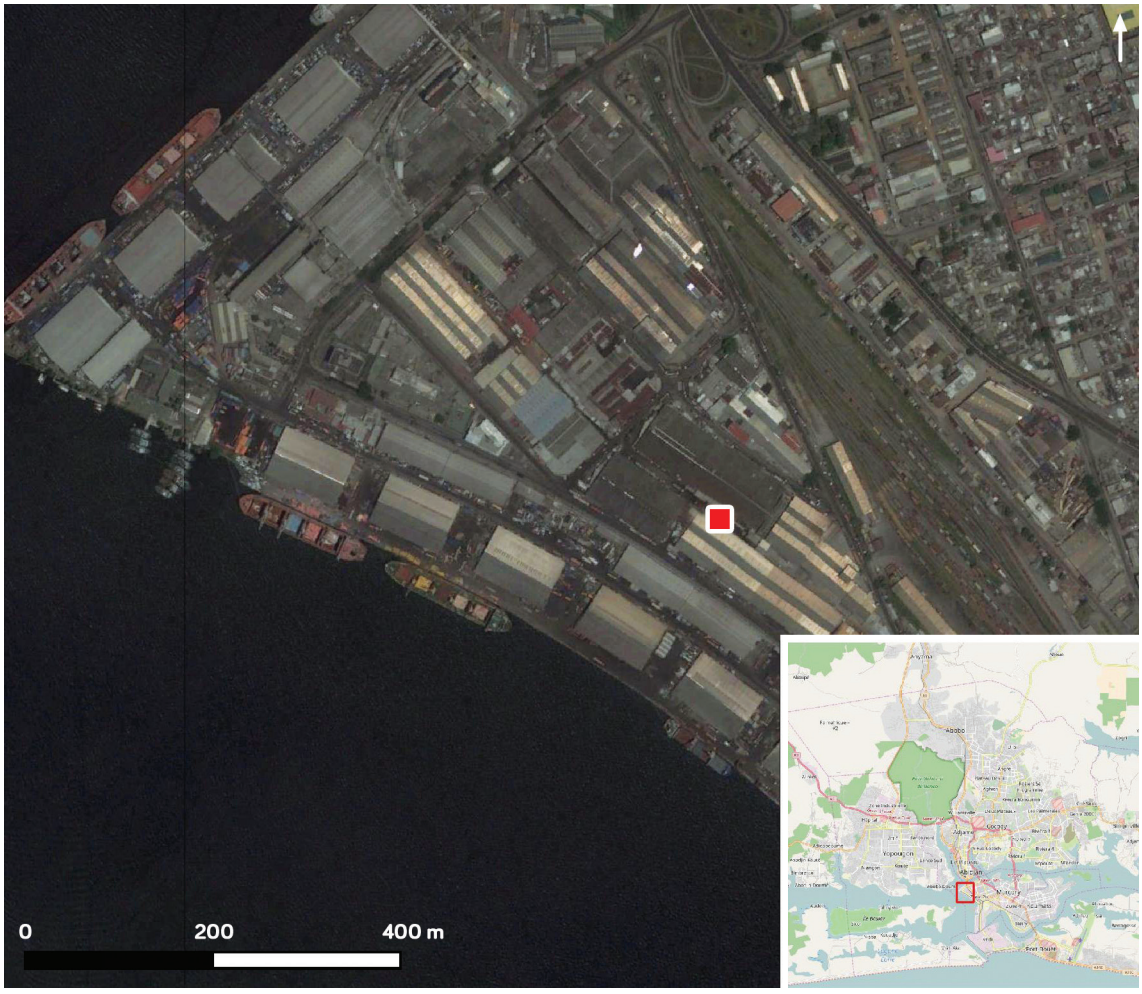
This concreted industrial site is located within the autonomous port of Abidjan, in an area of the city known as Treichville.

No waste was dumped at this location. Rather, the objects of interest were four silos owned by the PKL company, which between 2006 and 2012 were used to store a stock of maize originally destined for the production of baby food. This maize, which was moved here after the dumping event, was thought to have been potentially contaminated through airborne pollution while it was stored in a silo in proximity to the Vridi Canal sites at the time of the dumping.

The maize, in dry kernel form, was transported to a site near Agboville (see Site 8) in 2012 for elimination by composting. The silos were then cleaned by Envipur, but the stigma associated with the Probo Koala wastes was so powerful that they remained empty for years.

The objective of UN Environment's analysis was to verify whether any contamination could be detected in the silos. It must be added that in addition to the fact

Map 5. Site 1: Treichville



that the silos had been cleaned, there was no expectation that the pollutants of concern would be found, as these are highly transient by nature.

Approach

One air sample was taken using a stainless steel passivated canister located within the small opening of one of the metal storage silos.

Results

Table 9 provides the laboratory analysis results for the air sample taken on site. Air quality values from Site 17 (Plateau Dokoui 2), selected due to its central urban location, have been included for comparison purposes.

Conclusions

The laboratory results do not show any presence of hydrogen sulfides or mercaptans in the silo. A number of hydrocarbons can been found in the air sample, but their concentrations are comparable to those observed at other urban locations within the city, including at Site 17, which is a comparable urban site. As there are multiple possible sources of air pollution present (fugitive missions from the port, overall urban traffic, oil tankers in the harbor as well as refining and storage facilities), it is not possible to discern any specific source or suggest specific remedial measures.

Table 9. Air pollution analysis results for Site 1 (Treichville)

Parameters/units		Site 1 Treichville	Site 17 Plateau Dokoui 2
Dimethyl sulfide	ppm v/v	< 0.1	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1	< 0.1
Methyl tert-butyl ether	µg/m3	ND	ND
Benzene	µg/m3	ND	ND
Toluene	µg/m3	10	4
Ethylbenzene	µg/m3	ND	ND
Xylene	µg/m3	ND	ND
Naphthalene	µg/m3	ND	ND
TPH (C4-C6)	µg/m3	18	27
TPH (C6-C8)	µg/m3	59	34
TPH (C8-C10)	µg/m3	35	29
TPH (C10-C12)	µg/m3	23	ND
TPH (C4-C12)	µg/m3	130	100
Aliphatic (C4-C6)	µg/m3	18	27
Aliphatic (C6-C8)	µg/m3	47	28
Aliphatic (C8-C10)	µg/m3	26	19
Aliphatic (C10-C12)	µg/m3	22	ND
Aromatic (EC5-EC7)	µg/m3	ND	ND
Aromatic (EC7-EC8)	µg/m3	10	4
Aromatic (EC8-EC10)	µg/m3	ND	ND
Aromatic (EC10-EC12)	µg/m3	ND	ND

Site 2: Vridi Canal 1 (Cap Logistics)

Spill history

The site is located along the edge of a warehouse complex, within the large industrial zone along the Vridi Canal. Wastes from the Probo Koala were reportedly dumped into a partly open and partly culverted roadside drain, causing overflow from the drain onto the surrounding area a few meters away. In addition, some leakage is thought to have occurred as the waste flowed through the pipe, as it was not fully sealed. Clean-up efforts undertaken by Trédi in 2006-2007 included the replacement of the pipework, and the excavation of the surrounding soil. A company named EMEB-CI was contracted to carry out additional clean-up of the site between October 2010 and June 2011, which comprised the replacement of the internal sanitation network and the cleaning of the manholes and pipes connected to the main network. There is now a high concrete-block wall along the road, separating the location where the wastes overflowed from the point where they were dumped.

Map 6. Site 2: Vidri Canal (Cap Logistics)

Approach

Three soil samples were taken at this site: one from the existing drain and two from the overflow point on the warehouse grounds, including one surface (0-20 cm) sample and one 1 m-depth sample.

Results

Table 10 shows the analysis results for the soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 10. Soil pollution analysis results for Site 2 (Vridi Canal – Cap Logistics)

Parameters (mg/kg)	Site 2 Vridi Canal 1			Government standard (mg/kg)
	0-20 cm	1 m	0-20 cm	
Total Hy C5-C44	233	1.89	301	1,000
Benzene	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	0.00205	5
Xylene	< 0.009	< 0.009	< 0.00908	5
Total sulfur (%)	< 0.02	< 0.02	0.0395	10
Pb	40	4.6	150	400
Cd	0.17	< 0.1	0.21	20
As	20	2.4	7.6	37
Cr	76	11	59	130
Ni	24	3.3	23	140
Co	9.6	1.2	5.1	240
Hg	0.032	0.007	0.024	7
Cu	27	3	42	190
Zn	46	6	190	9,000

Site 3: Vridi Canal 2 (Petroci)

Spill history

The site is located along the same road as Site 2, within the Vridi Canal industrial zone, on grounds owned by the Ivorian national oil company, Petroci. The site of interest represents the location at which the pipe connected to the drain into which Probo Koala wastes were dumped at Site 2 intersects with a concreted canal flowing to the lagoon. The pipework and canal were reportedly remediated by Trédi in 2006-2007, and continue to carry drainage to the lagoon.

Approach

As the pipe and canal are concreted, no soil samples were retrieved from this location. Results of the groundwater and surface water samples collected at this location are discussed in Chapter 4.

Results

See Chapter 4.

Map 7. Site 3: Vidri Canal (Petroci)

Conclusions

Given that the canal is concreted, no further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Site 4: Koumassi (Industrial zone)

Spill history

This site is located in the industrial zone of Koumassi, an area in the south of Abidjan. It is reported that wastes from the Probo Koala were dumped into an open roadside drain running alongside buildings used for commercial purposes. The original concrete drain and surrounding soil were removed and remediated by Trédi in 2006-2007, and the resulting void backfilled with material excavated from elsewhere. The original drain was replaced by a buried drainage pipe. Finally, the site was re-surfaced in conjunction with the removal of an obsolete weighbridge that had operated at that location for several years. At the time of sampling, the location had become an informal dumping site for household and municipal waste.

Approach

One surface (0-20 cm) soil sample was taken at the exact location of the dumping, adjacent to the commercial building at the junction of the street. Before the soil sample was collected, the overlying waste had to be cleared by hand.

Map 8. Site 4: Koumassi (Industrial zone)

Results

Table 11 shows the analysis results for the surface soil sample taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 11. Soil pollution analysis results for Site 4 (Koumassi)

Parameters (mg/kg)	Site 4 Koumassi	Government standard (mg/kg)
	0-20 cm	
Total Hy C5-C44	197	1,000
Benzene	< 0.009	1
Ethylbenzene	< 0.003	25
Toluene	0.00319	5
Xylene	< 0.009	5
Total sulfur (%)	0.0642	10
Pb	92	400
Cd	1.7	20
As	1.5	37
Cr	19	130
Ni	8.4	140
Co	1.6	240
Hg	0.022	7
Cu	61	190
Zn	95	9,000

Site 5: MACA 1

Spill history

The spill location is located along a busy road in the industrial zone of Yopougon, in front of Abidjan's prison (Maison d'Arrêt et de Correction d'Abidjan, or MACA). It is reported that a truck containing wastes from the Probo Koala remained parked on the roadside for three days, during which time the wastes leaked from the vehicle and discharged into the adjacent ditch. During clean-up works undertaken by Trédi in 2006-2007, the soil within, and adjacent to, the ditch was excavated and taken off-site for treatment. The land adjacent to the ditch is informally cultivated, primarily producing banana and cassava.

Approach

Four soil samples were obtained from the site, as follows:

- One composite surface soil sample (0-20 cm) was taken beside the road where the spill was reported to have flowed;

Map 9. Site 5: MACA 1

- A 1 m-depth sample was taken approximately 2 m to the east of the composite soil sample location;
- A second 1 m-depth soil sample was taken from the base of an open ditch which had been excavated for the placement of cabling; and
- A third 1 m-depth soil sample was taken approximately 10 m to the north of the other soil samples.

Results

Table 12 shows the analysis results for the four soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 12. Soil pollution analysis results for Site 5 (MACA 1)

Parameters (mg/kg)	Site 5 MACA 1				Government standard (mg/kg)
	0-20 cm	1 m	1 m	1 m	
Total Hy C5-C44	21.4	3.62	0.397	1.59	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	< 0.02	< 0.02	< 0.02	10
Pb	55	22	12	12	400
Cd	0.21	0.2	0.2	0.12	20
As	4.4	4.4	5.4	3.7	37
Cr	66	68	84	59	130
Ni	5.4	5.4	6.1	3.7	140
Co	0.95	0.85	0.96	0.66	240
Hg	0.049	0.054	0.103	0.052	7
Cu	7.1	5.5	5.3	4.2	190
Zn	33	18	12	11	9,000

Site 6: MACA 2

Spill history

Wastes from the Probo Koala are reported to have been dumped onto the roadside at this site located some 3 km from Site 5 (MACA 1) on the busy Yopougon-Agboville road. The liquid wastes flowed down the steep, heavily vegetated, embankment into the Banco Forest, a national park. Partially remediated by Trédi following the dumping, this site was included on the list of sites requiring additional clean-up measures undertaken by Biogénie starting in 2010. In the course of these different clean-up phases, potentially contaminated material was excavated for off-site treatment, and the resulting void back-filled with clean soil.

Approach

Four soil samples were taken at this small site, including two composite surface (0-20 cm) soil samples; and two 1 m-depth samples.

Map 10. Site 6: MACA 2

Results

Table 13 shows the analysis results for the four soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 13. Soil pollution analysis results for Site 6 (MACA 2)

Parameters (mg/kg)	Site 6 MACA 2				Government standard (mg/kg)
	0-20 cm	0-20 cm	1 m	1 m	
Total Hy C5-C44	32.5	34.4	0.783	0.254	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	0.0235	< 0.02	< 0.02	10
Pb	11	12	8.6	8.9	400
Cd	0.15	0.11	0.17	0.16	20
As	3.7	3.2	3.9	3.8	37
Cr	52	41	53	54	130
Ni	3.9	3.3	3.9	3.8	140
Co	0.8	0.79	0.84	0.75	240
Hg	0.059	0.053	0.068	0.073	7
Cu	5.8	4.8	5.5	5.1	190
Zn	27	23	12	11	9,000

Site 7: MACA 3

Spill history

Wastes from the Probo Koala are reported to have been dumped onto the roadside at this site located approximately 1 km from Site 6 (MACA 2) on the busy Yopougon-Agboville road. The liquid wastes flowed down the steep, heavily vegetated, embankment into the Banco Forest, a national park. Potentially contaminated material was excavated by Trédi for off-site treatment in 2006-2007, and the resulting void back-filled with clean soil.

Approach

Four soil samples were collected from the base of a deep depression adjacent to the road, where the spill is reported to have flowed under the road through a culvert. The following samples were obtained:

- One 1 m-depth sample taken in close proximity to the discharge point of the culvert;
- A second 1 m-depth sample taken approximately 10 m away from the culvert; and
- Two composite surface (0-20 cm) samples.

Map 11. Site 7: MACA 3

Results

Table 14 shows the analysis results for the four soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 14. Soil pollution analysis results for Site 7 (MACA 3)

Parameters (mg/kg)	Site 7 MACA 3				Government standard (mg/kg)
	1 m	1 m	0-20 cm	0-20 cm	
Total Hy C5-C44	30.1	15.2	75.3	77.7	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	<0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	< 0.02	< 0.02	< 0.02	10
Pb	11	7.1	9.4	11	400
Cd	0.19	0.14	0.13	0.12	20
As	4	2.9	2.3	3.8	37
Cr	48	37	31	56	130
Ni	4.9	3.2	2.9	5.7	140
Co	2	0.61	0.94	2	240
Hg	0.059	0.036	0.040	0.064	7
Cu	9.1	4.5	7.9	8.4	190
Zn	140	10	24	130	9,000

Site 8: Agboville

Spill history

This site, located within the municipality of Agboville, some 61 km north of Abidjan, is not a dumping location. Rather, Site 8 has been used to treat a stockpile of dry maize that was suspected to have been contaminated through airborne pollution following the 2006 dumping event in the Vridi area. As mentioned in the section on Site 1, this maize was moved here in 2012 from the Treichville silos it was stored in for several years after the dumping.

A contract for removal, transport and treatment of the maize was signed by the Government and a company named Envipur in November 2010, and the work started in January of 2012. Site 8 was originally a remote green-field site, selected and purchased by Envipur for its considerable distance from Abidjan. The maize was placed in a single cell constructed on the site, the base of which was lined with a geo-membrane. All drainage from the treatment cell is contained within concrete chambers, from where it is periodically pumped and placed in plastic tanks that are transported back to Abidjan for treatment. As part of its contracted services, Envipur has conducted

Map 12. Site 8: Agboville

periodic sampling and analysis of the composting maize itself, the leachate draining from the pile, as well as the small river running downstream, beyond the treatment site.

Once composting of the maize was deemed to have sufficiently progressed, the material was covered with a 1 m thick layer of soil dug up from around the treatment cell. By end 2016, treatment was declared to be nearing completion and at of the time of writing, a draft closure report was available from Envipur[30] and was awaiting approval from the Government.

Throughout the treatment and at the time of UN Environment's last site visit in January 2017, the site was fenced and guarded, restricting access to the public and grazing animals.

Approach

UN Environment conducted two rounds of sampling on this site, the first in July 2016 and the second in January 2017. The following soil/composted maize samples were taken during the initial exercise in July 2016:

- A composite surface sample (0-20 cm) and 1 m-depth sample were obtained from the top of the mound of composted maize, which was covered by approximately 1 m of soil; and

- At the lower level of the site, approximately 100 m away from the composted maize, two further soil samples were taken, one from the surface (0-20 cm) and one at 1 m in depth.

As the analyses conducted on the July 2016 samples included at least one result that exceeded the standard used by Envipur for heavy metal contamination, an additional round of sampling was undertaken in January 2017, consisting of the following samples:

- One 1 m-depth soil sample from the centre of the composting cell;

- One shallow composite soil sample (0-20 cm) from across the surface of the composting cell; and

- One shallow composite soil sample (0-20 cm) further down the slope near the guard's shack.

Results

Table 15 shows the analysis results for all soil samples taken at the site. Also included are the standards used by Envipur to judge the status of the maize pile upon project closure, based on the French standard NF U 44-095 for trace metal elements in composted materials used as fertilizer, as well as the Dutch intervention values, for comparison purposes. It should be noted that as the Government did not include hydrocarbons in the parameters requiring monitoring as part of the maize composting process, no comparison of the hydrocarbon values obtained has been made to locally set standards or international guidelines.

The results from both rounds of sampling show levels of chromium that exceed the standards used by Envipur. Chromium, depending on its oxidation state, can be very toxic (see Appendix 3 for more detail on the impacts of chromium on health and the environment). The chromium values in the maize pile also consistently exceed Dutch intervention values. Moreover, higher chromium levels were found in soil samples taken further away from the composting pile.

Given these results, it was important to determine whether chromium could be found in the leachate emanating from the composting maize pile, as well as in nearby waters. During both rounds of sampling, water samples were taken from a manhole connected to the concrete chambers collecting leachate from below the composting maize pile. During the first round, an additional water sample was also taken from the river downstream, as there was no groundwater source nearby.

Table 16 shows the analysis results for the water samples taken at the site. Also included are the Dutch water quality intervention values, which have been used for comparison purposes.

Chromium concentrations exceed intervention values in both the 2016 and the 2017 water samples collected from the manhole adjacent to the composting pile. Toluene levels are also marginally above intervention values, but as the overall hydrocarbon levels are far below, this single result cannot be considered to warrant intervention.

Table 15. Soil pollution analysis results for Site 8 (Agboville)

2016 Parameters (mg/kg)	Site 8 Agboville				French norm NF U 44-095 (mg/kg)	Dutch intervention values (mg/kg)
	0-20 cm	1 m	0-20 cm	1 m		
Total Hy C5-C44	10.3	1,440	4.41	2.01		5,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009		1.1
Ethylbenzene	< 0.003	0.41	< 0.003	< 0.003		110
Toluene	< 0.002	1.61	< 0.002	< 0.002		32
Xylene	< 0.009	< 0.009	< 0.009	< 0.009		17
Total sulfur (%)	< 0.02	0.027	< 0.02	0.0786		-
Pb	13	11	11	15	180	530
Cd	0.10	< 0.1	< 0.1	< 0.1	3	13
As	3.4	2.5	1.8	2.8	18	76
Cr	340	270	150	100	120	180
Ni	6.6	7.2	5.4	11	60	100
Co	1.3	1.1	1.1	2		190
Hg	0.054	0.052	0.04	0.071	2	36
Cu	12	11	7.7	6.5	300	190
Zn	28	35	13	26	600	720

2017 Parameters (mg/kg)	Site 8 Agboville			French norm NF U 44-095 (mg/kg)	Dutch intervention values (mg/kg)
	1 m	0-20 cm	0-20 cm		
Total Hy C5-C44	2,230	3.83	13.4		5,000
Benzene	< 0.09	< 0.009	< 0.009		1.1
Ethylbenzene	< 0.04	< 0.004	< 0.004		110
Toluene	2.6	< 0.007	< 0.007		32
Xylene	< 0.2	< 0.02	< 0.02		17
Total sulfur (%)	0.119	0.054	0.0641		-
Pb	9.98	13	12.5	180	530
Cd	< 0.02	0.514	< 0.02	3	13
As	2.82	< 6	3.56	18	76
Cr	237	243	254	120	180
Ni	5.31	5.47	5	60	100
Co	0.605	< 1	0.222		190
Hg	< 0.14	< 1.4	< 0.14	2	36
Cu	6.66	< 14	8.05	300	190
Zn	16.9	< 19	5.39	600	720

Conclusions

The presence of chromium within the compost pile exceeding the standards used by Envipur as well as Dutch intervention values is a matter of concern. As the composting process will not lead to a reduction in chromium concentrations, continued composting is not a solution for this issue. As the site is currently under the custody of Envipur and monitored by the Government, further risk assessment should be carried out based on a "source-pathway-receptor" approach to determine what additional actions need to be undertaken before the site can be closed.

Given that leachate samples also showed higher levels of chromium in both 2016 and 2017, as well as elevated levels of toluene in 2017, the leachate from this site should continue to be disposed of in specialized facilities, ensuring that these have appropriate technical capacity to handle this type of pollution.

Table 16. Water pollution analysis results for Site 8 (Agboville)

Parameters (mg/kg)	Site 8 Agboville 2016	Site 8 Agboville 2017	Dutch intervention values (µg/l)
Total Hy C5-35	4,470	355	600,000
Benzene	< 7	< 7	30
Ethylbenzene	192	< 5	1,000
Toluene	113	210	150
Xylene	< 11	< 11	70
Free sulfur	< 50	< 50	-
Pb	4.5	0.597	75
Cd	< 0.25	0.135	6
As	12	6.96	60
Cr	130	88.1	30
Ni	42	24.5	75
Co	10	5.62	100
Hg	5	< 0.01	0.3
Cu	5.6	3.41	75
Zn	150	35.4	800

Site 9: Alépé 1

Spill history

This site is a large open area adjacent to the main road linking Abobo and Alépé, located near the village of Djibi. Wastes from the Probo Koala are reported to have been dumped down an embankment from the roadside, and to have flowed downstream across the site.

Alépé 1 was the centre of multiple clean-up operations (see Chapter 1), starting with partial excavation by Trédi in the months following the dumping event. Further excavation was undertaken between September 2007 and March 2008 by Biogénie, then contracted directly by Trafigura; contaminated materials were stored on site in big bags. Starting in 2010, Biogénie was contracted by the Government to conduct additional and complementary clean-up, which included finalizing excavation and treating contaminated soils – from Alépé 1 and 2, as well as some other sites – using biological activation techniques. It is reported that the site was excavated down to a depth of 14 m in some locations, and that some 16,000 tons of soil were treated here. Following some delays due to the post-electoral violence in 2010-2011, the bio-remediation

Map 13. Site 9: Alépé 1

process at Alépé was considered to be completed by end 2014. The treated soil was then redistributed across the site in 2015.

Approach

The following five soil samples were obtained from the south-west portion of the site, in close proximity to the adjacent road, where it was reported that the Probo Koala wastes were dumped:

- Two composite surface (0-20 cm) soil samples; and
- Three 1 m-depth soils samples, of which the third was taken approximately 50 m north of the other two.

Results

Table 17 shows the analysis results for the five soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which were specifically set for this site, and have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 17. Soil pollution analysis results for Site 9 (Alépé 1)

Parameters (mg/kg)	Site 9 Alépé 1					Government standard (mg/kg)
	0-20 cm	1 m	0-20 cm	1 m	1 m	
Total Hy C5-C44	1.02	1.64	< 0.1	4.33	< 0.1	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	0.157	< 0.02	< 0.02	0.0218	10
Pb	3.7	5.7	2.4	7.2	11	400
Cd	< 0.1	< 0.1	< 0.1	0.1	0.1	20
As	1.4	1.8	0.95	2.5	4	37
Cr	18	22	13	32	51	130
Ni	1.8	2.2	0.89	3	4.4	140
Co	0.37	0.47	0.18	0.55	0.81	240
Hg	0.022	0.038	0.009	0.045	0.043	7
Cu	1.8	2.3	0.93	2.2	2.5	190
Zn	6.1	7.5	3.2	8.2	10	9,000

Site 10: Alépé 2

Spill history

This site is located down a steep and densely vegetated embankment on the side of the main road linking Abobo and Alépé, approximately 1 km from Site 9. Wastes from the Probo Koala are reported to have been dumped from two tanker trucks down the side of the embankment, and to have flowed along the bed of the rivulet at the bottom, eventually crossing under the road and flowing into a small pond that is thought to have been used for pisciculture.

As is the case for Site 9, remediation by excavation was started by Trédi and continued by Biogénie. Contaminated soil was excavated down to an average depth of 4 m on both sides of the road, and subsequently treated through biological activation at Alépé 1, with the resulting void back-filled with clean soil.

Approach

This site was divided in two sections: the eastern side of the road, where the spill was reported to have taken place; and the western side of the road, where

Map 14. Site 10: Alépé 2

the waste flowed through. The following samples were collected:

- On the eastern side of the site, one surface (0-20 cm) and one 1 m-depth soil sample were taken adjacent to the rivulet; and
- On the western side of the site, one composite surface soil sample (0-20 cm) was taken next to the small pond and one 1 m-depth soil sample was collected in an area of planted crops adjacent to the road.

Results

Table 18 shows the analysis results for the four soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 18. Soil pollution analysis results for Site 10 (Alépé 2)

Parameters (mg/kg)	Site 10 Alépé 2				Government standard (mg/kg)
	0-20 cm	1 m	0-20 cm	1 m	
Total Hy C5-C44	7.33	1.4	0.648	13.9	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	0.0461	< 0.02	0.0825	10
Pb	5.9	1.7	2	6.3	400
Cd	< 0.1	< 0.1	< 0.1	< 0.1	20
As	1.5	0.77	0.78	2.7	37
Cr	17	8.9	10	25	130
Ni	2.1	0.53	0.47	3.1	140
Co	0.42	0.1	< 0.1	0.53	240
Hg	0.027	0.008	0.005	0.041	7
Cu	3.4	0.81	0.63	2.5	190
Zn	24	6.2	4.5	6.7	9,000

Site 11: Akouédo 1

Spill history

This spill site is located within Abidjan's municipal waste disposal site at Akouédo, in an area that is currently not actively used. Wastes from the Probo Koala are reported to have been dumped into the ditch running parallel to the dirt road that traverses the vast waste disposal grounds. During clean-up operations by Trédi in 2006-2007, contaminated materials were excavated and removed for off-site treatment, and the remaining void back-filled with clean soil. At the time of sampling, small, informal plantations of food crops, such as banana, maize, papaya and gombo, could be seen growing on either side of the dirt road.

Approach

One composite surface (0-20 cm) soil sample was taken approximately 5 m from the track, on the far side of the drainage ditch, where the soil was covered with a layer of refuse.

Map 15. Site 11: Akouédo 1

Results

Table 19 shows the analysis results for the surface soil sample taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 19. Soil pollution analysis results for Site 11 (Akouédo 1)

Parameters (mg/kg)	Site 11 Akouédo 1	Government standard (mg/kg)
	0-20 cm	
Total Hy C5-C44	180	1,000
Benzene	0.0102	1
Ethylbenzene	< 0.003	25
Toluene	0.00224	5
Xylene	< 0.00936	5
Total sulfur (%)	0.0388	10
Pb	220	400
Cd	1.9	20
As	7.9	37
Cr	61	130
Ni	30	140
Co	4	240
Hg	0.27	7
Cu	97	190
Zn	390	9,000

Site 12: Akouédo 2

Spill history

This spill site is the second located within the Abidjan's municipal waste disposal site at Akouédo. It is comprised of a slanted concrete pad upon which suction-tankers routinely park to discharge sewage sludge. Probo Koala wastes are reported to have been brought onto the site in a suction-tanker that parked on the concrete pad. The liquid waste leaked from the vehicle onto the concrete and flowed into the surrounding drainage ditch. Clean-up by Trédi in 2006-2007 entailed breaking up and removing part of the concrete pad, as well as excavating the contaminated soil within the ditch for off-site treatment. At the time of sampling, numerous crops were observed to be growing in close proximity to the site, including maize, papaya and cassava.

Approach

One composite surface (0-20 cm) soil sample was taken at the bottom of the concrete pad. A layer of refuse had to be removed to gain access to the underlying soil.

Map 16. Site 12: Akouédo 2

Results

Table 20 shows the analysis results for the surface soil sample taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

The site shows slightly elevated levels of hydrocarbon as compared to the clean-up standards set by the Government. However, all other parameters are below the established limit values.

Conclusions

Considering that the site has remained operational as an active waste disposal site throughout the ten years since it was cleaned up following the dumping of wastes from the Probo Koala, and that this is a location where heavy vehicles are routinely parked, results showing elevated levels of hydrocarbons are not unexpected. Against this background, it is not possible to attribute this contamination to any specific incident of pollution.

Furthermore, concentrations in this case are far below Dutch intervention values (5,000 mg/kg). No immediate action is therefore recommended. However, when the waste disposal site is closed, a comprehensive environmental assessment should be undertaken as part of environmental due diligence and the site should be decommissioned following good industry practices.

Table 20. Soil pollution analysis results for Site 12 (Akouédo 2)

Parameters (mg/kg)	Site 12 Akouédo 2	Government standard (mg/kg)
	0-20 cm	
Total Hy C5-C44	1,020	1,000
Benzene	< 0.009	1
Ethylbenzene	< 0.003	25
Toluene	0.0149	5
Xylene	< 0.01096	5
Total sulfur (%)	0.0275	10
Pb	23	400
Cd	0.2	20
As	7.1	37
Cr	64	130
Ni	30	140
Co	4	240
Hg	0.092	7
Cu	12	190
Zn	50	9,000

Site 13: Akouédo 3

Spill history

This spill site is the third within Abidjan's municipal waste disposal site at Akouédo. It is located in a low-lying depression close to the walled eastern boundary of the site. Wastes from the Probo Koala were not actually dumped here; rather, they flowed downstream from Site 11 nearby – approximately 200 m to the west. It is reported that during clean-up operations by Trédi in 2006-2007, contaminated materials were excavated and treated on site.

Approach

Two surface (0-20 cm) soil samples were taken near the concrete perimeter wall where the spilled material flowed to from Site 11 to the west.

Map 17. Site 13: Akouédo 3

Results

Table 21 shows the analysis results for the two surface soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 21. Soil pollution analysis results for Site 13 (Akouédo 3)

Parameters (mg/kg)	Site 13 Akouédo 3		Government standard (mg/kg)
	0-20 cm	0-20 cm	
Total Hy C5-C44	12.2	41.3	1,000
Benzene	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	5
Total sulfur (%)	< 0.02	0.0211	10
Pb	20	230	400
Cd	0.16	2	20
As	31	7.1	37
Cr	85	54	130
Ni	7.5	29	140
Co	1.5	5.9	240
Hg	0.074	0.54	7
Cu	5.2	120	190
Zn	36	810	9,000

Site 14: Coco-Service

Spill history

The site is located along the express way linking Adjamé and Abobo, a major multi-lane roadway, which is lined for several kilometers with informal small businesses, primarily dismantling vehicles and selling spare parts. Wastes from the Probo Koala are reported to have been dumped into a concrete roadside drain that discharges into an open concrete channel, which in turn discharges into a small stream.

Clean-up works undertaken by Trédi in 2006-2007 included removing and replacing the drainage structure, while the surrounding soil was excavated and treated off-site. At the time of sampling, the site was used as a tipping point for household trash, and to burn tires and other refuse. A small banana plantation could also be found on a flat area between the road and the stream below.

Map 18. Site 14: Coco-Service

Approach

Two surface (0-20 cm) soil samples were taken: one at the top of the slope, at the level of the adjacent road; and the other at the bottom of the slope, near the stream.

Results

Table 22 shows the analysis results for the two surface soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up, except for copper. Given that all other heavy metals are below the standard, this single exceedance is not considered to warrant a follow up action. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 22. Soil pollution analysis results for Site 14 (Coco-Service)

Parameters (mg/kg)	Site 14 Coco-Service		Government standard (mg/kg)
	0-20 cm	0-20 cm	
Total Hy C5-C44	439	322	1,000
Benzene	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	5
Total sulfur (%)	0.0392	0.032	10
Pb	170	39	400
Cd	0.47	0.46	20
As	4.7	6.1	37
Cr	62	89	130
Ni	12	8.4	140
Co	3.7	24	240
Hg	0.082	0.041	7
Cu	51	500	190
Zn	300	1,500	9,000

Site 15: Abobo Sagbé

Spill history

This spill site is located within a vast expanse of informal and unregulated small businesses including mechanics, spare parts dealers, auto body shops and other vehicle-related workshops located in the Abobo area, at the edge of the Banco National Park. Wastes from the Probo Koala are reported to have been dumped onto an open plot of land, which at the time was situated at a distance from the workshops, but is now surrounded by them. Clean-up works undertaken by Trédi in 2006-2007 included excavating the surrounding soil for off-site treatment, with the remaining void was backfilled with clean soil.

Approach

Two surface (0-20 cm) and two 1 m-depth soil samples were taken at the spill location.

Map 19. Site 15: Abobo Sagbé

Results

Table 23 shows the analysis results for the four soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 23. Soil pollution analysis results for Site 15 (Abobo Sagbé)

Parameters (mg/kg)	Site 15 Abobo Sagbé				Government standard (mg/kg)
	0-20 cm	1 m	0-20 cm	1 m	
Total Hy C5-C44	12	1.42	658	1.76	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	< 0.002	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	0.0287	0.0756	0.0247	0.02	10
Pb	11	11	13	10	400
Cd	< 0.1	0.1	0.11	< 0.1	20
As	2.4	3.6	2.6	3.7	37
Cr	37	60	41	57	130
Ni	3	5.1	3.3	4.7	140
Co	0.76	0.84	0.63	0.8	240
Hg	0.03	0.05	0.03	0.047	7
Cu	4	4.5	4.7	3.9	190
Zn	15	13	19	9.7	9,000

Site 16: Plateau Dokoui 1

Spill history

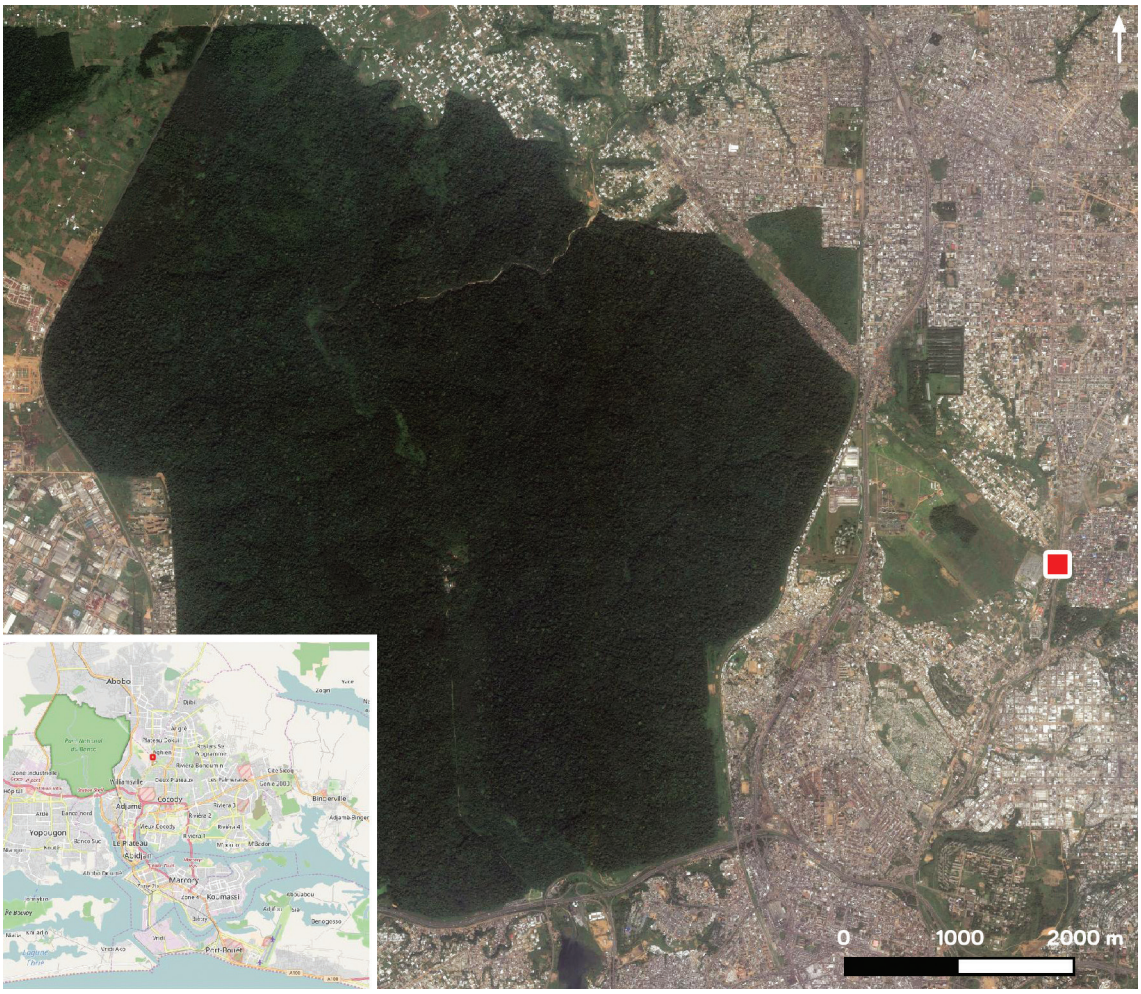
The spill site is located off the express way linking Adjamé and Abobo, and consists of a rainwater holding basin that has been completely re-engineered since the time of the dumping, and recently provided with a concrete dam, base and drainage channels. Wastes from the Probo Koala were reported to have been dumped directly into the basin. Remediation work conducted by Trédi in 2006-2007 included pumping contaminated water and excavating sediment from the basin for off-site treatment. At the time of sampling the water within the basin was almost completely covered with a thick layer of predominantly plastic waste, comprising mainly of soft-drink bottles and plastic bags.

Approach

Three sets of surface (0-20 cm) and 1 m-depth soil samples (6 samples in total) were taken from around the basin:

- The first was collected on the east side of the basin towards the north;

Map 20. Site 16: Plateau Dokoui 1



- The second set was taken towards the south-eastern end of the basin; and
- The third set was taken on the opposite side of the dam.

Results

Table 24 shows the analysis results for all soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 24. Soil pollution analysis results for Site 16 (Plateau Dokoui 1)

Parameters (mg/kg)	Site 16 Plateau Dokoui 1						Normes gouvernementales (mg/kg)
	0-20 cm	1 m	0-20 cm	1m	0-20cm	1m	
Total Hy C5-C44	305	3.55	324	7.63	36.2	6.12	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	0.0023	< 0.002	0.00488	< 0.002	< 0.002	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	0.0278	0.0587	0.0925	0.0747	< 0.02	< 0.02	10
Pb	62	11	47	12	18	15	400
Cd	0.33	0.14	0.27	0.11	0.14	0.14	20
As	7.6	4.4	6.4	4.5	4	5.3	37
Cr	120	59	93	60	51	60	130
Ni	14	5.8	11	5.6	4.9	5.3	140
Co	3.1	0.94	2.4	1	0.87	0.89	240
Hg	0.21	0.069	0.16	0.065	0.044	0.056	7
Cu	28	5.5	21	5.7	6.3	5.6	190
Zn	180	13	140	23	19	15	9,000

Site 17: Plateau Dokoui 2

Spill history

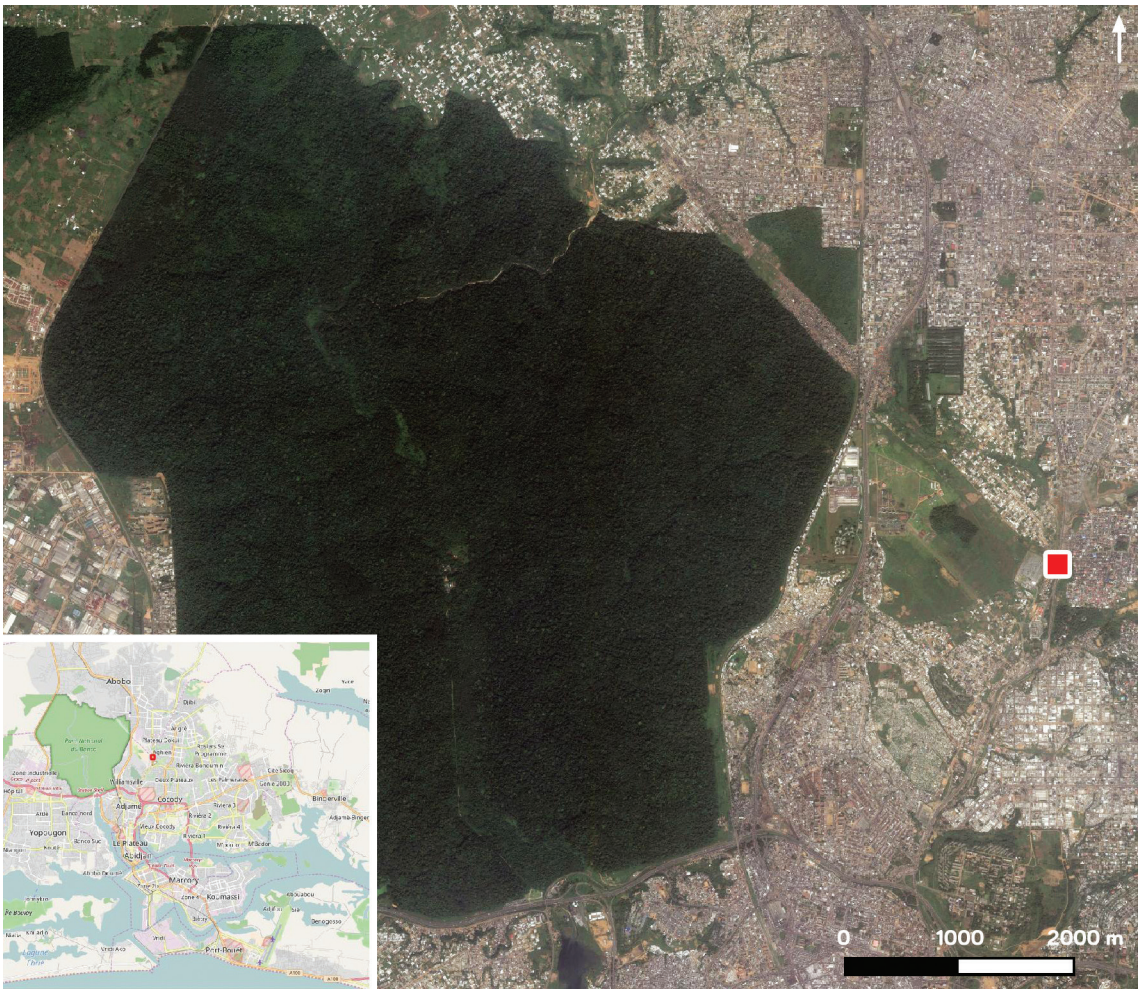
This site, which is adjacent to the Adjamé-Abobo express way, consists of an operational roadside sewage disposal tank. Wastes from the Probo Kola are reported to have been discharged into the concrete structure, which was emptied and cleaned as part of clean-up operations conducted by Trédi in 2006-2007. During the cleaning process, small quantities of sewage reportedly overflowed and ran down the adjacent steep slope towards a culvert discharging into the nearby rainwater holding basin (Site 16). The contaminated soil was then excavated and removed for off-site treatment. At the time of sampling, small-scale, informal industrial and agricultural activities were observed between the roadside and the culvert.

Approach

Two sets of surface soil (0-20 cm) and 1 m-depth soil samples (4 samples in total) were taken:

- The first at the top of the slope next to the sewage storage tank; and
- The second downwards of the slope.

Map 21. Site 17: Plateau Dokoui 2



Results

Table 25 shows the analysis results for the soil samples taken at the site. Also included are the standards set by the Government in its contract with Biogénie for clean-up and remediation of contaminated materials, which have been used for comparison purposes.

Conclusions

The laboratory results show that the current concentrations of the contaminants of concern in soil are all below the standards set by the Government of Côte d'Ivoire for clean-up. No further action is needed on this site to remediate the impacts of the 2006 toxic waste dumping from the Probo Koala.

Table 25. Soil pollution analysis results for Site 17 (Plateau Dokoui 2)

Parameters (mg/kg)	Site 17 Plateau Dokoui 2				Government standard (mg/kg)
	0-20 cm	1 m	0-20 cm	1 m	
Total Hy C5-C44	156	279	1.1	0.104	1,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	25
Toluene	0.00522	< 0.002	0.00215	< 0.002	5
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	5
Total sulfur (%)	0.0629	0.0394	0.0201	0.0278	10
Pb	18	42	14	7.7	400
Cd	0.19	0.21	< 0.1	< 0.1	20
As	1.5	1.7	3.4	3.7	37
Cr	17	35	47	54	130
Ni	3.8	14	4.1	3.7	140
Co	0.97	1.3	0.82	0.61	240
Hg	1.2	0.79	0.11	0.025	7
Cu	19	38	6.5	3.5	190
Zn	100	190	33	8.9	9,000

pH Measurements in Soil

As sodium hydroxide was one of the major constituents of the wastes from the Probo Koala, the disposal of these wastes could have led to a change in the pH conditions of the soil. Indeed, sodium hydroxide is a highly caustic substance that could have increased soil pH much above the neutral range, even affecting soil fertility.

All soil samples collected were analysed for pH and results are presented in Table 26 below. These show that the pH values are not in the caustic range (9 or above), demonstrating that the impact of the disposal of caustic substances can no longer be detected, either because it was removed by the various clean-up activities undertaken, or because it was leached out by rainfall, a combination of the above being most likely.

Table 26. Analysis results for pH levels in soil

Site	Sample	pH Value
Site 2 (Vridi Canal 1)	0-20 cm 1 m 0-20 cm	7.57 7.3 7.03
Site 4 (Koumassi)	0-20 cm	7.61
Site 5 (MACA 1)	0-20 cm 1 m 1 m 1 m	6.6 5.28 4.18 4.37
Site 6 (MACA 2)	0-20 cm 0-20 cm 1 m 1 m	4.26 3.64 4.01 3.95
Site 7 (MACA 3)	1 m 1 m 0-20 cm 0-20 cm	4.54 4.15 6.7 4.38
Site 8 (Agboville)*	0-20 cm 1 m 0-20 cm 1 m	4.38 4.58 4.72 3.83
Site 9 (Alépé 1)	0-20 cm 1 m 0-20 cm 1 m 1 m	5.01 5.68 5.76 5.27 4.11
Site 10 (Alépé 2)	0-20 cm 1 m 0-20 cm 1 m	7.16 6.6 6.58 4.16
Site 11 (Akouédo 1)	0-20 cm	7.34
Site 12 (Akouédo 2)	0-20 cm	7.67
Site 13 (Akouédo 3)	0-20 cm 0-20 cm	5.63 7.52
Site 14 (Coco-Service)	0-20 cm 0-20 cm	7.67 6.27
Site 15 (Abobo Sagbé)	0-20 cm 1 m 0-20 cm 1 m	4.14 4.08 4.07 4.07
Site 16 (Plateau Dokoui 1)	0-20 cm 1 m 0-20 cm 1 m 0-20 cm 1 m	6.61 4.89 7.12 5.75 6.08 5.56
Site 17 (Plateau Dokoui 2)	0-20 cm 1 m 0-20 cm 1 m	7.28 7.1 5.8 4.55
Site 19 (Anyama)	0-20 cm 1 m	3.97 4.09

* 2016 samples

04 Other Environmental Issues

Environmental audit of the sites affected by the dumping of toxic wastes from the "Probo Koala"

The primary objective of this environmental audit was to verify if the sites affected by the dumping of toxic wastes from the Probo Koala in 2006 continued to pose any risks for the environment and for the health of the communities living on or near them. Results presented in Chapter 3 demonstrate that contaminants associated with the Probo Koala wastes are currently not present in the soil in concentrations exceeding the specifications set by the Government of Côte d'Ivoire.

During preparatory work for this audit, however, the Government noted that communities were concerned that while the contaminated soil had been remediated, contamination may have migrated to other media, such as water, and may be reaching the food chain through comestible products. UN Environment's audit was therefore designed to undertake groundwater monitoring as well analyses of fruit and vegetables grown on the sites where Probo Koala wastes were dumped.

While it was not expected that air pollutants from the 2006 dumping event would continue to linger in the area years after the event, air quality monitoring was also included in the suite of analyses for sake of completeness and to address the theoretical likelihood that pollutants remaining in the soil may continue to be released into the air.

Finally, the Government also requested that samples of sediment and shellfish – which are often used as indicators of pollution as they can accumulate contaminants over a period of time – be analysed.

This chapter presents an overview of the aggregated results of the analyses of air, water, sediment, fruit, vegetables and oysters sampled during the audit.

4.1 Air Quality

As the focus of UN Environment's study was contamination from the Probo Koala toxic wastes, the parameters for air quality analysis were selected based on the most likely composition of the wastes, as described in Chapter 1. No national standards exist for these elements in Côte d'Ivoire. The approach taken was therefore to compare air quality results from the affected sites with Control Site 21, some 69 km away from Abidjan near Agboville, where the impact of urban pollution was expected not to be felt.

The air quality analyses from all locations, including the control site, are presented in Table 27 below.

Table 27. Air pollution analysis results

Parameters/units		Site 1 Treichville	Site 2 Vridi Canal 1	Site 3 Vridi Canal 2	Site 4 Koumassi	Control site 21 Agboville
Dimethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl tert-butyl ether	µg/m3	ND	ND	ND	ND	ND
Benzene	µg/m3	ND	ND	ND	ND	ND
Toluene	µg/m3	10	54	110	2,500	ND
Ethylbenzene	µg/m3	ND	ND	ND	ND	ND
m,p-Xylene	µg/m3	ND	9.4	ND	ND	ND
0-Xylene	µg/m3	ND	ND	ND	ND	ND
Naphthalene	µg/m3	ND	ND	ND	ND	ND
TPH (C4-C6)	µg/m3	18	12	22	76	10
TPH (C6-C8)	µg/m3	59	100	180	3,800	20
TPH (C8-C10)	µg/m3	35	45	60	380	35
TPH (C10-C12)	µg/m3	23	75	37	ND	53
TPH (C4-C12)	µg/m3	130	240	300	4,300	120
Aliphatic (C4-C6)	µg/m3	18	ND	22	76	ND
Aliphatic (C6-C8)	µg/m3	47	45	72	1,300	17
Aliphatic (C8-C10)	µg/m3	26	ND	28	290	31
Aliphatic (C10-C12)	µg/m3	22	73	35	ND	53
Aromatic (EC5-EC7)	µg/m3	ND	ND	ND	ND	ND
Aromatic (EC7-EC8)	µg/m3	10	54	110	2,500	ND
Aromatic (EC8-EC10)	µg/m3	ND	43	33	87	ND
Aromatic (EC10-EC12)	µg/m3	ND	ND	ND	ND	ND

Parameters/units		Site 5 MACA 1	Site 7 MACA 3	Site 8 Agboville	Site 9 Alépé 1	Control site 21 Agboville
Dimethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl tert-butyl ether	µg/m3	ND	ND	ND	ND	ND
Benzene	µg/m3	ND	ND	ND	ND	ND
Toluene	µg/m3	54	ND	ND	11	ND
Ethylbenzene	µg/m3	ND	ND	ND	ND	ND
m,p-Xylene	µg/m3	ND	ND	ND	ND	ND
0-Xylene	µg/m3	ND	ND	ND	ND	ND
Naphthalene	µg/m3	ND	ND	ND	ND	ND
TPH (C4-C6)	µg/m3	13	31	11	20	10
TPH (C6-C8)	µg/m3	120	35	23	53	20
TPH (C8-C10)	µg/m3	39	31	41	42	35
TPH (C10-C12)	µg/m3	24	16	33	39	53
TPH (C4-C12)	µg/m3	200	110	110	150	120
Aliphatic (C4-C6)	µg/m3	ND	31	ND	20	ND
Aliphatic (C6-C8)	µg/m3	66	30	21	40	17
Aliphatic (C8-C10)	µg/m3	ND	21	21	31	31
Aliphatic (C10-C12)	µg/m3	23	ND	32	37	53
Aromatic (EC5-EC7)	µg/m3	ND	ND	ND	ND	ND
Aromatic (EC7-EC8)	µg/m3	54	ND	ND	11	ND
Aromatic (EC8-EC10)	µg/m3	30	ND	21	ND	ND
Aromatic (EC10-EC12)	µg/m3	ND	ND	ND	ND	ND

Parameters/units		Site 10 Alépé 2	Site 11 Akouédo 1	Site 12 Akouédo 2	Site 14 Coco-Service	Control site 21 Agboville
Dimethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methyl tert-butyl ether	µg/m3	ND	ND	ND	ND	ND
Benzene	µg/m3	ND	ND	ND	ND	ND
Toluene	µg/m3	7.7	ND	12	10	ND
Ethylbenzene	µg/m3	ND	ND	ND	ND	ND
m,p-Xylene	µg/m3	12	ND	ND	ND	ND
0-Xylene	µg/m3	ND	ND	ND	ND	ND
Naphthalene	µg/m3	ND	ND	ND	ND	ND
TPH (C4-C6)	µg/m3	20	40	37	12	10
TPH (C6-C8)	µg/m3	110	31	59	40	20
TPH (C8-C10)	µg/m3	64	66	51	48	35
TPH (C10-C12)	µg/m3	24	63	29	58	53
TPH (C4-C12)	µg/m3	220	200	180	160	120
Aliphatic (C4-C6)	µg/m3	20	40	37	ND	ND
Aliphatic (C6-C8)	µg/m3	100	27	46	27	17
Aliphatic (C8-C10)	µg/m3	ND	57	26	ND	31
Aliphatic (C10-C12)	µg/m3	23	62	28	56	53
Aromatic (EC5-EC7)	µg/m3	ND	ND	ND	ND	ND
Aromatic (EC7-EC8)	µg/m3	7.7	ND	12	10	ND
Aromatic (EC8-EC10)	µg/m3	51	ND	25	36	ND
Aromatic (EC10-EC12)	µg/m3	ND	ND	ND	ND	ND

Parameters/units		Site 15 Abobo Sagbé	Site 16 Plateau Dokoui 1	Site 17 Plateau Dokoui 2	Control site 21 Agboville
Dimethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Ethyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Methyl ethyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Carbonyl sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Tertiary butyl mercaptan	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen sulfide	ppm v/v	< 0.1	< 0.1	< 0.1	< 0.1
Methyl tert-butyl ether	µg/m3	ND	ND	ND	ND
Benzene	µg/m3	4.6	ND	ND	ND
Toluene	µg/m3	16	7.5	4	ND
Ethylbenzene	µg/m3	ND	15	ND	ND
m,p-Xylene	µg/m3	11	ND	ND	ND
0-Xylene	µg/m3	ND	ND	ND	ND
Naphthalene	µg/m3	ND	4.4	ND	ND
TPH (C4-C6)	µg/m3	29	21	27	10
TPH (C6-C8)	µg/m3	90	52	34	20
TPH (C8-C10)	µg/m3	79	56	29	35
TPH (C10-C12)	µg/m3	41	ND	ND	53
TPH (C4-C12)	µg/m3	240	130	100	120
Aliphatic (C4-C6)	µg/m3	29	21	27	ND
Aliphatic (C6-C8)	µg/m3	70	41	28	17
Aliphatic (C8-C10)	µg/m3	23	ND	19	31
Aliphatic (C10-C12)	µg/m3	39	ND	ND	53
Aromatic (EC5-EC7)	µg/m3	4.6	ND	ND	ND
Aromatic (EC7-EC8)	µg/m3	16	7.5	4	ND
Aromatic (EC8-EC10)	µg/m3	57	67	ND	ND
Aromatic (EC10-EC12)	µg/m3	ND	ND	ND	ND

The results of this analysis can generally be summarized as follows:

1. Mercaptans, hydrogen sulfide and related components cannot be detected in any of the locations, including the control location. This is significant considering that the key odorants in the Probo Koala wastes were most likely hydrogen sulfide and mercaptans.

2. Concentrations of the various analytes at the affected sites are generally comparable to the concentrations found at the control site.

Site 4 (Koumassi), however, shows significantly elevated levels of hydrocarbon pollutants as compared to the background sites. Given the site's location, elevated levels of hydrocarbons are not unexpected. Indeed, the industrial zone of Koumassi is scattered with small-scale industrial plants operating in the automobile and metal working sectors in particular. During UN Environment's several visits to the site, heavy smoke emissions were observed from numerous chimneys in the immediate area. The chimneys were very old structures and clearly lacked any smoke emission control technology.

While not related to the dumping of wastes from the Probo Koala, the impacts of such poor local air quality could be significant. In particular, the presence of high levels of toluene, as well as other aromatics, is a matter of concern. Daily exposure to this pollution will undoubtedly adversely affect the health of thousands of workers and residents in the area.

As detailed in Box 3, several measures can be taken in the short and medium term to reduce people's exposure to pollution and improve air quality in the area. More generally, the Government should consider establishing national standards for air quality, as well as a regular air quality monitoring programme.

4.2 Water Quality

Groundwater

As explained in Chapter 2, the Government had originally agreed to have groundwater monitoring wells drilled for each impacted site following specifications provided by UN Environment. For various reasons, however, the Government was not able to undertake the drilling of the wells within the project's timeframe. Consequently, it was agreed that groundwater samples would be collected from existing wells around the impacted sites, where these could be found. These wells comprised both private wells and those maintained by the national drinking water authority (ONEP).

Three key sets of parameters were analyzed for groundwater samples, which together would constitute a theoretical "fingerprint" of the Probo Koala wastes: (i) sulfur; (ii) phenols; and (iii) hydrocarbons. In addition, a number of heavy metals that were included in the Government's contract for soil clean-up, were also analyzed.

The results for groundwater quality are presented in Table 28 below, along with those from a well near a control location (Site 19). In the absence of national standards for water quality, Dutch intervention values have been included for comparison purposes.

Table 28. Groundwater pollution analysis results

Parameters (µg/l)	Site 3 Vridi Canal 2	Site 4 Koumassi		Site 5 MACA 1		Site 7 MACA 3	Control site 19 Anyama	Dutch intervention values (µg/l)
	Well 3 m	Metal works zone	Well	Factory zone	Factory zone	Private well 20 m	Borehole	
Total Hy C5-35	< 10	< 10	< 10	< 10	< 10	< 10	< 10	600,000
Benzene	< 7	< 7	< 7	< 7	< 7	< 7	< 7	30
Ethylbenzene	< 5	< 5	< 5	< 5	< 5	< 5	< 5	1,000
Toluene	< 4	< 4	< 4	< 4	< 4	< 4	< 4	150
Xylene	< 11	< 11	< 11	< 11	< 11	< 11	< 11	70
Free sulfur	< 50	< 50	< 50	< 50	< 50	< 50	< 50	-
Pb	1.3	1.1	35	0.64	< 0.25	9.9	< 0.25	75
Cd	< 0.25	< 0.25	0.67	< 0.25	< 0.25	< 0.25	< 0.25	6
As	3.3	0.46	0.78	< 0.25	< 0.25	3.8	< 0.25	60
Cr	7	0.48	1.8	< 0.25	< 0.25	36	0.41	30
Ni	13	< 0.25	< 0.25	< 0.25	< 0.25	4.5	1.5	75
Co	1.5	0.43	1.1	< 0.25	< 0.25	0.89	1.4	100
Hg	0.41	< 0.25	2.1	0.41	0.41	< 0.25	< 0.25	0.3
Cu	6.8	3.1	13	9.1	1.9	6.3	1.8	75
Zn	78	3.8	610	4.5	3.1	62	5.4	800

Parameters (µg/l)	Site 8 Agboville	Site 10 Alépé 2		Site 14 Coco-Service		Control site 19 Anyama	Dutch intervention values (µg/l)
	Manhole	Well	Well	Borehole	Borehole	Borehole	
Total Hy C5-35	4,470	< 10	< 10	16	82	< 10	600,000
Benzene	< 7	< 7	< 7	< 7	< 7	< 7	30
Ethylbenzene	192	< 5	< 5	< 5	< 5	< 5	1,000
Toluene	113	< 4	< 4	< 4	< 4	< 4	150
Xylene	< 11	< 11	< 11	< 11	< 11	< 11	70
Free sulfur	< 50	< 50	< 50	< 50	< 50	< 50	-
Pb	4.5	25	< 0.25	5.4	< 0.25	< 0.25	75
Cd	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	6
As	12	< 0.25	0.48	< 0.25	0.33	< 0.25	60
Cr	130	0.53	< 0.25	< 0.25	190	0.41	30
Ni	42	230	2.7	260	12	1.5	75
Co	10	440	5	1.3	1.2	1.4	100
Hg	5	< 0.25	< 0.25	0.85	< 0.25	< 0.25	0.3
Cu	5.6	200	2.3	27	2.5	1.8	75
Zn	150	320	0.56	230	9.1	5.4	800

Two broad observations can be made regarding groundwater quality as it relates to the dumping of wastes from the Probo Koala:

1. None of the wells show the combined presence of sulfur and hydrocarbons that could have been considered as indicative of leachate contamination from sites impacted by the Probo Koala wastes.

2. In some locations, heavy metal concentrations, including mercury and chromium, exceed Dutch intervention values and are far above background levels. As conventional treatment systems for drinking water do not remove heavy metals, their concentrations in drinking water supplies should be monitored regularly. If heavy metals are found in the drinking water supplied to the city, additional treatment, such as carbon filtration, should be introduced.

A comparison with the pollutant concentrations in the control well indicates that the sample from the well near Site 4 (Koumassi) contains elevated levels of lead, zinc and mercury. Given the industrial nature of the area, and the fact that the results in question, except for mercury, are still below the Dutch intervention values, no immediate action is needed. In combination, however, the groundwater and air pollution findings expose Koumassi as a developing pollution "hotspot" that requires Government attention (see Box 3).

Box 3. Addressing environmental issues in Koumassi

Located in the south of Abidjan and surrounded on three sides by the waters of the Ébrié Lagoon, Koumassi is one of the ten urban municipalities that make up the District of Abidjan. Its industrial zone is characterized by a high intensity of small-scale industrial activity, typically within aging, and at times dilapidated, compounds – along with low-income and informal housing, often within the shells of obsolete industrial units. A high incidence of metal works and small foundries were observed during UN Environment's field visits. Stack-emission controls seemed largely absent on the multiple chimneys in the neighborhood, as these were seen to be routinely discharging thick plumes of black smoke, the particulates from which were settling within the immediate environment.

While the industrial units in Koumassi are not large in size, their collective emissions are sufficient to result in elevated levels of hydrocarbons in the air. Such situations are not unusual, as many countries do not have environmental systems for small and medium-scale industries, or do not subject them to an environmental clearance process. Even when limits are set, they are generally set for individual industries and collective impact is not monitored or controlled.

However, as the findings of UN Environment's audit for this site show elevated levels of hydrocarbons in the air, as well as higher concentrations of some heavy metals in groundwater, the following measures are recommended:

1. First and foremost, it is important to address the risks faced by the workers in these plants and workshops, who are most directly exposed to the pollution. Small and medium-scale industries typically have fewer occupational health controls and employees have less awareness about what health impacts exposure to air pollutants may have. The first priority should therefore be to provide employees with training on occupational health and access to personal protection equipment.

2. Even if small-scale industries are not regulated, creating a simple guideline on emissions controls and waste management, providing guidance on such issues as the minimum height for a chimney, storage and disposal of chemicals and solid wastes, setting up of simple grease traps before effluent disposal and other such measures would be very beneficial. Such a guidance note would need to be provided to all industries in the area.

3. Working together with all industries in the area, a comprehensive assessment should be conducted to gather information on such issues as the different types of industries, chimneys and stack-emissions controls, effluents, effluent disposal arrangements and occupational health. The findings of this assessment should be used as a basis for establishing a combined effluent treatment system, if needed, and specific measures for better environmental management in the area. Such an audit should also provide information about the community living around the area, and suggest zoning restrictions to reduce the exposure of the most vulnerable populations (children, the elderly and those in ill health).

Surface water

Surface water samples were taken from water bodies such as roadside drains, ponds, streams and rivulets on or near the sites of investigation, where these could be found. Surface water bodies – especially drains and streams – are transient in nature, and receive pollution on a daily basis from the urban environment. It was therefore not reasonable to expect any contamination to remain from a specific event ten years in the past. However, the water quality in these various sources could act an indicator of overall environmental conditions in the area.

Analysis results for surface water quality are presented in Table 29. It was not possible to compare these results, as Côte d'Ivoire does not have a national standard for surface water quality, and surface water was not sampled at any of the control sites.

Table 29. Surface water quality analysis results

Parameters (µg/l)	Site 2 Vridi Canal 1	Site 3 Vridi Canal 2	Site 8 Agboville	Site 10 Alépé 2		
	Surface water drain	Surface water drain	Rivulet	Downstream river	Pond	Spring
Total Hy C5-35	23,700	75,100	21	33	17	19
Benzene	< 7	< 7	< 7	< 7	< 7	< 7
Ethylbenzene	< 5	< 5	< 5	< 5	< 5	< 5
Toluene	< 4	< 4	< 4	< 4	< 4	< 4
Xylene	< 11	< 11	< 11	< 11	< 11	< 11
Free sulfur	77.3	< 150	< 50	< 50	< 50	< 50
Pb	1,000	21	0.36	1.7	0.85	0.33
Cd	32.2	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
As	40	7	0.39	1.2	1.7	< 0.25
Cr	240	15	3.3	2.7	1.2	< 0.25
Ni	82	51	3	0.49	< 0.25	< 0.25
Co	17	2	3.9	< 0.25	0.63	< 0.25
Hg	2.3	2.3	0.62	< 0.25	0.83	< 0.25
Cu	280	46	1.1	1.6	3.2	0.48
Zn	1,800	470	3.4	9.6	18	2.6

Parameters (µg/l)	Site 12 Akouédo 2	Site 13 Akouédo 3		Site 14 Coco-Service	Site 16 Plateau Dokoui 1	
	Drainage ditch	Pond	Pond	Rivulet	Basin	Basin
Total Hy C5-35	187	< 10	130	2,580	422	
Benzene	< 7	< 7	< 7	< 7	< 7	< 7
Ethylbenzene	< 5	< 5	< 5	< 5	< 5	< 5
Toluene	< 4	< 4	< 4	< 4	211	480
Xylene	< 11	< 11	< 11	< 11	< 11	< 11
Free sulfur	< 50	< 50	< 50	711	216	
Pb	4	100	0.69	8.4	7	3
Cd	0.39	2.7	< 0.25	< 0.25	< 0.25	0.33
As	4.6	4.3	1.2	1.4	4.7	3.8
Cr	7.8	17	0.94	5.8	9.2	6.7
Ni	13	28	10	2.7	1.7	< 0.25
Co	6.6	7.6	3	1.4	1.2	1.9
Hg	6.6	4	< 0.25	2.2	0.52	5.4
Cu	7.3	130	13	37	12	5.3
Zn	20	660	16	72	49	29

Two main observations can be made regarding surface water quality:

1. Samples from Sites 2 and 3 (Vridi Canal 1 and 2) show high levels of hydrocarbons, which is indicative of industrial pollution from local sources.

2. Heavy metal pollution is further observed in surface water samples from Sites 2 and 3 (Vridi Canal 1 and 2) and the Akouédo sites, which is also to be expected in urban industrial areas and municipal waste disposal sites.

The following recommendations can be made to address these issues:

1. A leachate monitoring plan should be made for the Akouédo municipal waste disposal site, covering its operational lifecycle, including decommissioning.

2. The Government should establish environmental monitoring systems for the Vridi industrial zone, based on sound environmental standards, to ensure that pollution is not draining into and further contaminating the Ébrié Lagoon.

Ébrié Lagoon

Water samples were also taken at various depths from the Ébrié Lagoon. The results are presented in Table 30.

The Ébrié Lagoon is the recipient of all surface run-off from metropolitan Abidjan, as well as sewage and industrial effluents. Parts of this vast water body have also been impacted by encroachment by back-filling of the lagoon for construction purposes, at times using unsuitable waste materials, as well as direct disposal of solid waste.

The water in the lagoon is flushed regularly by the influx of seawater during the tidal cycle, which explains the absence of accumulation of hydrocarbons and other pollutants in the lagoon. The Ébrié Lagoon faces significant environmental challenges, however, which have been well documented, including by UN Environment's Post-Conflict Environmental Assessment of Côte d'Ivoire (2015), which discussed the need to control the disposal of the various waste streams affecting the lagoon.

Table 30. Ébrié Lagoon water pollution analysis results

Parameters (µg/l)	Site 20 Ébrié Lagoon								
	Surface water	3.7 m	Surface water canal 16 m	Surface water	6 m	Surface water	4 m	Surface water	2.5 m
Total Hy C5-35	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Benzene	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7	< 7
Ethylbenzene	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Toluene	< 4	< 4	< 4	< 4	< 4	< 4	< 4	< 4	< 4
Xylene	< 11	< 11	< 11	< 11	< 11	< 11	< 11	< 11	< 11
Free sulfur	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
Pb	0.63	< 0.25	0.43	0.53	< 0.25	2	1.1	0.38	2
Cd	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
As	2.3	1.7	1.5	1.6	3	1.9	2	1.7	3.6
Cr	0.97	1.3	1.4	1.3	1.2	1.9	2	2	6.5
Ni	1.2	1.3	1.1	2.2	2	1.9	2	1.1	13
Co	0.42	< 0.25	< 0.25	0.35	0.7	< 0.25	0.47	0.39	2.6
Hg	< 0.25	2.1	0.3	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Cu	0.66	1.4	1.2	1.5	2.1	1.8	1.2	1	13
Zn	2.9	2.7	8.1	7.3	5.5	6.1	3.8	2.8	15

4.3 Sediment

Sediment can accumulate pollution from the water bodies they underlie, and unless significantly disturbed, can therefore serve as records of pollution over time. Samples of sediment were collected from the sites of investigation, wherever possible. An effort was also made to collect sediment from the base of the Ébrié Lagoon, which is challenging due to the large quantity of plastic debris on the lagoon's bed. The results of the analyses, along with the relevant Dutch intervention values for comparison purposes, are presented in Table 31 below.

The results indicate that hydrocarbon levels in the samples analyzed are well below Dutch intervention values. However, three samples of sediment from the base of the lagoon and one from Site 14 (Coco-Service) exhibit slightly elevated levels of some heavy metals – chromium, copper, zinc and lead – which are marginally above Dutch intervention values, reinforcing once again the importance of better management of the run-off into the lagoon, especially from industrial units and untreated sewage. The decision on how contaminated sediment should be handled is very complex, and should be considered as part of planning for the overall clean-up of the Ébrié lagoon.

Table 31. Sediment pollution analysis results

Parameters (µg/l)	Site 7 MACA 3	Site 10 Alépé 2	Site 14 Coco-Service	Site 20 Lagoon					Dutch intervention values (mg/kg)
	Drain pipe	Rivulet	Rivulet	4.4 m	11.2 m	4 m	3 m	Koumassi shore	
Total Hy C5-C44	4.92	3.88	420	3,440	375	156	449	198	5,000
Benzene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	1.1
Ethylbenzene	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	0.0093	110
Toluene	< 0.002	0.022	0.00833	< 0.002	0.0224	0.0072	< 0.002	< 0.002	32
Xylene	< 0.009	< 0.009	< 0.009	< 0.009	< 0.09	< 0.009	< 0.009	< 0.009	17
Total sulfur (%)	< 0.02	0.0295	0.0881	3.32	2.56	1.17	1.83	4.37	
Pb	9.5	17	444 - 1700*	55	190	45	39	9.4	530
Cd	< 0.1	0.16	< 0.1	0.8	1.6	0.39	0.5	0.16	13
As	2.4	4.3	5.7	11	8.7	11	9.4	5.4	76
Cr	30	47	70	200	100	140	120	45	180
Ni	2.8	7.1	15	49	29	42	49	21	100
Co	0.73	1.4	1.5	16	6.4	12	15	11	190
Hg	0.03	0.099	0.1	0.5	2	0.46	0.72	0.12	36
Cu	7.8	10	21	63	210	53	84	15	190
Zn	17	69	50	280	890	190	190	44	720

*Strong inhomogeneities due to non-homogenizable lead particles

4.4 Molluscs

Molluscs are an important bio-monitoring "tool" for measuring the health of an ecosystem as they accumulate pollutants over time and hence magnify even trace elements. Four samples of oysters were collected near the locations where Probo Koala wastes could have migrated into the lagoon.

The results of this analysis are presented in Table 32 below. In the absence of national food quality standards, the European Commission's maximum levels of certain contaminants in food stuffs (EC regulation 1881/2006) are used for comparison.

As can be seen in Table 32, concentrations of benzo(a)pyrene and mercury, respectively, are above the standard in two of the oyster samples. These results are comparable to a larger set of fish and aquatic life samples analyzed by UN Environment as part of the Post-Conflict Environmental Assessment, pointing to the now well documented pollution of Ébrié Lagoon. The fact that pollution is accumulating in the food chain indicates the need to improve the water quality in the lagoon and to conduct more regular surveillance of the biota, as this has the potential to impact human health.

Table 32. Mollusc pollution analysis results

Parameters (mg/kg)	Site 20 Ébrié Lagoon				EC regulation (mg/kg)
	Dem'Badon	Blackouss	Vridi Canal	Koumassi	
Benzene	< 0.01	< 0.01	< 0.01	< 0.01	
Toluene	< 0.05	< 0.05	< 0.05	< 0.05	
Ethylbenzene	< 0.05	< 0.05	< 0.05	< 0.05	
Benzo(a)pyrene	0.012	0.0019	0.0012	< 0.001	0.01
Xylene	< 0.05	< 0.05	< 0.05	< 0.05	
Total sulfur (%)	770	1,300	1,700	1,800	
PAH	0.156	0.0635	0.0556		
Pb	< 0.01	< 0.01	< 0.01		1.5
Cd	0.093	0.16	0.14		1
As	0.13	0.38	1.6		
Cr	< 0.01	< 0.01	< 0.01		
Ni	< 0.01	0.081	0.033		
Co	0.039	0.21	0.13		
Hg	0.1	0.7	0.1		0.5
Cu	6.3	25	19		
Zn	240	1,700	500		

4.5 Fruit and vegetable

As noted in the introduction to this chapter, one of the specific concerns of the communities living on or near the sites affected by the dumping of toxic wastes from the Probo Koala was whether it was possible for contaminants from these wastes to have accumulated within locally grown food products. Accordingly, samples of fruit and vegetable were collected, where possible, from the sites of investigation. Sampled comestible products include cassava, sweet potato, eggplant, gombo, banana, papaya, guava and pomegranate.

Fruit and vegetable samples were tested using similar protocols as those used for analysis of soil and water samples. The results of this analysis are presented in Table 33 below. In the absence of national food quality standards, the European Commission's maximum levels of certain contaminants in food stuffs (EC regulation 1881/2006) are used for comparison. It should be noted that as it was found that there were interferences from naturally occurring substances with the hydrocarbon analyses, the analytical results relating to hydrocarbons were discarded.

Table 33. Fruit and vegetable pollution analysis results

Parameters (mg/kg)	Site 5 MACA 1		Site 7 MACA 3	Site 8 Agboville		Site 9 Alépé 1	EC regulation (mg/kg)
	Cassava	Cassava	Sweet potato	Cassava	Cassava	Cassava	
Total sulfur (%)	0.0862	< 0.02	0.0943	< 0.02	0.0408	< 0.02	
PAH	< 0.118	0.261	< 0.118	< 0.118	< 0.118	< 0.118	
Pb	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	0.1
Cd	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.1
As	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	
Cr	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	
Ni	< 0.2	< 0.2	0.234	1.65	0.406	< 0.2	
Co	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
Hg	< 0.14	< 0.14	< 0.14	< 0.14	< 0.14	< 0.14	
Cu	2.01	2.57	2.67	3.04	2.07	1.9	
Zn	24.6	22.2	11.4	6.98	12.4	17.6	

Parameters (mg/kg)	Site 10 Alépé 2		Site 11 Akouédo 1	Site 12 Akouédo 2	Site 13 Akouédo 3	EC regulation (mg/kg)
	Banana	Cassava	Melon	Sweet potato	Gombo/okra	
Total sulfur (%)	0.0767	< 0.02	0.0612	0.0341	0.0583	
PAH	< 0.118	< 0.118	< 0.118	< 0.118	< 0.118	
Pb	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	0.1
Cd	< 0.02	< 0.02	< 0.02	0.106	0.0825	0.1
As	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	
Cr	< 0.9	< 0.9	3.55	< 0.9	2.41	
Ni	0.341	< 0.2	4.43	< 0.2	0.797	
Co	< 0.1	< 0.1	0.307	< 0.1	0.143	
Hg	< 0.14	< 0.14	< 0.14	< 0.14	< 0.14	
Cu	9.85	< 1.4	13.7	10.3	8.88	
Zn	44.7	14.2	52.9	17.4	76.5	

Parameters (mg/kg)	Site 14 Coco-Service	Site 15 Abobo Sagbé		Site 17 Plateau Dokoui 2	Control site 21 Agboville	EC regulation (mg/kg)
	Banana	Papaya	Guava	Sweet potato	Pomegranate	
Total sulfur (%)	< 0.02	0.0944	0.067	< 0.02	0.0547	
PAH	< 0.118	< 0.118	< 0.118	< 0.118	< 0.118	
Pb	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	0.1
Cd	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.1
As	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	
Cr	< 0.9	1.25	< 0.9	< 0.9	1.62	
Ni	< 0.2	0.854	< 0.2	< 0.2	0.82	
Co	< 0.1	0.322	< 0.1	< 0.1	0.149	
Hg	< 0.14	< 0.14	< 0.14	< 0.14	< 0.14	
Cu	2.97	8.18	3.76	8.59	3.85	
Zn	6.93	23.1	23	23.7	22.9	

Based on the results, the following observations can be made:

1. All samples, including the pomegranate sample from Control Site 21 at Agboville, show the presence of various analytes and heavy metals. Fruits and vegetables naturally accumulate heavy metals from the soil. As most of the heavy metals are essential to human health in small quantities, their uptake through fruits and vegetables is not considered to be a risk.

2. The concentration of cadmium is slightly above EC regulations for the sweet potato sample collected from Site 12, located within the municipal waste disposal site at Akouédo. Presence of slightly elevated levels of heavy metals in vegetables grown on waste disposal sites is well documented. While results for one sample are not sufficient to issue a safety advisory, it would be appropriate – from a due diligence point of view – to conduct additional sampling at this site. In addition, as previously mentioned, an appropriate decommissioning plan needs to be developed for the waste disposal site as a whole, covering leachate monitoring, landfill gas collection arrangements and land use restrictions.

3. The EC standard for lead is below the detection limit of the laboratory analyses. However, considering that all samples, including control samples, show comparable heavy metal values, these results are not considered to warrant further follow up.

05 Conclusions and Recommendations

The main objective of this environmental audit, based on the request of Government of Côte d'Ivoire, was to undertake an independent and scientific environmental audit of the sites that were impacted by the dumping of toxic wastes from the Probo Koala, in order to verify if these continued to pose any environmental or public health risks. This chapter presents UN Environment's main findings and recommendations.

5.1 Conclusions

The results of the laboratory analysis that was undertaken on the 130 samples of soil, water, air, sediment, molluscs, fruit and vegetables that were collected by UN Environment, which are presented in Chapters 3 and 4 of this report, clearly indicate the following for the different types of sites affected by the dumping of toxic wastes from the Probo Koala:

Toxic wastes dumping sites

- None of the sites where wastes from the Probo Koala were actually dumped show contamination exceeding the limits set by the Government of Côte d'Ivoire for remediation. As a result, none of these sites require additional intervention, even when gauged against Dutch intervention values, which are among the most commonly used guidelines for contaminated site management and remediation worldwide.

Dumping sites presenting other types of pollution

- Elevated levels of air and groundwater pollution parameters are found at Site 4 (Koumassi) as compared to the control sites. This reflects the lack of adequate environmental monitoring of the numerous small to medium-scale industrial plants in the area. While concentrations do not reach levels requiring emergency intervention, the results show Koumassi to be something of an "environmental hotspot" requiring Government attention and follow-up.

- As compared to the control sites, the municipal waste disposal site at Akouédo unsurprisingly shows elevated levels of several pollutants, including slightly elevated levels of cadmium in some vegetables gown on Site 12 (Akouédo 2).

Other sites of interest

- The silos that stored the suspected contaminated maize within the autonomous port of Abidjan are free of any of the pollutants linked to the Probo Koala wastes.

- Site 8 (Agboville), where maize that was potentially indirectly impacted by Probo Koala wastes was composted, shows elevated levels of chromium in soil samples taken within the treated maize pile, as well soil samples taken further down-site. These levels are above both the standards used by Envipur to monitor the composting process, and Dutch intervention values. Furthermore, high levels of chromium were also found in the water samples from the adjacent manhole, which acts as a drainage collection point for the treatment cell.

5.2 Recommendations

Based on the conclusions above, the following specific recommendations can be made to the Government of Côte d'Ivoire:

- **Remediation of the Agboville maize composting site:** As two rounds of sampling have indicated that the site has elevated levels of chromium and that chromium is leaching into the drainage collection system, this site should be closely monitored. Access to the site should continue to be restricted, and sign boards should be put up warning people not to enter or harvest grass or vegetables from the site. Leachate from this site should be appropriately disposed of in a dedicated facility following comprehensive chemical analyses. Furthermore, the Government should review its contract and address the matter with the contractor, Envipur. Additional sampling and risk assessment on a "source-pathway-receptor" model will be needed to determine what interventions are required at the site.

- **Due diligence needed for decommissioning of Akouédo municipal waste disposal site:** The Government has informed UN Environment that the municipal waste disposal site at Akouédo has been earmarked for closure for a long time. Once a closure date is selected, a comprehensive environmental due diligence survey should be conducted, including establishing systems for

leachate collection and landfill gas monitoring. Land use restrictions, including on farming on the site, may also have to be put in place.

- **Environmental assessment of the Koumassi area:** Based on the contamination levels found in air and groundwater samples taken at Site 4, it is strongly recommended that the Government: (i) ensure that workers are provided with personal protection equipment and training on occupational health; (ii) establish guidelines on emissions controls and waste management for small and medium-scale industries; and (iii) undertake a comprehensive environmental assessment of the Koumassi area, comprising soil, water and air quality, as a basis for developing an action plan for mitigating impacts on public health.

More generally, while the environmental audit concludes that none of the sites where wastes from the Probo Koala were dumped show contamination exceeding the limits set by the Government or acceptable international standards, the following issues should be highlighted:

- Tens of thousands of people were impacted by the dumping of the toxic wastes from the Probo Koala in 2006. UN Environment's study focuses on whether the dumping sites continue to pose environmental and health risks to the populations living on or near them, and its conclusions on this count are reassuring. The findings, however, do not preclude that health impacts from their original exposure to the wastes in 2006 are still affecting communities. While it cannot be addressed through an environmental survey, the question of whether those who were impacted at the time of the dumping continue to suffer physiological or psychosomatic impacts is a critical one, particularly as systematic monitoring of affected populations has not taken place over the last decade. It is strongly recommended that the Government of Côte d'Ivoire undertake to review a representative selection of original cases and consider the need to establish a monitoring programme of the health of these communities.

- Although a number of measures have been taken by the Government to improve the monitoring and management of liquid wastes from ships in the ports, access controls to the municipal waste disposal site at Akouédo, which was the original target of the waste dumping, remain somewhat weak. The Government should undertake to further review its operating procedures for hazardous waste management and to ensure that adequate chain of custody procedures are enforced to prevent such events from occurring again.

- Moreover, the environmental monitoring systems and capacity built by UN Environment within CIAPOL in the aftermath of the toxic waste dumping event – which included the provision of state-of-the-art laboratory equipment – were lost during the post-electoral violence of 2010-2011, which devastated the institution. As a result, CIAPOL is no longer able to execute its mandate to its full extent. An assessment of CIAPOL was conducted in 2012 by the UNEP-DHI Centre on Water and Environment.[31] The Government should draw on the recommendations of this assessment to restructure CIAPOL and provide it with additional resources to ensure that it can respond to current environmental challenges.

As evidenced in Koumassi, environmental "hotspots" are developing in Abidjan in the absence of effective surveillance. While these may not yet have major environmental and public health impacts, the consequences of this pollution may be rapidly felt in a fast-growing metropolis such as Abidjan.

Appendices

Appendix 1. Notes and references

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3. Government of Côte d'Ivoire. National Institute of Statistics (1998). Recensement Général de la Population et de l'Habitat, 1998 [in French].
4. Government of Côte d'Ivoire. National Institute of Statistics (2014). Recensement Général de la Population et de l'Habitat, 2014 [in French]
5. UN Environment (2015). Côte d'Ivoire : Post-Conflict Environmental Assessment, p. 9
6. See for example : UN General Assembly (2009). Report of the Special Rapporteur on the adverse effects of the movement and dumping of toxic and dangerous products and wastes on the enjoyment of human rights (A/HRC/12/26/Add.2); or Amnesty International and Greenpeace (2012). The Toxic Truth.
7. As noted on p. 24, the fuel tank was removed soon after the dumping event and was treated in France by Trédi. This site is accordingly not featured on the official list of dumping sites for the toxic wastes from the Probo Koala.
8. Government of Côte d'Ivoire. National Institute of Public Hygiene (2008). Synthèse des études cliniques et épidémiologiques réalisées sur l'intoxication aux déchets toxiques déversés à Abidjan en août 2006; p. 8 [in French].
9. See for example: Government of Côte d'Ivoire. Cellule opérationnelle de coordination du Plan national de lutte contre les déchets toxiques. Note aux rédactions no. 005-/27-09/06-CICG (27 September 2006 [in French]); or Government of Côte d'Ivoire. Cellule opérationnelle de coordination du Plan national de lutte contre les déchets toxiques. Note aux élus et maires du District d'Abidjan no. 002-/13-10/06-CICG (13 October 2006) [in French].
10. Report of the Government of Côte d'Ivoire to the 8th Conference of the Parties of the Basel Convention regarding the dumping of toxic wastes in Abidjan, Côte d'Ivoire, section VI.
11. See for example: http://www.lemonde.fr/afrique/article/2006/09/07/demission-du-gouvernement-ivoirien-apres-une-pollution-mortelle-de-dechets-toxiques_810339_3212.html [in French].
12. Report of the Government of Côte d'Ivoire to the 8th Conference of the Parties of the Basel Convention regarding the dumping of toxic wastes in Abidjan, Côte d'Ivoire, section VI. Also see for example: Voice of America. Protesters Block Streets in Ivory Coast over Toxic Waste Scandal (6 September 2006), accessed at http://www.voanews.com/a/a-13-2006-09-06-voa48/328215.html
13. As quoted by Amnesty International and Greenpeace in The Toxic Truth (2012), p. 207.
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15. Government of Côte d'Ivoire, Ivorian Anti-pollution Center (CIAPOL) (2013). Projet de dépollution complémentaire des sites de déversement des déchets toxiques dans le District d'Abidjan : Rapport no. 1 de contrôle des travaux de Biogénie et suivi environnemental des sites impactés par les déchets toxiques , période de 2010 à 2013 [in French].
16. Government of Côte d'Ivoire, Ministry of Environment, Water and Forests (2010). Marché Envipur: Enlèvement, transport et traitement du maïs avarié et nettoyage des silos de la société PKL [in French].
17. As noted in Chapter 1, there were 12 actual dumping locations. However, one of these (Abobo Plaque) was covered in concrete following the initial clean-up in 2006, with the result that no sampling would have been possible. UN Environment and the Government of Côte d'Ivoire agreed not to include this dumping site in the scope of the assessment.
18. Some locations, such as the port facility at Treichville, had concreted/tarmac surfaces, while others, such as at Koumassi, lacked a soil cover and were covered in household waste.
19. Standards to be met by clean-up operations were set the Government of Côte d'Ivoire in its 2009 contract with Biogénie for excavation, transport and treatment of soil and materials polluted by the Probo Koala wastes. See: Government of Côte d'Ivoire, Ministry of Environment, Water and Forests (2009). Contrat de prestation de services: Excavation, transport et traitement biologique de terres et matières polluées par les déchets du Probo Koala ; Annexe 3 [in French].
20. See: Envipur SA (2017). Rapport d'activité 2010-2017 : Enlèvement, transport et traitement du maïs avarié et nettoyage des silos de la société PKL [in French].

21. Based on French standard NF U 44-095 on composts from waste water treatment containing organic materials of interest.
22. https://rwsenvironment.eu/subjects/soil/legislation-and/soil-remediation/
23. See: Government of Côte d'Ivoire, Ministry of Environment, Water and Forests (2009). Contrat de prestation de services: Excavation, transport et traitement biologique de terres et matières polluées par les déchets du Probo Koala; Annexe 3 [in French].
24. See: Government of Côte d'Ivoire, Ministry of Environment, Water and Forests (2013). Avenant no. 1 au Contrat de prestation de services: Excavation, transport et traitement biologique de terres et matières polluées par les déchets du Probo Koala ; Article VIII [in French]
25. See: Government of Côte d'Ivoire, Ivorian Anti-pollution Center (CIAPOL) (2015). Projet de dépollution complémentaire des sites de déversement des déchets toxiques dans le District d'Abidjan : Rapport no. 9 de contrôle des travaux de Biogénie et suivi environnemental des sites impactés par les déchets toxiques , période de novembre 2014 à janvier 2015, p. 6 [in French].
26. See: http://rwsenvironment.eu/publish/pages/97218/soil_remediation_circular_2013_july_2013.pdf
27. Site 20 – the Ébrié Lagoon – is not included in this discussion as it is neither a site where clean-up occurred or a control site. Results obtained from water, molluscs and sediment samples taken in the lagoon are discussed in Chapter 4.
28. Standards to be met by clean-up operations were set the Government of Côte d'Ivoire in its 2009 contract with Biogénie for excavation, transport and treatment of soil and materials polluted by the Probo Koala wastes, see: Government of Côte d'Ivoire, Ministry of Environment, Water and Forests (2009). Contrat de prestation de services: Excavation, transport et traitement biologique de terres et matières polluées par les déchets du Probo Koala ; Annexe 3 [in French].
29. See: Envipur SA (2017). Rapport d'activité 2010-2017 : Enlèvement, transport et traitement du maïs avarié et nettoyage des silos de la société PKL [in French].
30. See: Envipur SA (2017). Rapport d'activité 2010-2017 : Enlèvement, transport et traitement du maïs avarié et nettoyage des silos de la société PKL [in French].
31. UNEP-DHI Centre on Water and Environment (2012). Report of the Mission charged with the Scientific, Technical and Organisational Assessment of the Ivorian Anti-pollution Center (CIAPOL) [in French].
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Appendix 2. Complete list of analytes

Inorganics	Soil and sediment	Water	Air	Comestible vegetation	Molluscs
Sulfur, elemental	✓	×	×	✓	×
Sulfur, total	✓	×	×	✓	✓
Sulfur, free	×	✓	×	×	×
Sulfur dissolved	×	✓	×	×	×
Metals					
Arsenic (As)	✓	✓	×	✓	✓
Cadmium (Cd)	✓	✓	×	✓	✓
Chromium (Cr)	✓	✓	×	✓	✓
Cobalt (Co)	✓	✓	×	✓	✓
Copper (Cu)	✓	✓	×	✓	✓
Lead (Pb)	✓	✓	×	✓	✓
Mercury (Hg)	✓	✓	×	✓	✓
Nickel (Ni)	✓	✓	×	✓	✓
Selenium (Se)	✓	✓	×	✓	×
Zinc (Zn)	✓	✓	×	✓	✓
Vanadium (V)	✓	✓	×	×	✓
Manganese (Mn)	✓	✓	×	×	✓
Molybdenum (Mo)	✓	✓	×	×	✓
Antimony (Sb)	✓	✓	×	×	✓
Thallium (Tl)	✓	✓	×	×	✓
Thorium (Th)	✓	✓	×	×	✓
Uranium (U)	✓	✓	×	×	✓
Phenols					
Phenol	✓	✓	×	✓	×
Cresols	✓	✓	×	✓	×
Xylenols	✓	✓	×	✓	×
Phenols, total detected monohydric	✓	✓	×	✓	×

Total Petroleum Hydrocarbon Criteria Working Group (TPH CWG)	Soil and sediment	Water	Air	Comestible vegetation	Molluscs
Gasoline range organics (GRO), surrogate % recovery	✓	✓	×	✓	×
Gasoline range organics (GRO) time of transmission (TOT) (Moisture Corrected)	✓	×	×	✓	×
Gasoline range organics (GRO) >C5-C12	×	✓	×	×	×
Methyl tertiary-butyl ether (MTBE)	✓	✓	✓	✓	×
Benzene	✓	✓	✓	✓	✓
Toluene	✓	✓	✓	✓	✓
Ethylbenzene	✓	✓	✓	✓	✓
m,p-Xylene	✓	✓	✓	✓	×
o-Xylene	✓	✓	×	✓	×
Sum of detected m,p,o-xylene	✓	✓	×	✓	✓
Sum of detected benzene, toluene, ethylbenzene and total xylene isomers (BTEX)	✓	✓	×	✓	×
Aliphatics (C4-C6)	×	×	✓	×	×
Aliphatics (C5-C6)	✓	✓	×	✓	×
Aliphatics (C6-C8)	✓	✓	✓	✓	×
Aliphatics (C8-C10)	✓	✓	✓	✓	×
Aliphatics (C10-C12)	✓	✓	✓	✓	×
Aliphatics (C12-C16)	✓	✓	×	✓	×
Aliphatics (C16-C21)	✓	✓	×	✓	×
Aliphatics (C21-C35)	✓	✓	×	✓	×
Aliphatics (C35-C44)	✓	×	×	✓	×
Total aliphatics >C12-C35 (aq)	×	✓	×	×	×
Total aliphatics >C12-C44	✓	×	×	✓	×
Aromatics (EC5-EC7)	✓	✓	✓	✓	×
Aromatics (EC7-EC8)	✓	✓	✓	✓	×
Aromatics (EC8-EC10)	✓	✓	✓	✓	×
Aromatics (EC10-EC12)	✓	✓	✓	✓	×

Total Petroleum Hydrocarbon Criteria Working Group (TPH CWG)	Soil and sediment	Water	Air	Comestible vegetation	Molluscs
Aromatics (EC12-EC16)	✓	✓	×	✓	×
Aromatics (EC16-EC21)	✓	✓	×	✓	×
Aromatics (EC21-EC35)	✓	✓	×	✓	×
Aromatics (EC35-EC44)	✓	×	×	✓	×
Aromatics (EC40-EC44)	✓	×	×	✓	×
Total aromatics >EC12-EC35 (aq)	×	✓	×	×	×
Total aliphatics and aromatics >C5-35 (aq)	×	✓	×	×	×
Total aromatics >EC12-EC44	✓	×	×	✓	×
Total aliphatics and aromatics >C5-C44	✓	×	×	✓	×
Total petroleum hydrocarbon (TPH) (C4-C6)	×	×	✓	×	×
Total petroleum hydrocarbon (TPH) (C6-C8)	×	×	✓	×	×
Total petroleum hydrocarbon (TPH) (C8-C10)	×	×	✓	×	×
Total petroleum hydrocarbon (TPH) (C10-C12)	×	×	✓	×	×
Total petroleum hydrocarbon (TPH) (C4-C12)	×	×	✓	×	×
Poly-aromatic hydrocarbons (PAHs)					
Naphthalene-d8 % recovery	✓	×	×	✓	×
Acenaphthene-d10 % recovery	✓	×	×	✓	×
Phenanthrene-d10 % recovery	✓	×	×	✓	×
Chrysene-d12 % recovery	✓	×	×	✓	×
Perylene-d12 % recovery	✓	×	×	✓	×
Naphthalene	✓	✓	✓	✓	✓
Anthracene	✓	✓	×	✓	✓
Acenaphthylene	✓	✓	×	✓	✓
Acenaphthene	✓	✓	×	✓	✓
Benzo(a)anthracene	✓	✓	×	✓	✓
Benzo(b)fluoranthene	✓	✓	×	✓	✓

Poly-aromatic hydrocarbons (PAHs)	Soil and sediment	Water	Air	Comestible vegetation	Molluscs
Benzo(k)fluoranthene	✓	✓	×	✓	✓
Benzo(a)pyrene	✓	✓	×	✓	✓
Benzo(g,h,i)perylene	✓	✓	×	✓	✓
Chrysene	✓	✓	×	✓	✓
Dibenzo(a,h)anthracene	✓	✓	×	✓	✓
Fluoranthene	✓	✓	×	✓	✓
Fluorene	✓	✓	×	✓	✓
Indeno(1,2,3-cd)pyrene	✓	✓	×	✓	✓
Phenanthrene	✓	✓	×	✓	✓
Pyrene	✓	✓	×	✓	✓
Poly-aromatic hydrocarbons (PAHs), total detected U.S. Environmental Protection Agency (USEPA) 16	✓	✓	×	✓	✓
Volatile organic compounds (VOCs)					
Toluene-d8	✓	✓	✓	✓	×
Methyl tertiary-butyl ether (MTBE)	✓	✓	×	✓	×
Benzene	✓	✓	×	✓	×
Toluene	✓	✓	×	✓	×
Ethylbenzene	✓	✓	×	✓	×
m,p-Xylene	✓	✓	×	✓	×
o-Xylene	✓	✓	×	✓	×
Sum of benzene, toluene, ethylbenzene and total xylene isomers (BTEX)	✓	✓	×	✓	×
Dimethyl sulfide	×	×	✓	×	×
Ethyl mercaptan	×	×	✓	×	×
Methyl ethyl sulfide	×	×	✓	×	×
Carbonyl sulfide	×	×	✓	×	×
Dimethyl sulfide	×	×	✓	×	×
Tertiary butyl mercaptan	×	×	✓	×	×
Hydrogen sulfide	×	×	✓	×	×

Appendix 3. Impacts of chromium on human health and the environment

Chromium (Cr) is a lustrous, brittle and silver-grey hard metal that is mined as chromite ($FeCr_2O_4$) ore. Its main uses are in alloys such as stainless steel, chrome plating and metal ceramics, where is it is used to impart corrosion resistance and a shiny finish. Chromium is also used in dyes and paints, as a catalyst in the dyeing and tanning of leather, and to make moulds for the firing of bricks, among other applications.[32]

Human health impacts of chromium exposure

People are typically exposed to chromium through food, drinking water, soil and air; contact with consumer products containing chromium is also a minor source of exposure.[33]

The human health hazards associated with exposure to chromium depend on its oxidation state. The two principle oxidation states of chromium are trivalent chromium – Cr(III) – which is considered to be an essential nutrient for humans, and hexavalent chromium – Cr(VI) – which is highly toxic and a known carcinogen.

Eating food that contains Cr(III) is the main route of chromium uptake in humans, as Cr(III) occurs naturally in many vegetables, fruits, meats, egg yolks, nuts, yeasts and grains.[34] Various methods of food preparation and storage may also alter the chromium contents of food. As Cr(III) is a key nutrient, shortages may cause heart conditions, disruptions of metabolisms and diabetes, although excessive level of Cr(III) can cause health effects as well, such as skin rashes.

Cr(VI) is known to cause various serious health effects. Depending on the dose of the intake, these can range from severe eye and skin irritations, nasal irritations and nosebleeds to stomach ulcers and gastrointestinal bleeding, respiratory problems, weakened immune systems, kidney and liver damage, alteration of genetic material, different forms of cancer and ultimately death.[35, 36] People who work in the steel and textile industry are typically most affected. People who smoke tobacco also have a higher chance of exposure to Cr(VI), which in turn may contribute to the overall lung cancer risk associated with smoking.[37]

Environmental impacts of chromium

Chromium enters the air, water and soil through both natural processes and human activities, such as coal combustion and the discharge of both solid and liquid industrial wastes from steal, chemical, leather and textile manufacturing, and other industrial applications.

Chromium in air is associated mostly with the particulate phase and has been reported to reside in the atmosphere for approximately 14 days, eventually settling on soil, surface water, crops and vegetation.[38] Chromium strongly attaches to soil particles and as a result does not move towards groundwater. In water, chromium typically absorbs in sediment and becomes immobile, with only a small part eventually dissolving.

Plants usually absorb only Cr(III), and crops contain systems that arrange the chromium uptake to be low enough not to cause any harm. However, when the amount of chromium in the soil rises, it can lead to higher concentrations in crops. Acidification of soil can also influence chromium uptake by crops.

High concentrations of chromium, due to the disposal of metal products in surface waters, also inflict damage to fish, with marked degenerative changes to the gills, kidney and liver tissues.[39] In animals, chromium can cause respiratory problems, a lower ability to fight disease, birth defects, infertility and tumor formation.

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