Objectives, Scope and Methodologies

A multidisciplinary team of international and Nigerian experts conducted fieldwork for the UNEP assessment over a 14-month period
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Objectives, Scope and Methodologies

3.1 Objectives

Based on the initial request from the Government of Nigeria and the background work undertaken by UNEP, the following objectives were formulated for the assessment:

1. Undertake a comprehensive assessment of all environmental issues associated with the oilfield related activities in Ogoniland, including the quantification of impacts
2. Provide useful guidance data to undertake remediation of contaminated soil and groundwater in Ogoniland
3. Provide specific recommendations regarding the scope, modalities and means of remediation of soil and groundwater contamination
4. Technical evaluation of alternative technologies which could be employed to undertake such remediation
5. Provide recommendations for responding to future environmental contamination from oilfield operations
6. Provide recommendations for sustainable environmental management of Ogoniland
7. Enhance local capacity for better environmental management and promote awareness of sound environmental management and sustainable development
8. Be part of the peace dividend and promote ongoing peace building efforts.

The full project document approved by the PIC is available online.

3.2 Scope of the investigation

Geographical scope

The geographical scope of the investigation concerned the areas in and around Ogoniland, with a specific focus on the four Ogoniland local government areas (Eleme, Gokana, Khana and Tai). However, the precise location of the boundaries between these LGAs and neighbouring LGAs was not always evident on the ground. Nor did official information necessarily correspond to local community understanding. Consequently, some of the assessment and sampling work straddled the officially mapped boundaries of the four LGAs.

UNEP technical assistant obtaining fish at a local market

Bodo West is an area within the extensive network of deltaic creeks. Though uninhabited it includes a number of oil wells. The wells themselves are submerged, while the associated production station (now decommissioned) is on land. Bodo West is officially mapped as belonging to Ogu/Bolo LGA but since there are no local settlements, it has been regarded by both SPDC and the Ogoni people as part of the Ogoniland oil facilities. Bodo West was therefore included in the scope of UNEP's work.

UNEP's investigations of surface water, sediments and aquatic biota focused on two major water systems, namely the Imo River in the east of Ogoniland and the numerous creeks that extend towards Ogoniland from the Bonny River.

In order to demonstrate that the environmental problems affecting Ogoniland are being felt in neighbouring areas, limited investigations were also carried out in the adjoining Andoni LGA.

Technical scope of the assessment

The investigation into **soil and groundwater contamination** focused on the areas impacted by oilfield operations in Ogoniland. These included the locations of all oil spills reported by SPDC or the local community, all oilfield infrastructure (whether still in operation or abandoned) and all the land area contaminated by floating oil in creeks. In a number of these locations SPDC had reportedly initiated or completed clean-up operations.

Investigations into **aquatic pollution** were carried out along the Imo River and the creeks, focusing on surface water quality, sediment contamination and contamination of fish. Since not all the fish consumed by Ogoni communities come from local water bodies, fish sold at local markets were also examined to establish whether contaminated food is reaching Ogoniland from external sources.

Surveys of **vegetation contaminants** were also made of vegetation around spill sites and mangroves impacted by oil pollution.

The impact of **pollutants on public health** was assessed in three ways: by taking air quality measurements in communities around spill sites, by measuring drinking water quality around spill sites and by a review of public health data obtained from medical centres in Ogoniland. To gain a better understanding of the data, a preliminary social survey of local communities was undertaken.

In reviewing the **institutional and legal structures** related to the environment and the petroleum industry in the Niger Delta, UNEP looked at the governmental institutions directly involved: the Federal Ministry of Environment, NOSDRA and the DPR – an agency under the Ministry of Petroleum Resources which has a statutory role in environmental management.

SPDC has internal procedures dealing with a range of issues that have environmental consequences. UNEP's review of **SPDC practices and performance** included company documentation on responses to oil spills, clean-up of contaminated sites and abandonment of sites. In addition, the assessment also examined whether clean-up of oil spills and contaminated sites in Ogoniland was implemented in accordance with SPDC's internal procedures. The assessment also checked whether environmental clean-up operations accorded with Nigerian national standards.

Lastly, the assessment considered the impact of **illegal operations**. In addition to the licensed operators undertaking legitimate oil production, transport and refining activities in Ogoniland, a number of groups and individuals carry out unlicensed, and therefore illegal, oil-related activities which also have serious environmental consequences.

3.3 Structure of the study team

A major scientific study of this complexity, with extensive geographical and thematic scope, can only be executed using a large team equipped with diverse skills and expertise. The task required scientific teams to work side by side with support teams composed of community, logistics and security personnel. This demanded a high level of coordination and oversight. At the peak of its work, the Ogoniland assessment team numbered over 100 people, with daily convoys into the field requiring up to 15 vehicles. The study team was organized as follows.

Project management

The study team was managed by an international UNEP project coordinator in Port Harcourt. The project was overseen by UNEP's Post-Conflict and Disaster Management Branch, based in Geneva, in conjunction with the UNEP headquarters in Nairobi.

Technical teams

Fieldwork was conducted simultaneously by technical teams covering four thematic areas: **contaminated land, water, vegetation** and **public health**. Each team was composed of international experts supported by national experts, employed by UNEP as project staff, and by senior academics and technicians primarily from Rivers State University of Science and Technology (RSUST).

As the assessment of contaminated land was the most critical part of the assessment, the **Contaminated Land Team** contained the largest number of international experts, primarily contaminated site assessment professionals with extensive experience.

Early morning field trip by members of the aquatic team, Khana LGA, August 2010

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Professor Roselyn Konya, Bishop Matthew Kukah, Chairman of the Presidential Implementation Committee, and HM King Gininwa attending a project briefing at State House, Abuja, August 2010

The Aquatic Team dealt with issues of surface water, sediments and aquatic biota, and was led by experts from the World Maritime University in Sweden.

The **Vegetation Team** was led by an international expert from Bern University in Switzerland and the team's studies covered agriculture, forestry and mangroves, all important aspects of the interface between environment and livelihoods.

The **Public Health Team** looked primarily at air quality as well as public health impacts associated with environmental conditions in Ogoniland. The team was led by an international expert from Boston University, USA and supported by an expert team of Nigerian nationals.

Cross-cutting teams

Working in parallel with the thematic teams were a number of smaller teams whose role was to provide data on cross-cutting issues. These involved **remote sensing** (analysis of satellite imagery and provision of aerial photography); **legal and institutional reviews**; and **community surveys** undertaken by RSUST to establish the level of local environmental knowledge and to understand local concerns and perceptions of issues related to the oil sector. In addition, a team of Nigerian nationals, led by an international laboratory expert, ensured that all **samples of water, soil, sediments and fish tissue** collected by the thematic teams reached the correct laboratories for analysis within the shortest possible time, together with appropriate documentation and in compliance with relevant international protocols.

Support teams

A series of support teams provided specific services to the thematic teams, helping to ensure timely completion of project assignments. These teams covered:

- **Well-drilling**. Assessment of contaminated water, soil and sediment, as well as understanding the shallow geology of the Niger Delta, required a large number of groundwater monitoring wells to be drilled throughout the study area. Following an international bidding exercise, this work was assigned to Fugro International (Nigeria).

Members of the UNEP project team with Rivers State University of Science and Technology academic staff and students

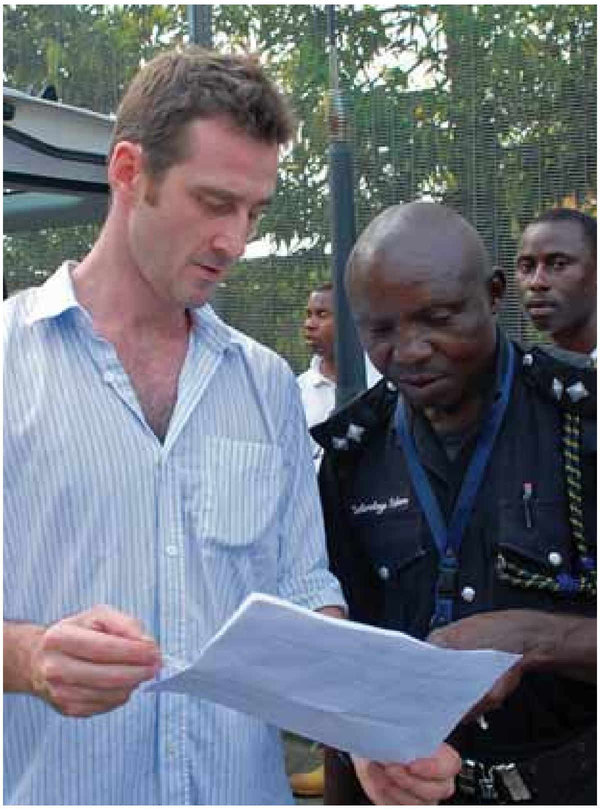
UNEP team preparing to depart into the field

- **Topographical surveys**. In order to obtain information about groundwater flow directions and quantitative information on subsurface contamination, an accurate topographic survey of selected locations throughout the study area was necessary. This work was undertaken by Universal Survey Services (Nigeria).

- **Data management**. The survey generated large quantities of scientific data in various formats, varying from completed site checklists in paper format to video records of aerial surveys. A team of national and international data experts ensured that all data collected in the field were backed up as quickly as possible on a local server at Port Harcourt, with a secondary back-up in Geneva. The Data Management Team also verified the completeness of information provided on field data sheets and cross checked the accuracy of the sample identification codes with corresponding GPS data.

- **Health, safety and logistics**. The work undertaken by the study teams was carried out in an area with serious challenges to public health, road safety and personal security, with personnel arriving and departing via the international airport in nearby Port Harcourt. A project office comprising over 30 national staff was established to assist the dozens of experts, national and international, who were constantly moving around the study area, visiting multiple sites each day. A team of safety and logistics experts was on hand throughout the fieldwork period. At the peak of the project, up to 15 vehicles were in use for fieldwork, airport pick-ups and office runs.

- **Security**. UN Department of Safety and Security (UNDSS) guidelines were followed throughout the project and operational safety was provided by the Nigerian Government. Through the cooperation of the Governor of Rivers State, a contingent of 16 Nigerian Mobile Police (MOPOL) officers provided security cover during all field deployments, as well as travel to and from the project office, accommodation and the international airport.



A project team safety and logistics expert and MOPOL superintendent discussing field trip plans

- **Land access.** Facilitating access to specific sites where UNEP specialists needed to collect data was a major exercise and one that needed to be handled delicately as ownership was not always clear, with attendant potential for local conflict. Multiple negotiations were often required, involving traditional rulers, local youth organizations and individual landowners or occupiers. A Land Access Team, provided by RSUST, working in conjunction with UNEP's Communications Team, managed these challenging issues, explaining precisely what the UNEP team would be undertaking, where and at what times.

- **Community liaison and communication**. The environmental assessment of Ogoniland was constantly in the public eye, such that there was continual demand for information. A dedicated Communications Team consisted of UNEP communications staff and community liaison staff who were familiar with the local languages. The team was responsible for explaining the purpose of the project and the specific activities to be carried out and for

UNEP distributed project information as part of its ongoing outreach to local communities ensuring that entry of the scientific teams into any community had the necessary approval from all sections of the local population (LGAs, traditional rulers, youth, police, etc.). The team provided regular project updates, for example online at the project's dedicated website and via a monthly newsletter, and also sought ongoing community input.

- **Administration**. The Administrative Team included staff from UNEP and the United Nations Development Programme (UNDP) and was based in three geographical locations: a project office in Port Harcourt, with support teams in Abuja and Geneva, which between them covered critical functions such as finance, travel, human resources and procurement.

- **Presidential Implementation Committee (PIC).** The PIC met periodically, typically once every quarter, and was briefed by the project coordinator on progress, challenges and impediments, and future work programmes.

Use of local resources

It was decided during the project planning phase that the team of international experts leading the assessment would work closely with local institutions. In addition to helping to secure the success of the project, this would enhance local capacity building and resource-sharing opportunities. The participation of local institutions was achieved in several ways. Firstly, 30 national staff were engaged in various capacities (technical, logistics, security, liaison, administrative) as part of the UNEP project team in Port Harcourt. Secondly, UNEP formed partnerships with the four LGA secretariats,

The UNEP-Rivers State University of Science and Technology Project Collaboration Coordinator, Mrs Iyenemi Ibimina Kakulu, and the university's Vice Chancellor, Professor Barineme Beke Fakae

UNEP experts during a reconnaissance exercise at Ebubu Ejama, Tai LGA, in January 2010 through their respective chairmen, which enabled access to local community leaders and gave UNEP a presence in each LGA, where its community liaison staff were allocated office space. Thirdly, each of the international thematic teams was paired with local experts and academics provided by RSUST, giving the teams ready access to local knowledge and sites, while RSUST students were brought in as technical assistants both in the field and in the project office. In addition, support teams were recruited locally wherever possible to undertake specific assessments.

Laboratories

Another decision taken early in the planning stage was that all analyses of samples collected during the study would be carried out, wherever technically feasible, by international laboratories with appropriate accreditation, in order to ensure quality and independence. Two separate laboratories were contracted: Al Control Geochem, United Kingdom, an ISO/IEC 17025:2005-accredited laboratory; and ALS Scandinavia AG, Sweden, a specialist in fish tissue analysis. NORM analyses were done at the Spiez Laboratory in Switzerland, which is also accredited to ISO 17025.

3.4 Assessment methodologies

The wide scope of the environmental assessment of Ogoniland, both geographically and thematically, is evident from Chapter 2 and sections 3.1 to 3.3 above. To overcome the challenges this presented and to achieve satisfactory outcomes for all parties involved, it was clear from the outset that a combination of standard approaches as well as innovative methodologies would be needed.

A training session at Port Harcourt, October 2009, was part of UNEP's commitment to capacity building

More than 4,000 people attended a town hall meeting at Bori, Khana LGA, in November 2009, at which the UNEP assessment project was launched. Pictured (from left to right) at the event are Senior Special Adviser to the President, Magnus Kpakol; MOSOP President, Ledum Mitee; HM King Gininwa; and HM King Barnabas B. Paago Bagia, Gbenemene Gokana

The different disciplines conducted investigations within their individual specialisms, backed by well-resourced support teams. While everything possible was done to enable interdisciplinary learning in terms of both approach and substance, the various strands had to work in parallel to complete the assessment within a reasonable time frame. Completion of the project was achieved in three phases:

1. **Scouting/reconnaissance exercises**. A team of experts conducted a series of scouting missions to the region, with two aims: (i) to become familiar with the area and (ii) to obtain community acceptance for the assessment. This was followed by structured reconnaissance of the areas where information about an oilfield facility or an oil spill incident already existed. The information documented from questionnaires and photographs allowed prioritization of a number of sites for follow-up assessment.

2. **Intensive fieldwork**. Individual thematic teams (covering soil and groundwater, water/aquatic life, vegetation, and public health), backed by cross-cutting issues teams and support teams, were deployed for the months of intensive field and office work.

3. **Analysis and writing of the report**. The teams were brought together to assess progress and review the initial analytical results. Based on this review, a final round of data gathering and analyses was carried out, after which the thematic experts prepared the individual contributions that form the basis for this synthesis report.

Phases 1 and 2 are described below in more detail. Phase 3 results are presented in chapters 4 and 5.

UNEP opened its project office in Port Harcourt in October 2009. In November 2009, senior UNEP staff met with key stakeholders in town hall meetings in the four local government areas (Eleme, Gokana, Khana and Tai). The final sampling visit was completed in January 2011. The period of most intensive fieldwork ran from April 2010 to December 2010.

Community engagement

In terms of stakeholder interest, the environmental assessment of Ogoniland was unlike any other environmental assessment previously undertaken by UNEP. In particular, it warranted community involvement and updates at all stages. This almost continuous engagement gave UNEP access to vital local knowledge concerning areas contaminated by oil, as well as consent for access to land and waterways for study purposes.

Public meetings staged throughout Ogoniland during each phase of the study helped to build understanding and acceptance of the project and to foster community participation. Between November 2009 and January 2011, more than 23,000 people participated in 264 formal community meetings (Table 6). Initially town hall meetings were held in each LGA with over 15,000 people participating. These meetings were then followed up with a series of sensitization sessions, or secondary meetings, in villages and community centres.

To provide an additional forum for open discussion of issues surrounding the study, UNEP formed a Community Consultation Committee composed of representatives from a wide cross section of project stakeholders. The committee met on average once every two months.

Table 6. Public meetings held to engage communities in Ogoniland

LGA	Number of meetings held	Number of people present
Eleme	52	3,323
Gokana	87	5,552
Khana	55	9,107
Tai	70	5,289

UNEP project team members meeting with community women leaders, November 2009

UNEP community liaison assistant addressing a public meeting, Gokana LGA, April 2010

Eight schools in Ogoniland took part in the pilot phase of a schools programme called 'Green Frontiers', initiated by UNEP to raise environmental awareness among Ogoni children and youth and to inspire practical action for conserving their environment.

Great care had to be exercised in areas where internal frictions surrounding the UNEP assessment were apt to arise. In many cases this meant that even though permission was granted initially, the project team had to withdraw as tempers became frayed. UNEP's community liaison staff were key intermediaries between the project team, local leaders and interest groups, helping to broker agreement. While team members were never at serious risk of physical attack, UNEP had to remain vigilant that a project aimed at peace-building should not engender division or violence.

3.5 Phase 1: Scouting exercises, desktop reviews and reconnaissance

The initial part of the project involved visits to the study area by experts with a view to understanding the key issues, geographical scope and practical constraints – fundamental to designing the appropriate methodology for the assessment. Scoping exercises were done in two stages: an aerial survey of the study area (Map 5), including SPDC facilities, followed by ground visits to look at oilfield infrastructure, contaminated sites and pollution-affected creeks. Where available, anecdotal information about environmental damage in Ogoniland informed this work.

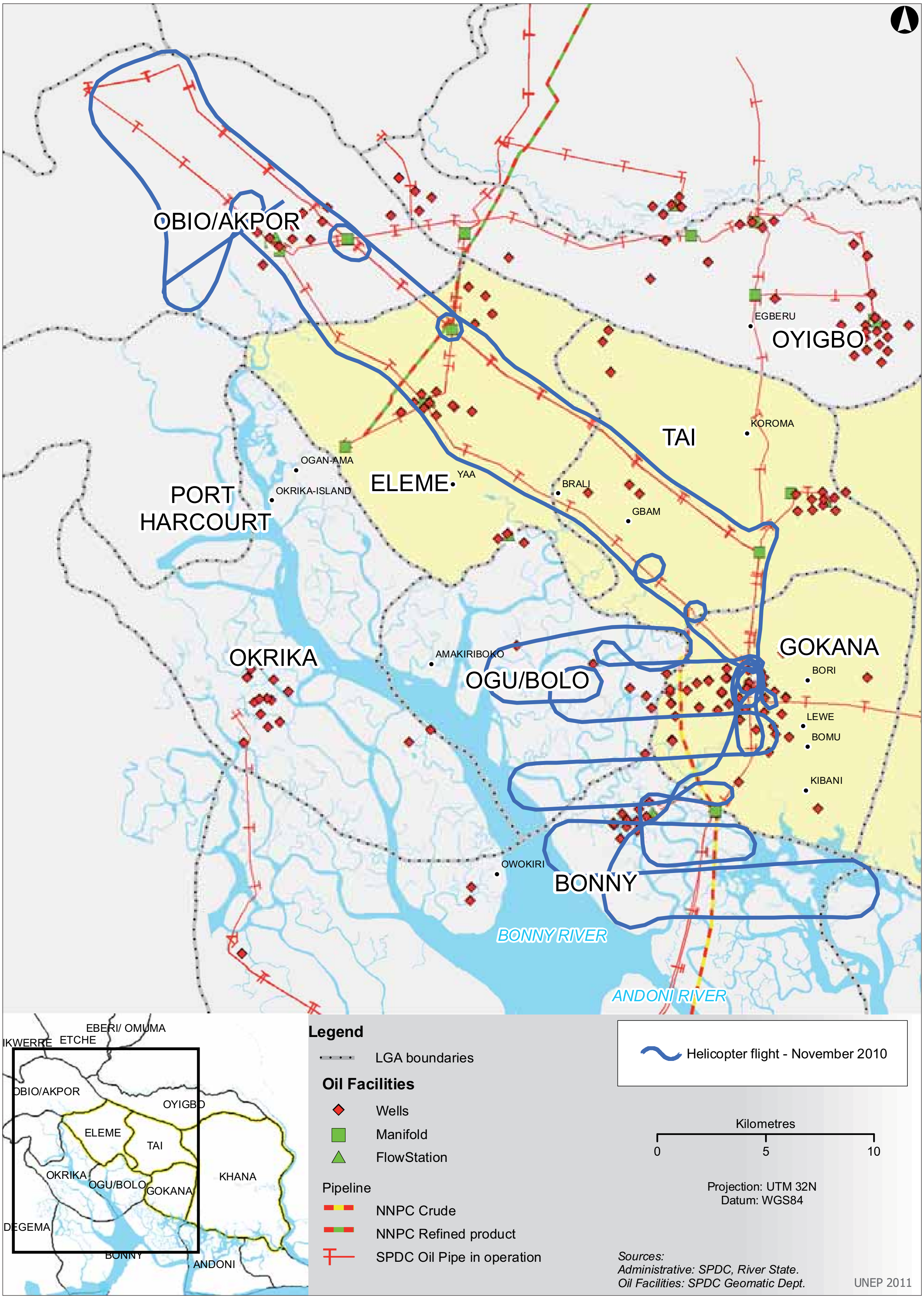
Once the scouting survey was completed, a desktop review was conducted of all available information on oilfield infrastructure in Ogoniland and known associated environmental contamination. Information on oil spills came from the SPDC oil spill database, air and ground observations by the UNEP team, information provided by local communities and information gathered from satellite images. All accessible oil wells and pipelines were visited, even if there were no reported spills at these locations.

With all the initial information assimilated, a three-step reconnaissance phase began:

1. Town hall meetings with community leaders (kings, chiefs, representatives of community elders, women and youth leaders) at which UNEP community liaison staff gave background information about the study, the tasks to be performed and the approach to be taken by the UNEP assessment teams

A UNEP technical team examines infrastructure during the reconnaissance phase

Map 5. Typical helicopter routing for aerial observation



2. Verification of landowners by land access staff who negotiated access to property and scheduled site visits

3. Location of reported spill points identified by an advance party comprised of national UNEP technical staff

With the preparatory work done, UNEP technical teams started to visit sites, equipped with standard questionnaires, GPS and GPS cameras. The basic information collected about each site included GPS coordinates, photographs, proximity to oilfield facilities, proximity to communities, any other significant environmental features, and matters of importance from a logistics and security point of view. In all, 202 locations were visited and 122 km of pipeline rights of way were surveyed.

3.6 Phase 2: Intensive fieldwork

Once the data from the reconnaissance phase had been consolidated, a prioritized list of sites for follow-up assessment was drawn up, based on the observed contamination, potential receptors and size of the impacted area. A total of 69 contaminated land sites were shortlisted for further investigation (Map 6 and see also section 4.4). Of these 67 sites were situated close to oil industry facilities. Subsequent site visits to these locations were carried out after further negotiations with, and permissions from, the appropriate communities.

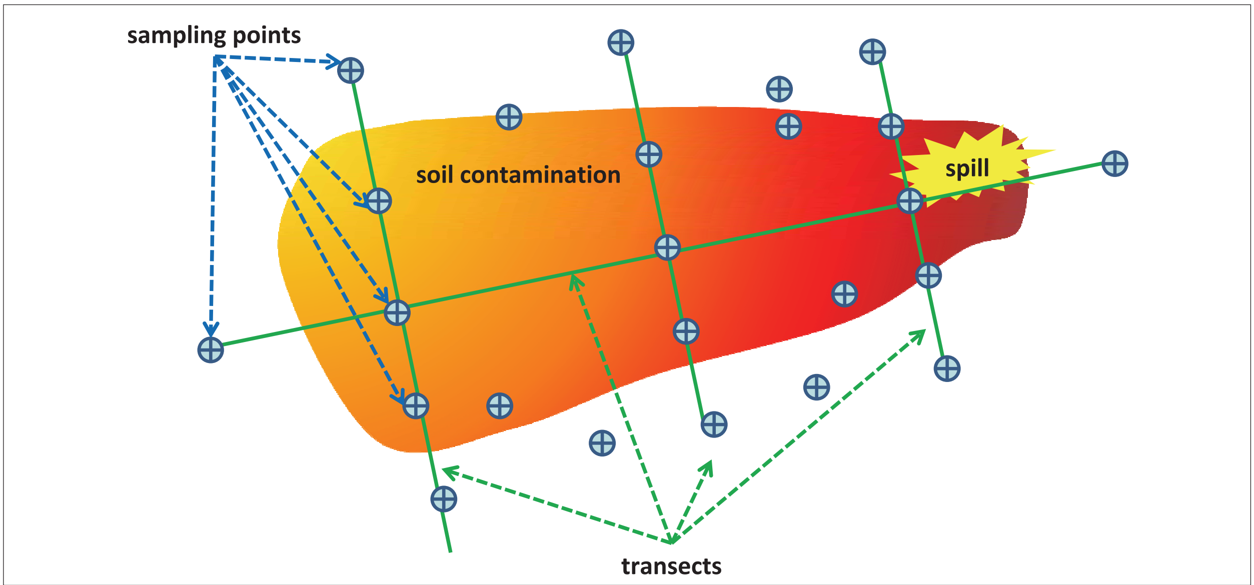
During the course of the second visit, locations for groundwater monitoring wells were delineated and the landowners involved were consulted about the planned works.

Inevitably, additional information gathered from on-site observations and field testing made it necessary to modify the work programmes at different sites, making site access and site characterization an iterative process. To achieve this, the teams on site were required to have expertise in analytical chemistry, geology, geochemistry, hydrogeology and risk analysis.

Assessment of soil contamination

The objective of site-specific sampling was to identify: (i) whether a site was contaminated and (ii) if so, whether the contamination had migrated laterally and vertically. In many instances the pollution was found to have spilled over into nearby creeks and, in the case of older spills, vegetation had started growing again. Thus it was not always easy to identify the geographical extent of a spill. Given the security conditions, access restrictions and the large number of sites to be investigated, the UNEP team could only stay at a specific site for a limited duration, often just one day. Consequently, an adaptive sampling strategy was the norm for the sites assessed, the priority being to identify the epicentres of pollution and the depth of penetration. A combination of deep sampling and surface

Figure 3. A conceptual description of typical positioning of soil sample boreholes



Map 6. Contaminated land sites investigated by UNEP

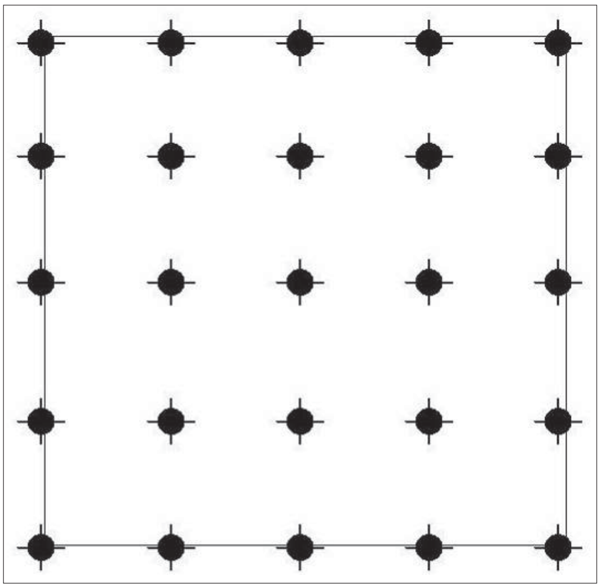
sampling was undertaken. The approach was always to identify the primary direction of spill migration and carry out cross-sectional transects covering the polluted area (Figure 3). However, this strategy often had to be modified to adapt to the prevailing ground situation and time constraints. Where the ground situation had unusual features, such as a waste pit or swamp, samples (often of sediment) were taken from the most accessible part of the area.

Using hand augers operated by two trained assistants, soil samples were taken out of the boreholes and spread onto a polythene sheet. The soil was segregated typically into intervals of 60 cm and samples were collected from each interval for analysis. In the first round of investigations, sampling was only carried out to a depth of 2 metres. However, after review of early results, the sampling depth was increased to 5 metres. Where monitoring wells were drilled, deeper soil samples were also collected.

In situations where extensive surface contamination was observed, composite soil samples were collected for analysis (Figure 4). In this situation, special grass plot sampling equipment was used to gather samples from a number of points. The individual samples were then amalgamated to form a composite sample. These samples are also referred to as grass plot samples.

All soil samples were analysed for hydrocarbons and non-hydrocarbon parameters.

Figure 4. Grid of soil samples for a composite sample



A soil sample is spread onto a polythene sheet

Assessment of groundwater contamination

On larger and more heavily contaminated sites, groundwater monitoring wells were installed by Fugro. This process was based on an adaptive sampling strategy. The primary intent was to verify if there was indeed groundwater contamination and if yes identify the farthest reach of the pollutant plume (Figure 5). The wells drilled by a contractor using hand-augering systems followed standard monitoring well construction practices. Wellheads were secured with lockable covers.

Subsequent to the initial phase of the assessment, 25 per cent of the wells were found to have been vandalized, making samples from such wells unreliable for inclusion in the final report. A decision was therefore taken during the later phase of the analyses to take water samples from boreholes on the same day that the boreholes were drilled. No wells were installed in these locations.

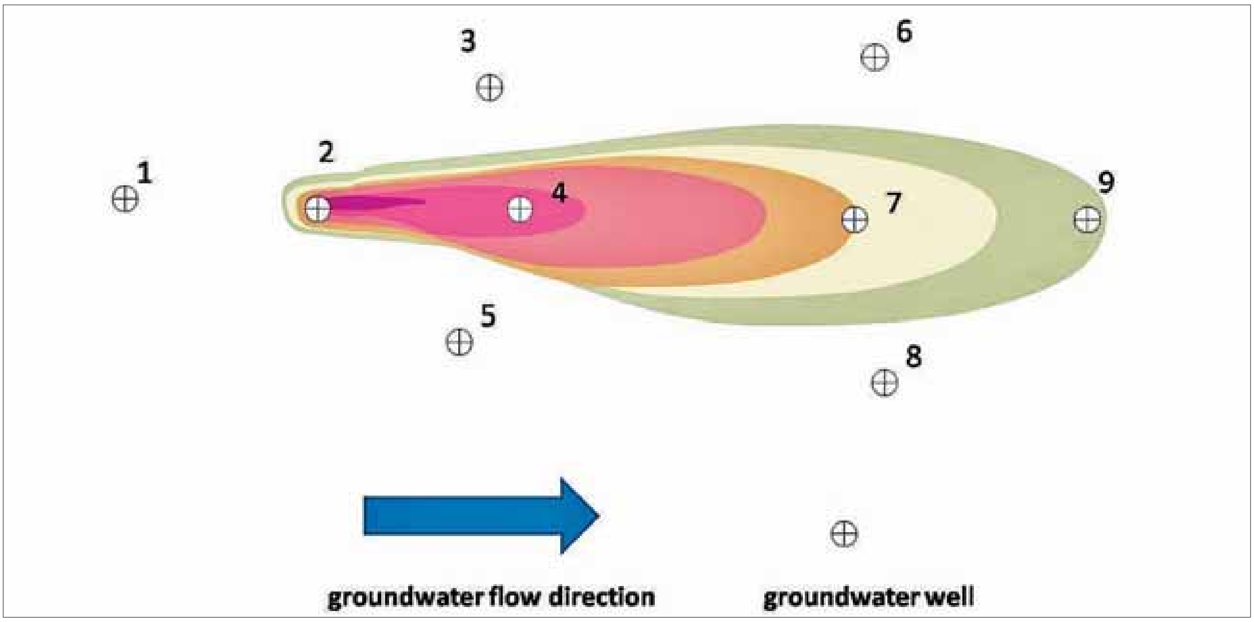
Fugro staff installing a groundwater monitoring well, April 2010

To widen the monitoring of groundwater, a number of existing community wells (both dug wells and boreholes) were included in the sampling. To ensure proper quality control, each groundwater well was given a unique identifier, marked inside the well cover. During sampling, the well identifiers were noted in the sampling protocol. An interface meter was used to measure the depth to groundwater in the wells and to verify the presence and thickness of any floating hydrocarbon product in the groundwater. Groundwater sampling was carried out with bailers. Conductivity, pH, temperature and oxygen were all documented, along with the depth to the groundwater table. When a floating free product was observed, the groundwater underneath the floating layer was not collected.

The equipment used to measure water levels was properly decontaminated between samples to avoid cross-contamination. For the same reason, disposable bailers were used for each well. Where used, the foot valve pump and hose were left securely inside the well for return visits.

All water samples were analysed for a series of hydrocarbon and non-hydrocarbon pollutants. As with the soil and sediment samples collected, each sample was assigned a unique identification number and the exact location was registered.

Figure 5. Contaminant plume and groundwater monitoring well configuration



Assessment of naturally occurring radioactive materials

An assessment of naturally occurring radioactive materials (NORM) in the study area was carried out by an expert accredited under ISO/IEC 17025:2005 between late November and mid December 2010. Wellheads, pumping stations and fresh and old spill sites were sampled. Dose-rate measurements, including surface contamination measurements, were performed at each location. In addition, freshly spilled crude oil at one site, old crude oil from a closed pumping station at another site and crude oil-contaminated soil from an old spill site were also collected [33]. For analytical purposes, a zero-reference soil sample (an old termite mound) was taken from a clearly uncontaminated location in the assessment area.

Assessment of surface water and sediment contamination

The study area was bounded on two sides by open water bodies, the Imo River on one side and a network of creeks on the other. The creeks wrapped around the study area but also extended via small side arms into inland areas. Neither the river nor the creeks were confined to the study area; the Imo originating beyond Ogoniland and flowing past it before reaching the sea and the creeks extending through and interconnecting with numerous other branches in other areas of Ogoniland.

Surface water contamination was assessed by: (i) aerial observations over the creeks, (ii) observation of water bodies from boats, (iii) observation of water bodies from land, (iv) water quality monitoring and (v) monitoring of sediments. The first three approaches were primarily based on visual observations and documented by photography. Water quality monitoring was conducted using a combination of field kits and laboratory analysis of samples taken. The monitoring of sediments was done entirely by laboratory analysis of samples.

In terms of visual observation, the focus was on identifying the presence of hydrocarbons on the surface of water bodies and, where possible, identifying the possible source of the contamination. Hydrocarbons can form very thin layers in water bodies and are therefore distinct enough to be noticed even at very low concentrations. Hydrocarbon layers were photographed using a GPS camera, which automatically fixed the coordinates.

In terms of field monitoring, a portable multi-parameter analyser was used to collect information on pH, temperature and conductivity, and the coordinates of sampling locations were logged.

Surface water sampling

In order to determine contamination of surface water samples were taken from estuaries, rivers, streams and ponds (Map 7). Samples were collected as near to the middle of the water body as could be reached using wading gear and a 2-metre extendable metal grab. Samples were collected against the flow of the water, where any flow was discernible. The sampling bottles were submerged to a depth of 10-20 cm under the surface and rinsed once with the water at that depth before the water sample was taken. If a boat was used, samples were collected at 50 cm depth by a Limnos water collector.

UNEP technical assistant collecting surface water sample

Map 7. Location of surface water, sediment and fish sampling

Sediment sampling

Areas of calm water where sedimentation occurs may accumulate pollutants which are later released through re-suspension due to tidal mixing or flooding after heavy rains or as a result of biological processes. Suitable areas for the collection of accumulated pollutants in the bottom sediment are therefore sites which consist of fine organogenic mud, sand and silt.

Sediment samples were collected at 37 locations (Map 7). At each location, five sub-samples were collected in a plastic bucket and mixed before being transferred to a glass sampling jar. In most cases a piston sampler with a diameter of 6 cm was used for sampling. Only the top 10 cm of the sediment core were used for the samples and care was taken to avoid flushing away the surface floc on top of the more solid sediment. In some locations deeper cores were taken to examine whether pollution had penetrated further down. The samples were stored frozen until the analyses were performed.

Assessment of fish contamination

In order to determine the concentrations of pollutants in the tissues of fish and shellfish, samples were collected for analysis of petroleum hydrocarbons, including PAHs.

Fish and shellfish were collected from 28 sites (Map 7), usually where sampling of water and sediment were carried out. In most cases, fish were purchased directly from local fishermen either in the process of fishing or transporting fish they had just caught. A number of fish samples from unknown origins were also purchased from local markets; although these samples could not be used to determine pollution at specific sites, their value lay in demonstrating health risks to the community where fish were found to be contaminated.

For analytical purposes, tissue samples from four to six different fish were pooled to form a composite sample. Fish tissues were obtained by cutting the dorsal muscle from the fish with a

Sediment samples were collected at 37 locations

A snapper (genus Lutjanus) is dissected for analysis. Fish and shellfish were collected from 28 sites

scalpel and transferring it to a glass jar. In most cases about 50 g of tissue was collected for each sample. All the samples were frozen and shipped to the laboratory following standard quality-control procedures.

Each sample was analysed for metals, extractable hydrocarbons, PAHs and pesticides, following internationally recognized analytical methods. The samples were homogenized prior to analysis. Preparation of samples (homogenization, extraction and clean-up) was carried out in a laboratory room used exclusively for biotic samples. Specially pre-cleaned glassware was used for organic analyses, and specially pre-cleaned Teflon beakers were used for analysis of metal samples. All preparation and analysis were carried out in a clean room environment.

PAHs and chlorinated pesticides were analysed by a process of chemical extraction, evaporation and measurement through gas chromatograph equiped with a mass spectroscopy (GC-MS). Petroleum hydrocarbons were also solvent extracted and analysed using a similar process, through a gas chromatograph-flame ionization detector (GC-FID). Samples were analysed for metals using high-resolution inductively coupled plasma mass spectroscopy (ICP-MS).

Assessment of impact of oil contaminants on vegetation

Two types of impact can be distinguished: (i) impacts related to physical disturbance, such as the cutting of seismic lines and seismographic survey, development of access infrastructure (roads, dredging of channels in wetlands) and drilling; and (ii) impacts related to oil spills and fires and disposal of other hazardous materials.

From a livelihood point of view, no relevant statistical data were available about the average productivity of agricultural crops and forest trees in Ogoniland and changes over time.

Aerial and field observations were conducted as part of the scouting surveys. Photographic records were gathered along with reference coordinates so as to cross-reference them with observations from other study segments.

Swampland vegetation (Bara, Gokana LGA)

Assessment of damage to mangroves

The scouting missions revealed extensive damage to the mangroves in the Ogoni study area and it was clear that the geographical extent was so wide that a combination of approaches would be needed to assess the overall condition of mangroves. This involved:

- aerial observations (from a helicopter) of the extent of mangrove damage, documented by aerial photography to show the progression of damage from the edge of the water to landward areas
- analyses of high-resolution satellite images to delineate impacted areas and to estimate the total mangrove area impacted by oil
- observations made from both land and water to understand the specific nature of the impacts, documented by photography
- sampling of soil on the substrata of mangrove vegetation, with a view to correlating it with the stresses on the vegetation
- sampling of hydrocarbons attached to the mangrove vegetation

Assessment of impacts on air pollution and public health

The Public Health Team designed an exposure and health questionnaire to ascertain how exposure to oil occurs and whether it is associated with adverse health effects. Students and faculty members from RSUST administered the questionnaire systematically in 10 highly exposed communities across the four LGAs. Reference communities (i.e. one with no documented oil spills or other significant known sources of petroleum hydrocarbons) were also selected (Okwale in Khana, Koroma in Tai and Intels camp in Eleme).

Medical records from four primary health-care centres (one in each LGA) serving the same highly exposed communities and from one primary health-care centre serving the reference community in each LGA were also collected and analysed.

Information from the questionnaire survey and review of medical records was combined with data from field sampling and a comparison made between the highly exposed communities and reference communities to identify any health effects that might be related to oil spills.

Preparatory work

Before gathering medical records or field samples, the Public Health Team participated in focus group discussions and sensitization meetings and listened to community concerns about the effects of oil. This information helped guide the selection of sampling locations and types of sample to be collected.

In addition, and prior to the collection of medical records, J.W. Igbara, working in cooperation with RSUST, undertook a review of public health issues associated with oil production in Ogoniland [34]. This study, which included visits to health institutions and interviews with health-care workers, took into account community complaints about fish kills, impacts on agricultural land, odours, drinking water tasting of kerosene, and a wide range of health effects from mild coughing and eye irritation to death. Many people expressed the view that environmental contamination from the oil industry had caused increased morbidity and mortality. Oral interviews with health-care workers and other key informants provided insights into health-care provision and the prevalence of disease and oil pollution issues in the study area. Some medical personnel believed that industrial activities were the cause of increased frequency of respiratory disorders (e.g. broncho- and lobar pneumonia, upper respiratory tract infections, asthma), skin conditions and gastroenteritis. Some also suggested that environmental contamination might be adversely affecting immune systems, thus increasing susceptibility to infectious disease.

Interviews and questionnaire

The Public Health Team supplemented Igbara's work through interviews with pharmacists, a traditional birth attendant and health-care professionals at facilities serving areas in each of the four LGAs where larger oil spills had occurred (Table 7). Interviewees were asked about the type and number of staff, dates of operation, medical record-keeping protocols, the number of patients seen daily, the number of beds, type of treatment provided and catchment area. There appeared to be five categories of primary health care:

Women leaders at Kpean community, Khana LGA, raising their health concerns during a sensitization meeting

government clinics, private clinics, pharmacists, traditional healers and the church. These are not mutually exclusive and the available options and choices made are changing with time. Choices are based, among other factors, on cost, accessibility, availability of services when needed (e.g. night/day), effectiveness and tradition/cultural preferences. Prenatal (called antenatal care in Ogoniland) care seems to be provided increasingly by government-funded health clinics. At least some government clinics provide free prenatal care and care for young children. However, it was not clear what fraction of the population chooses to give birth at health centres rather than at home and/or with traditional birth attendants.

Responses from community members and medical professionals helped guide selection of both the communities in which an exposure and health survey was conducted by questionnaire, and the health-care facilities where medical records were collected.

The questionnaire was used in those communities expected to have incurred some of the highest exposure to petroleum from oil spills, and included some of the communities in which air sampling and medical record collection were implemented. The questions asked – based on meetings with community members, community leaders and health-care providers – covered the respondent's demographic characteristics; pathways of exposure to petroleum from oil spills and other sources of petroleum hydrocarbons (e.g. cooking practices, smoking, local food consumption, drinking water source); and health information (e.g. health history and current symptoms, source and level of satisfaction with health-care services). Respondents were not asked directly about oil contamination.

The questionnaire was reviewed by two individuals with detailed knowledge of the community being studied, and pilot-tested by several Ogoniland residents working in UNEP's project office. RSUST students, who had been given advance training to ensure accuracy and consistency, conducted the questionnaire survey orally, with the assistance of an interpreter where needed. Heads of household were interviewed systematically until approximately 20-25 per cent of the dwellings in each community had been covered.

Table 7. Summary of samples collected by the Public Health Team

LGA	Community	Village	VOCs	$PM_{2.5}$ & PM_{10}	Rainwater	Drinking water	Medical records	Health questionnaires
Eleme	Agbi-Ogale				x	x		
	Agbonchia	Okpee	x		x			x
	Akpajo	Nsisioken	x	x	x			
	Aleto		x	x				
	Alode	Nkeleoken	x	x				
	Ebubu	Ejamah	x	x	x		x	x
	Ebubu	Obolo		x				x
	Ebubu	Oyaa-Ejamah	x					
	Ebubu	Egbalor						x
	Obajioken-Ogale				x	x		
		Ekporo		x				
Tai	Biara/Botem		x	x				
	Gio		x	x				
	Korokoro	Aabue	x	x	x	x		x
	Koroma		x	x				
	Kpite	LGA Headquarters	x	x			x	
	Kpite	Muu Boogbara	x		x			x
	Sime	Omunwannwan	x					
	Sime	Aabue						
	Norkpo 1		x		x			
Gokana	K. Dere		x		x			x
	B. Dere		x					
	Bera							x
	Bodo	Debon	x	x				x
	Bodo	Sugi-Sivibirigbara	x				x	
	Bodo	Kegburuzo Junction	x					
	Bodo-West		x	x				
	Kpor	Orboo-Ooodukor	x	x				
	Kpor	Kpalaade	x	x				
Khana	Kwawa	Wiikuekakoo	x		x			x
	Kaa							x
	Kpean	WIIYAKARAGU		x		x	x	
	Kpean	Wiiborsi	x	x	x			x
		Uewaagu	x	x				
	Okwale		x		x		x	x
	Port Harcourt	RSUST-Nkpolu-Oroworukwo	x	x				
		Intels Camp	x					

Field sampling and analysis

All field sampling took place between July and December 2010 in those communities where bigger oil spills had occurred. Sampling locations were selected according to information gathered from community members, community leaders and health-care providers, as well as from environmental monitoring data and historical information that indicated the location and extent of oil spills. The sampling programme is summarized in Table 7.

The Public Health Team's environmental monitoring programme included collection of drinking water and rainwater used for domestic purposes and measurements of outdoor air from both highly exposed communities and reference communities. These samples, combined with samples of soil, sediment, surface water, drinking water, groundwater, fish and agricultural crops collected by other UNEP scientists from the same or nearby communities, shed light on human exposure to oil-related contamination. Together these samples allowed for assessment of cumulative exposure across different media including soil and drinking water.

Rainwater and drinking water

Sampling of drinking water was warranted given that UNEP detected petroleum hydrocarbons in surface water and groundwater samples. In response, the Public Health (PH) Team collected drinking water samples in addition to those already collected by the Contaminated Land (CL) Team.

Some community members expressed concern about rainwater quality, reporting that they historically used rainwater for drinking and other purposes, but that it is now contaminated and can no longer be used for this purpose. In response to this concern, UNEP collected 35 rainwater samples from rainwater collection vessels and three rainwater samples directly from the atmosphere.

Rainwater from collection vessels represents actual exposure because people are using it for washing, bathing, cleaning food and drinking. These samples reflect any contamination that originates in the rainwater, from the rainwater catchment system, and, if the collected rainwater is uncovered for any period of time, from contamination that deposits from the air (e.g. bird droppings). Most often, the catchment system collected rainwater from a roof into a metal or plastic collection vessel. Samples of rainwater collected directly from the atmosphere reflect contamination found in rainwater in the absence of any contribution from a catchment system and/or aerial deposition onto uncovered rainwater storage vessels.

Drinking water and rainwater sampling locations included places where the community had complained about rainwater quality; this applied also to the reference community. Drinking water and rainwater from collection vessels were sampled and analysed using the same methods employed by the Contaminated Land Team. Rainwater was sampled from the atmosphere using stainless steel containers placed on a stool 1 metre off of the ground in an open area without trees or other elevated vegetation or structures. The time between onset of direct collection of rainwater and storage of the rainwater in a freezer ranged from a matter of minutes to six hours, depending on how long it took to collect a sample of sufficient quantity and transport it to the freezer.

Rainwater and drinking water samples were not filtered before laboratory analysis.

UNEP expert consulting health-care centre staff

Outdoor air

Oil spills can influence air quality. Ubong (2010) reviewed air quality data available for Ogoniland, some of which reflected conditions near oil spills, including some measurements of total VOCs [35]. UNEP's air sampling programme expanded on this work by collecting air samples from spill areas where the highest concentrations of petroleum hydrocarbons were expected in air, based on results from UNEP's investigation of soil and surface water. Priority was given to locations where UNEP detected and/or observed the highest concentrations of oil contamination on or near the ground surface or sheens on surface water. In addition, air samples were analysed for individual VOCs rather than total VOCs because the toxicity of total VOCs depends on the composition of the mixture.

The outdoor air sampling programme is summarized in Table 7 and Map 8. It included 22 VOC samples from oil spill areas, 20 VOC samples from nearby communities, 2 VOC samples from reference locations and 23 respirable particulate samples from oil spill areas and nearby communities. Nearly all the samples were collected during the dry season, which lasts from March to November. However, two sampling locations were re-sampled in December to allow for comparison between wet season and dry season air quality.

On each sampling day, air samples were collected from the oil spill area and from the community area nearest the oil spill. Samples from the oil spill location provided a 'fingerprint' of VOC release from the worst oil spills in each LGA. Samples taken from the closest community location provided measures of exposure to these worst spills, combined with background exposure from other sources of petroleum hydrocarbons, such as vehicle exhausts. Air samples were also collected from the reference community in Okwale; these samples represented conditions in Ogoniland with limited land development and no known petroleum-related operations, both of which can influence the concentration of petroleum hydrocarbons in air. Air samples were also collected from two urban reference locations just outside Ogoniland, at the Intels Camp and RSUST Campus in Port Harcourt.

A Thermo Scientific Particulate Monitor DataRAM 4 is used to measure air quality, Bodo West

Map 8. Location of air quality and public health studies

Samples were collected and analysed for selected VOCs using USEPA Method TO-17, which involves sampling with thermal desorption tubes and laboratory analysis with gas chromatography/mass spectroscopy. Thermal desorption sampling tubes were manufactured by Markes International (Markes Part No: CI-AAXX-5017 Stainless Steel TD sampling tube (industrial standard 3 1/2 "x1/4"; prepacked with Carbopack [Mesh 60/80]) and conditioned and capped with brass long-term caps. Air was drawn through the thermal desorption tube at a flow rate of approximately 50 ml per minute using an SKC AirCheck 2000 pump. The sampling train was affixed to ladders to elevate sample tubes to about 1.5 metres (i.e. approximate breathing height). The pump calibration was checked in the field at the beginning and end of each sampling period. A dual tube sampler was set up at each sampling location, with one tube sampled for approximately one hour and the other tube sampled for approximately four hours from mid-morning to mid-afternoon. Security constraints prevented longer deployment of air samplers, though desired laboratory detection limits were still achieved. One field blank tube was collected on each sampling day.

Air concentrations of respirable particulate matter ($PM_{2.5}$ µm and PM_{10} µm) were measured at each community sample location on each air sampling day using a DataRam4 (Thermo Electron Corporation, DR-4000 Model). $PM_{2.5}$ and PM_{10} concentrations were each measured for a ½-hour to 1-hour period with the instrument elevated to an approximate breathing height of 1.5 metres.

Particulate sampling locations largely overlapped VOC air sampling locations and included areas with varying amounts of nearby vehicle traffic, waste burning and garri (cassava) processing, all of which can contribute to particulate concentrations in air. In all locations the DataRam4 was placed in open, outdoor areas. The ground surface varied widely among sites, from sand to dense vegetation.

Medical records

The Public Health Team considered that medical records could be helpful in identifying unusual symptoms or disease patterns associated with living near oil spills. Many community members reported that they sought health care from pharmacists and traditional healers, but the team did not find evidence that these providers maintained patient or client records. Some general hospitals and primary health-care centres held records for as long as 10 years, some even longer, while others only had records for the previous six months. Medical records available at primary health-care centres and general hospitals generally included the patient's name, age, sex, community and LGA names, complaint or diagnosis, and treatment. Some included additional information such as body weight and occupation. Diagnoses are not confirmed by testing at primary health-care centres.

All records reviewed by the Public Health Team were maintained in handwritten log books and summarized on forms provided by the Rivers State Ministry of Health. The primary health-care centres were selected for collection of medical records because, unlike general hospitals, they serve localized areas that could be matched to oil spill locations. In addition, a general hospital that served the reference community could not be identified.

The team selected one primary health-care centre from each LGA that serves communities where large oil spills had occurred and a fifth primary health-care centre in the reference community. Medical records for the previous year (i.e. 1 September 2009 to 31 August 2010) were collected using a portable scanner so that data analysis could be performed using original records. As noted earlier, some medical facilities maintain records for as long as 10 years, but many do not. Therefore, the one-year period was selected because most primary health-care centres keep records for this length of time, allowing for comparison among them.

UNEP expert examining medical records in a handwritten log book

Table 8. Location and number of health records collected

Primary health-care centre	Number of medical records analysed
Agbonchia	1,196
K'Dere	1,581
Kpite	543
Kwawa	1,421
Okwale	268

After agreeing to participate and indicating that records were available for the previous year, the primary health-care centre in Agbonchia, Eleme could not provide records prior to February 2010, despite repeated attempts to obtain earlier records from current and retired staff. There was insufficient time within the study schedule to select and collect records from an alternative centre. While these missing data are important from a temporal perspective, their exclusion did not adversely affect the number of records relative to other primary care centres. The total number of records analysed for each primary health-care centre is given in Table 8, with differences attributable to the relative number of records available from each centre.

Original medical records were transcribed onto a single database (in Microsoft Excel) and a subset of records from each primary health-care centre was reviewed to ensure accurate data entry.

Remote sensing

The components of the environmental assessment of Ogoniland in which remote sensing (Table 9) played a key role were: land-use study, for example tracking changes in land cover; vegetation surveys, including impacts of oil on mangroves; assessing pollution of creeks and other water bodies; and research into the artisanal refining of crude oil in primitive stills (see 'Artisanal refining', page 102).

Unlike all other components of UNEP's study for which it was only possible to obtain a snapshot at the time of the assessment, for those issues studied through remote sensing analyses of changes over time were achievable. However, since satellites did not exist when oil industry operations commenced in Ogoniland in the 1950s, a baseline comparison dating back to this period was not possible.

In addition, satellite images were used intensively as a primary source of information for daily operations in the field. These included:

- navigation, from scouting exercises through to full site assessments
- land-cover mapping
- change-detection analysis – images acquired on different dates were available for most of the sites, showing changes over time in vegetation, new houses, fire, etc.
- oil-spill detection – radar images were used to detect oil spills outside Ogoniland

Table 9. Summary of all satellite/aerial images used during the remote sensing analyses

Satellite	Spatial resolution	Acquisition dates	New acquisition / Archive	Primary use	Source
WorldView 2	50 cm	02/01/2011	New acquisition	Detailed mapping; Change detection	DigitalGlobe
Ikonos	1 m	2006-2007	Archive	Detailed mapping; Change detection	GeoEye
SPOT 5	2.5 m	17/01/2007	Archive	Detailed mapping; Change detection	SPOT IMAGE
Aster	15 m	19/01/2007 03/01/2007	Archive	Land-cover mapping	ERSDAC
Landsat TM	30 m	08/01/2003 17/12/2000 19/12/1986	Archive	Land-cover mapping	GLOVIS
Landsat MSS	80 m	15/05/1976	Archive	Land-cover mapping	GLOVIS
SPOT 4-5 VEGETATION	1 km	1998-2010 10-day synthesis	Archive	NDVI trend	VITO
ENVISAT	90 m	26/09/2010	Archive	Oil spill detection	ESA
SRTM	90 m	2000	Archive	Digital elevation model	CGIAR
Helicopter	10 cm	November 2011	New acquisition	On site verification	

Table 10. Software programs used in GIS mapping of Ogoniland

Software	Use
ESRI ArcGIS	Cartography; geocoding; digitization
ESRI SpatialAnalyst	Spatial analysis
ErMapper	Satellite image compression
ErMapper	Satellite image compression
GoogleEarth / GoogleEarth PRO	Data visualization; real time tracking
Erdas	Ortho-rectification; image mosaics
Idrisi	Image classification
Surfer	Contour modelling
Strater	Borehole log production
MapWindow	Garmin waypoints and tracks management software

GIS/cartography

GIS mapping/cartography was used extensively in the Ogoniland assessment (Table 10), with more than 200 maps generated at a scale of 1:5,000. A 1:50,000 cartographic atlas was also produced, giving all those working in the field access to the same information. The atlas was frequently updated as new data arrived from the field.

Spatial analyses included proximity analysis, which recorded the distances between contaminated sites and community wells and settlements, as well as contaminant dispersion. Statistical analyses were carried out, for instance on shifts in land cover, changes to land-cover classification and areas of land impacted by contaminated sites. In addition, groundwater modelling was carried out to generate contaminant-plume contours and to depict groundwater flow direction.

Land cover classification methodology

The Landsat archive contains a number of images of Ogoniland dating back as far as 1976. The best early image, from 1986, was used to develop a classification for that year. The best readily available recent imagery came from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images from 2007. Initially, it was thought that 2007 was sufficiently recent to provide a good indication of the current status of land cover in Ogoniland. This may have been true for some parts of the terrestrial area but further research showed that major changes have taken place since January 2009 in the mangroves adjoining Ogoniland.

Since no recent images were available, UNEP requested that the very high-resolution WorldView-2 satellite be programmed for acquisition in the study area. Due to the high cost of this acquisition, only a portion of the entire Ogoniland region could be captured. The image was taken on 7 January 2011 to provide an example of the current status in a selected area.

Example of an area classified as an industrial zone

The classification method adopted for the project was a two-stage hybrid procedure which used both spectral measurement from satellite images and stratification of the area into broad zones; the latter was used to make sure that within each zone the assignment of classes was appropriate. For example, pixels classified as mangrove should only occur in the mangrove zone, and pixels classified as urban should only occur in the urban zone.

First, the satellite-derived spectral information in the visible, near infrared and short-wave infrared regions of the spectrum were clustered by an unsupervised algorithm into spectrally similar clusters based solely on their spectral properties (colours). How these clusters related to land-cover classes was not known at this stage. It was assumed that different land-cover types in the landscape could be distinguished by their spectral properties. This is generally true of a range of landscape features – water, urban areas, vegetation and bare soil all have rather different visual characteristics.

To fully capture the range of diversity in the images, it was found that approximately 60 clusters had to be identified. The next step was to assign land-cover class names to each of the spectral clusters. This was done by a manual process of image interpretation, referring to any ancillary information that was available, including ground photographs and GoogleEarth images.

Each sample was assigned a unique identification number and the exact location was registered

The output of this stage was a first estimate of land cover in Ogoniland.

Different land-cover types generally have different visual characteristics – but only to a certain extent. Some land-cover types may appear spectrally similar; for example areas of freshwater swamp forest may appear very similar to mangroves but are different land-cover classes. Similarly, some urban areas may appear very similar to bare soil in rural areas. To ensure consistency of the land cover classification, a set of zones or strata were defined and each processed to ensure internal consistency according to a set of simple rules. The following zones were defined:

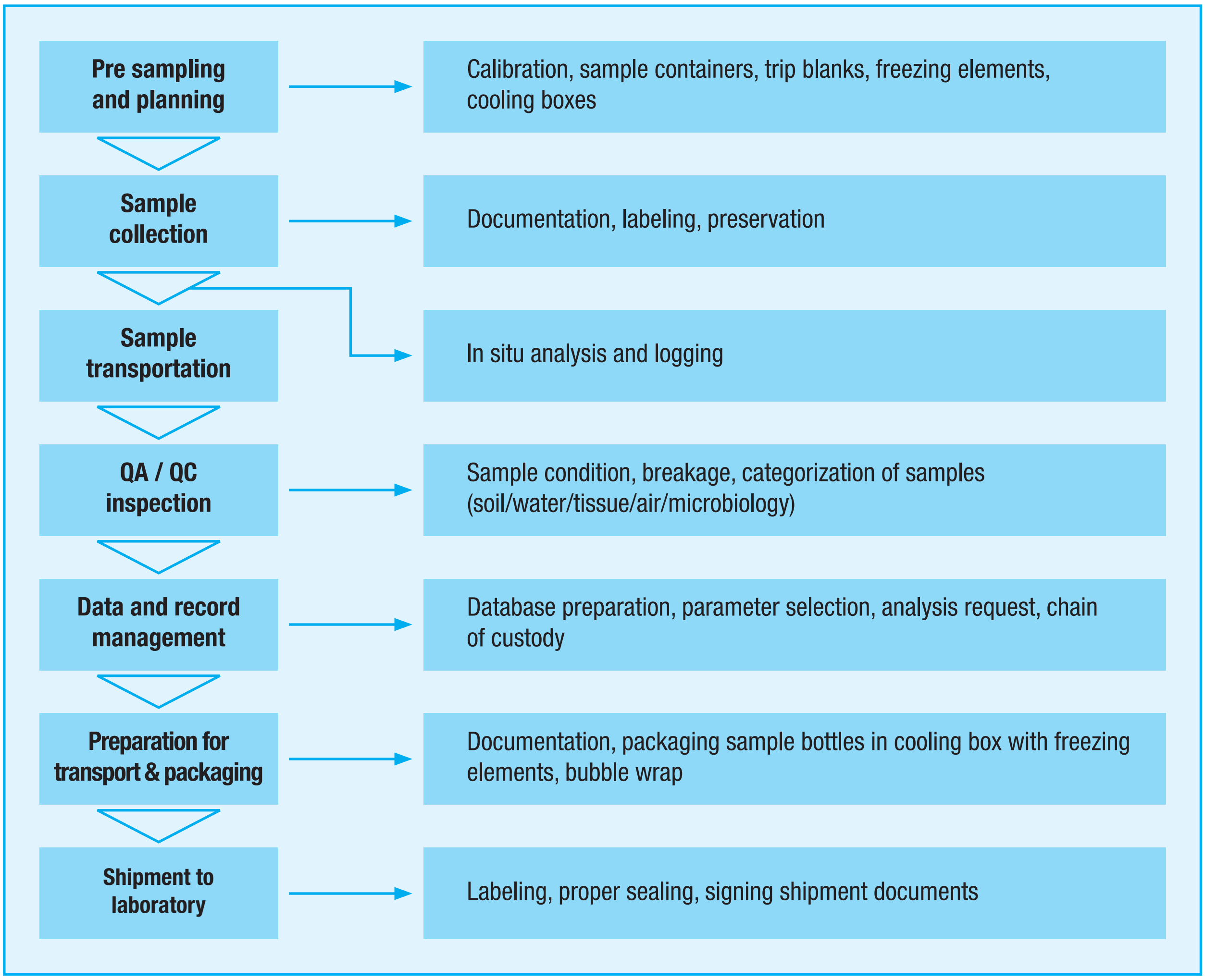
- Terrestrial zone
- Mangrove zone
- Freshwater riparian vegetation zone
- Forest zone (non-riparian)
- Coastal zone
- Urban / industrial zone
- Rural village zone
- Bare areas (areas with no vegetation)

A series of GIS procedures was developed to apply a set of generic principles in each zone; for example, mangroves can only occur in the mangrove zone. If mangrove pixels were found in other zones, they were reassigned to an appropriate land-cover class in the relevant zone.

Sample management

The field component of the UNEP study was a massive undertaking. Over 4,500 samples were collected and submitted to two international laboratories, both accredited to meet the international standard (ISO 17025) for testing and calibration laboratories. Thus, a robust sample management programme was an absolute necessity, the main objective being to safeguard the integrity and quality of the samples sent to the laboratories for analysis – essential if the laboratories were to generate a quality result. Samples collected in the field were kept in a cool box and were brought to the project office where they were stored in a freezer while chain of custody and customs forms were completed. Within 24 hours of collecting the samples, they were sent to the appropriate laboratories, again in cool boxes with sufficient ice packs. Figure 6 depicts the sample management flowchart used in this project.

Figure 6. Flowchart depicting the management of samples collected for laboratory analysis



Quality control samples

A majority of the errors in environmental analysis can be attributed to improper sampling, cross contamination and improper sample storage and preservation. Quality control samples are a way to measure precision, accuracy, representativeness, comparability and completeness. Essentially, two types of quality control samples were considered during the scientific investigation period of the Ogoniland project, namely:

- **Trip blank** – a sample that originates from analyte-free water taken from the laboratory to the sampling site and returned unopened to the laboratory with the VOC samples. One trip blank accompanies each cooling box containing samples submitted for VOC analysis. The trip blanks are used to assess the quality assurance/quality control (QA/QC) of sample preservation, packing, shipping and storage
- **Field blank** – an analyte-free sample that is collected in a sample bottle and sent to a laboratory for final analysis

Field blanks and trip blanks were collected for only a subset of the water samples. When sample concentrations were close to concentrations detected in blanks, they were qualified accordingly. Detected concentrations less than two times the field blank were negated (qualifier 'U') and detected concentrations between two and five times the field blank were qualified as estimated with potential high bias (qualifier 'J+'). This approach is consistent with the United States Environmental Protection Agency's (USEPA) National Functional Guidelines for Organics and Inorganics.

Field measurements

The various on-site measurements were performed with standard, calibrated equipment which differed from one parameter to another.

A Hatch Multimeter was used for monitoring basic parameters such as pH, conductivity and temperature.

To monitor fine particulate matter in outdoor air, with different fractions such as the inhalable fraction $PM_{10,}$ respirable fraction $PM_{2.5}$ and ultrafine fraction PM_1 (particles measuring less than 1 micron), a portable Thermo Scientific Particulate Monitor DataRAM 4 (DR-4000) was used. The same instrument was also used to measure air temperature and humidity.

To determine naturally occurring radioactive materials, an Automess 6150 AD 6/H calibrated dose-rate meter was used along with an Automess alpha-beta-gamma probe 6150 AD-17 (0.1-10000 cps) surface contamination probe.

Over 4,500 samples were collected for analysis

Analytical measurements

Though contaminated site assessment is an established industry, there is still no consistency in setting standards on measurement of hydrocarbons.

The main issue is that crude oil, or petroleum hydrocarbon, is a mix of thousands of individual hydrocarbons. Individually identifying each of them and setting standards presents a very complex – and expensive – challenge. Simply lumping all the hydrocarbons together to create a single standard would prevent differentiation between a hydrocarbon that is very toxic and another which is not.

The Nigerian legislation, EGASPIN, is based on a parameter referred to as mineral oil, though no specific analytical methods or carbon range are specified.

The Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) in the United States developed a methodological approach that takes into account the carbon chain length, solubility and toxicological effects of hydrocarbons in the mixture. TPHCWG divided petroleum hydrocarbons into two main groups: aromatic and aliphatic compounds.

As leaching factors and volatilization factors span many orders of magnitude, the TPHCWG classified aromatic and aliphatic hydrocarbons into a number of fractions with leaching factors and volatilization factors that lie in the same order of magnitude. With these so-called transport fractions, their transport and fate in the environmental compartments can be modelled more appropriately than with a single TPH value. For this reason, UNEP used the TPHCWG method of carbon banding (Table 11).

Since relevant Nigerian legislation is based on a single parameter, for the purpose of this report the broadest possible range of hydrocarbons analysed (C5-C44 for soil and C5-C35 for water) was used for comparison with mineral oil and reported as TPH. Where appropriate, individual parameters (e.g. benzene) or groups (e.g. BTEX or TPH) are reported and explained.

Table 11. Banding for hydrocarbons in TPH Criteria Working Group analyses

Samples	Hydrocarbon banding	
	Aliphatics	Aromatics
Soil	>C5-C6	>EC6-EC7
	>C6-C8	>EC7-EC8
	>C8-C10	>EC8-EC10
	>C10-C12	>EC10-EC12
	>C12-C16	>EC12-EC16
	>C16-C21	>EC16-EC21
	>C21-C35	>EC21-EC35
	>C35-C44	>EC35-EC44
Water	>C5-C6	>EC6-EC7
	>C6-C8	>EC7-EC8
	>C8-C10	>EC8-EC10
	>C10-C12	>EC10-EC12
	>C12-C16	>EC12-EC16
	>C16-C21	>EC16-EC21
	>C21-C35	>EC21-EC35

Laboratory analyses of NORM

Gamma spectrometry for the determination of natural radioactivity in collected samples was performed in Switzerland at the Spiez Laboratory's ISO/EN 17025-accredited testing laboratory for the determination of radionuclide concentration (accreditation number STS 028). Gamma spectrometry was performed with high-purity Germanium (HPGe) CANBERRA detectors with high relative efficiencies.

The same testing laboratory was used to carry out inductively coupled plasma mass spectrometry (ICP-MS) of the collected samples. This process is able to determine the existence of medium- and long-living radioisotopes, as well as non-radioactive elements. For this analysis, a Finnigan Element XR high-resolution (sector field) mass spectrometer was used.

The procedures applied and measurements taken for both analyses fulfilled the international norm.

Field data collection for remote sensing

A large number of GPS (Model GPS 60™) instruments were used to record geographic coordinates of pollution on the ground and the points from which samples were collected by the different thematic teams. GPS was also used to map the road network and accessibility for the purposes of planning daily transportation to and from sampling sites.

Using GPS cameras (Caplio 500SE GPS embedded model), more than 10,000 geo-referenced photographs were taken in Ogoniland during the course of the study. The photographs were used extensively during the scouting exercise, reconnaissance, boat trips and helicopter flights, allowing for geo-traceability of the information photographed in the field. The photographs were also used as ground truthing for the land-cover mapping work, which served to improve the accuracy of the land-cover classification.

GPS-embedded, rugged laptop computers were used in the field to verify any spill reported by SPDC, record new spills reported by Ogoni communities or spills discovered by the UNEP team during fieldwork.

UNEP technical assistant using a GSP instrument during a reconnaissance exercise, January 2010

Review of institutional issues

National legislation and institutions

UNEP's review attempted to cover the whole range of institutions dealing with legislation related to environmental management and oil and gas production in Nigeria, touching also on cross-cutting issues such as community-company-government interaction, transparency, fiscal issues and law enforcement. The assessment was carried out by a thorough review of available documentation (published reports, legislation, research papers, etc.). In addition, many institutions, both at federal and state level, were contacted and interviewed, though not all those contacted were available. Community members were interviewed to the extent possible given the challenges of accessibility and security.

SPDC procedures

The Shell Petroleum Development Corporation has a set of documents which form the operational basis for handling oilfield assets and emergencies. A review of these procedures was undertaken for the purpose of this assessment, based on the following documents:

- SPDC Corporate Oil Spill Response, Clean-up and Remediation Manual, SPDC 2005-00572, April 2005
- Overview of Process and Standards for Oil Spill Clean-up and Remediation, SPDC Document, April 2006

In addition, three specific advisories issued by Shell Global Solutions and which form the basis of SPDC internal procedures were also reviewed:

- Framework for Risk Management of Historically Contaminated Land for SPDC Operations in Niger Delta, OG.02.47028
- Framework for Risk Management of Historically Contaminated Land for SPDC Operations in the Niger Delta: Mangroves and other Swamp Areas, OG.03.47062
- Remediation Management System, 2010

3.7 Contamination assessment criteria

Contamination criteria, in the context of this report, are specifications of concentration of a pollutant against which a judgement is made as to whether or not it is acceptable. Criteria need to be differentiated from standards and guidelines. Standards are specifications set by a statutory body, often national, and are therefore legally enforceable. Guidelines on any given issue, on the other hand, whether made by government, industry organizations or international organizations, present ideals that are considered desirable but which are not legally enforceable. From a technical point of view, criteria, guidelines or standards are almost always derived from the same scientific basis and could often be the same.

Contamination assessment criteria – a numerical value above which a site could be deemed to be contaminated – are of importance from several angles. Firstly, the degree to which observed values vary from the assessment criteria is an indication of the degree of contamination, and therefore the degree of risk to which the environment is subjected. Secondly, assessment criteria determine the degree of environmental clean-up and restoration required at a site. This in turn dictates the policy and technological approaches to be used, both of which have a direct bearing on the cost of the clean-up operations.

A chemical substance is considered a pollutant when its concentration is above a harmful threshold. Such thresholds can have different connotations in different contexts. A chemical substance could be harmful to people directly; it could be harmful to the quality of air or water, which may in turn harm people; or it could be harmful to other biota, for example animals, but may or may not harm people. However, it is fair to say that in most situations harm is ultimately defined from an anthropocentric perspective. Table 12 shows the comparison of risk-based screening levels for some of the frequently regulated hydrocarbon pollutants [65]. It can be seen that the screening levels for the same parameter can vary, and vary substantially, between countries. There are scientific and policy reasons, such as a society's risk tolerance, as to why different countries may have different values for contamination criteria for the same pollutant.

Though the international community has more than 30 years of experience in different parts of the world on systematic assessment and clean-up of oilfield contamination, there is not yet an

Table 12. Comparison of country specific risk-based screening levels for hydrocarbon-related components in soil

Parameter	Country				
	Canada	China	Netherlands	Thailand	UK
Benzene	0.0068	0.2	1	6.5	0.33
Toluene	0.08	26	130	520	610
Ethyl Benzene	0.018	10	50	230	350
Xylenes	2.4	5	25	210	230

All values are in mg/kg

Soil caked into a crust of dried crude oil

internationally accepted guideline on what level of hydrocarbons constitutes contamination. It is against this background that the Ogoniland assessment team had to review the available criteria and make its recommendations.

It must be stated that defining the level of environmental clean-up is ultimately a policy decision for the Federal Government of Nigeria, and wherever national legislation exists with regard to a particular issue, it is recommend that the legislation be followed, except in cases where there are sound scientific reasons to adopt a more stringent line to protect public health and welfare. In addition, when it is felt appropriate to point out instances where particular legislation may need revision or clarification, it has been done. Until such revisions or clarifications are made, however, the existing legislation will have to be complied with.

Standards for soil

The Nigerian legislation dealing with soil and water contamination from oil operations is handled by the Federal Government's Department of Petroleum Resources. The Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN), issued in 1992, set out the standards which are currently the minimum operating requirement for the oil industry in Nigeria [7].

EGASPIN proposes two possible options for pollution incidents: (i) application of the Standard Guide for Risk-Based Corrective Action Applied at Petroleum Sites, prepared by the American Society for Testing of Materials (E1739-95, reapproved 2010); or (ii) an approach based on 'intervention values and target values'. Even though the EGASPIN document itself was reissued in 2002, no further guidance has been produced in the last 20 years, such that the approaches suggested in 1992 still form the operational basis for the oil industry in Nigeria.

EGASPIN defines intervention values as those that "indicate the quality for which the functionality of the soil for human, animal and plant life are, or threatened with being seriously impaired. Concentrations in excess of the intervention values correspond to serious contamination". Target values are defined as those which "indicate the soil quality required for sustainability or expressed in terms of remedial policy, the soil quality required for the full restoration of the soil's functionality for human, animal and plant life. The target values therefore indicate the soil quality levels ultimately aimed for".

In reviewing site contamination, UNEP has used the EGASPIN standards for soil (Table 13), which demonstrate the presence of higher levels of hydrocarbons and reveal continuing legislative non-compliance. However, this report makes recommendations for review of the EGASPIN (see Chapter 5). It is therefore expected that before the final clean-up is undertaken, a new set of standards will be introduced.

Standards for groundwater

The safety limits for groundwater pollution are also set out in the EGASPIN as both intervention and target values. Since some Ogoniland communities (those within the study area at least) use groundwater for drinking, without any treatment or monitoring, it is important that contamination levels of groundwater are compared against the criteria for drinking water quality. EGASPIN standards for groundwater are also presented in Table 13.

Standards for drinking water

WHO guidelines on drinking water

The World Health Organization (WHO) has developed and issued guidelines on drinking water quality for over 60 years. These guidelines – based on best available information on the risks associated with the consumption of water – have become the universal benchmark for setting drinking water standards. The risks associated with drinking water are constantly evaluated by WHO and the guidelines updated accordingly [36].

Nigerian national drinking water standards

The Nigerian Industrial Standard (NIS) 554:2207 deals with standards for drinking water quality nationally [37]. The standard was developed by the Ministry of Health, working through a technical committee of key stakeholders. Table 14 provides a comparison of the maximum levels of contaminants permissible according to Nigeria's drinking water standard and the corresponding WHO guideline.

Table 13. EGASPIN target and intervention values for soil and groundwater

Substance	Soil/sediment #		Groundwater	
	Target value	Intervention value	Target value	Intervention value
A. Aromatic compounds	(mg/kg dry material)		(µg/l)	
Benzene	0.05	1	0.2	30
Ethyl benzene	0.05	50	0.2	150
Phenol	0.05	40	0.2	2,000
Toluene	0.05	130	0.2	1,000
Xylene	0.05	25	0.2	70
B. Metals				
Barium	200	625	50	625
E. Other pollutants				
Mineral oil	50	5,000	50	600

The values given for soil are for 20 % soil organic matter with a forumula given for calibrating for other soil organic matter concentrations

Table 14. Comparative environmental standards for drinking water

Contaminant	Nigerian drinking water standard (µg/l)	WHO guideline (µg/l)
Benzene	No standards set	10
Toluene	No standards set	700
Ethyl benzene	No standards set	300
PAHs	7	No standards set
Arsenic	10	10
Barium	700	70
Mercury	1	6
Mineral oil	3	No standard set

Table 15. WHO air quality guidelines

Standard	$PM_{2.5}$	PM_{10}
Annual mean	10 µg/m^3	20 µg/m^3
24-hour mean	25 µg/m^3 n	50 µg/m^3

Air quality standards

No local air quality standards currently exist in Nigeria. In 2006, the WHO published guidelines for respirable particulate matter [38], as shown in Table 15.

In the absence of local standards, the WHO guidelines are used as a reference.

There are certain chemicals which were analysed in the assessment but for which no internationally recognized guidelines exist. In such cases, reference to any available standard is provided, primarily to give the observed values some context. No specific recommendations are made by UNEP on such standards.

3.8 Limitations, challenges and constraints

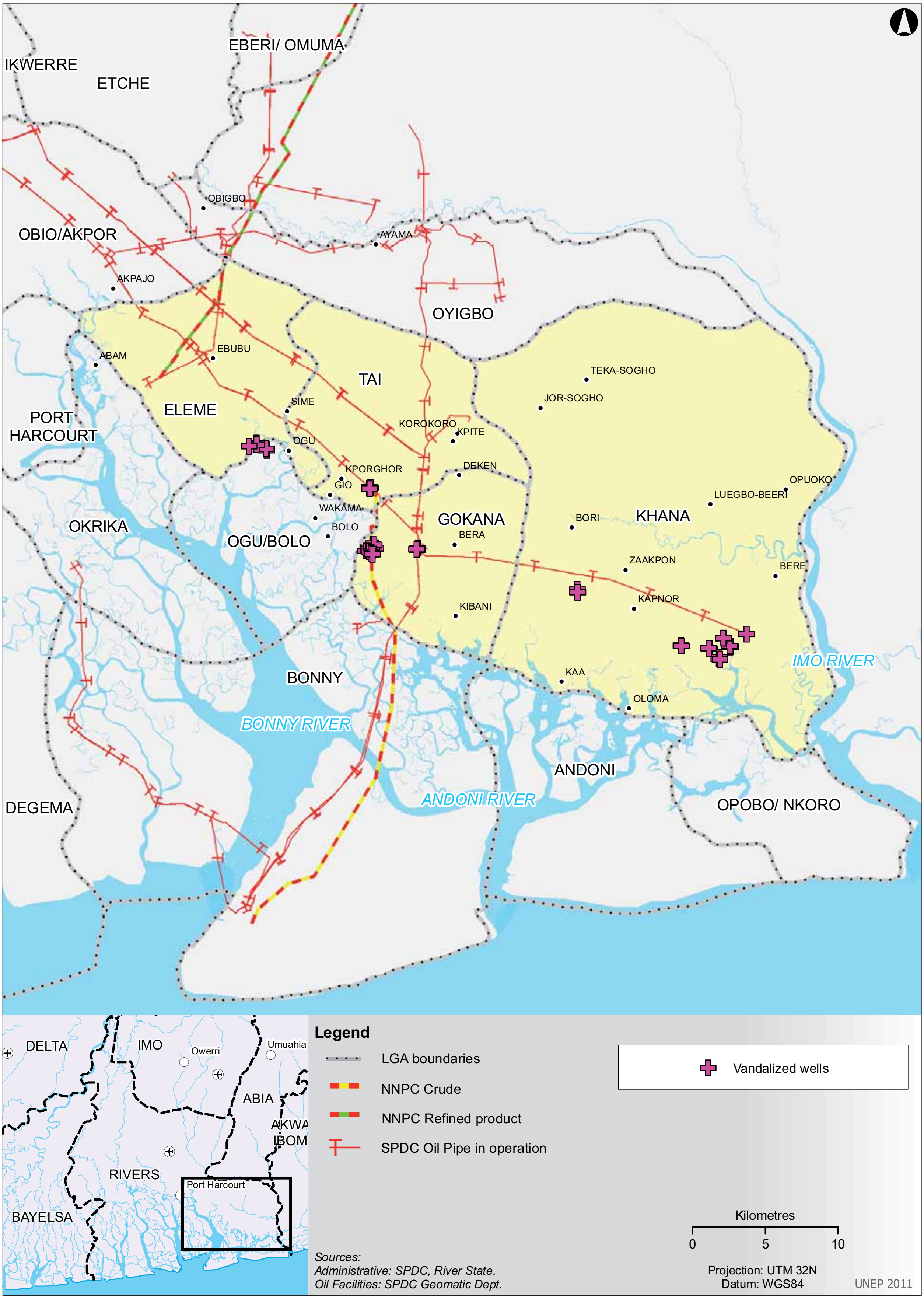
In carrying out a project of this scope, some constraints are inevitable. While every effort was made by the UNEP assessment team to limit the impact of these constraints on the scientific integrity of the study, the issues encountered are summarized here so that those who read this report may understand the context in which the work was undertaken.

Scientific constraints

There is no baseline information available on either the nature of the environment or socio-economic status of the community prior to the initiation of oil exploration. In fact, useful, recent and robust information covering Ogoniland is also not available. This includes a lack of reliable data about the quantity of oil spilled in the region. Consequently the observed situation has to be compared with a presumed baseline condition.

Despite many challenges, there was generally a strong spirit of cooperation between UNEP and Ogoniland communities

Map 9. Location of vandalised monitoring wells



The Nigerian Navy provided support during some field visits (note the navy vessel in the background)

In a number of sectors, the report lacks statistical coverage. For example, monitoring of drinking water was done on an opportunistic basis around contaminated sites. There are thousands of drinking water wells in Ogoniland (and there is no record of how many or where). This study did not seek to identify all possible locations of drinking water wells and then undertake a statistically appropriate sampling approach.

As the time available at individual sites was always restricted and the possibility of returning to a site was never known in advance, the study focused on collecting the minimum number of samples needed to form a reasonable picture of the contamination. The study could not, therefore, involve collecting duplicate samples.

This assessment compares the measured value of pollutants on the ground with established legal standards or other international guidelines. The findings based on this could be used as a basis for initiating public health protection measures on a preventive basis. This could also be used as a legally acceptable basis for site clean up. However, a more resource efficient approach will be to undertake site-specific risk assessments followed by consultations between the operator, regulator and community to establish clean-up levels for each site.

Security constraints

United Nations Department of Safety and Security (UNDSS) specifications are contractually binding and non-negotiable. In the UNDSS classification, Port Harcourt is a Phase III duty station, meaning that special security precautions must be observed. This was an aspect that the UNEP team working on the environmental assessment of Ogoniland had to keep in mind at all times, especially when in the field.

While the UNEP project team was rarely under any threat and maximum security was provided by the local government authorities, there were times when UNDSS advised the UNEP team to refrain from fieldwork. This obviously had an effect on the pace of on-the-ground surveys.

Of the 180 groundwater monitoring wells drilled by the project team, 38 were vandalized (Map 9, page 89) and could no longer be used for sampling.

Access restrictions

Traditional practices in Ogoniland are such that an elaborate procedure of consultation is mandatory prior to visiting a specific site. Two teams, a Community Liaison Team and a Land

The number of samples taken at each location was influenced by safety and access considerations

Access Team, were deployed to facilitate access to sites of interest. A considerable amount of time was invested in this essential activity, but however well the advance planning was carried out, there were repeated occasions when the project team was prevented from entering specific sites. In every instance the UNEP team complied with the wishes of the community, although the underlying reasons for denial of access often remained unclear. A policy was adopted whereby once a team had twice been prevented from visiting a site, the site was documented as 'inaccessible'. As a consequence, there are still some sites in Ogoniland that may be contaminated but which UNEP was unable to assess.

Information constraints

It was the intention of the UNEP team to identify all possible locations in Ogoniland that have been contaminated by oil industry operations. UNEP solicited, and received, information from all stakeholders, both the Ogoni community and SPDC, regarding such sites. Whenever such information was received, reconnaissance visits were arranged, subject to the security constraints

Samples were transported from field locations to laboratories in the shortest possible time mentioned above. The project team also visited oilfield infrastructure even when there was no specific information on contamination.

One of the observations made by UNEP during the course of the study was that vegetation had continued to grow and cover contaminated areas even though remediation measures had not been carried out. This was partly because some vegetation types can vigorously survive hydrocarbon pollution and partly because many vegetation types need only limited, comparatively clean amounts of topsoil to re-establish. Thus, even in cases where severe contamination had penetrated deeply, superficial vegetation cover gave the site a healthy appearance. Given that the oil industry has been operating in Ogoniland for more than 50 years while contamination records only go back 25 years, there could easily be other locations where contamination still exists below the surface but is obscured by vegetation.

Unfortunately, UNEP received insufficient information to enable it to undertake comprehensive assessments of oil operations in Ogoniland by companies other than SPDC. This included Port Harcourt Refinery Company and Pipelines and Products Marketing Company. Consequently, only spills that were apparent on the surface, and/or reported by the Ogoni community in the case of non-SPDC properties, were assessed by the UNEP team. The implication is that there may still be contaminated areas in Ogoniland about which there is currently no intelligence available to UNEP on which to base further surveys.

Sample management constraints

As previously described, analysis of all the samples collected in Ogoniland was undertaken in appropriately accredited laboratories in Europe. Many of the analytical parameters (e.g. VOCs) are sensitive to the temperature at which they are preserved. While all efforts were taken to maintain temperatures at the required levels during transportation of sample materials, and to get samples to laboratories in the shortest possible time, some degree of loss of contaminants is to be expected in the analytical results. Therefore, the reported results could be lower than the actual concentration in the sample when it was collected.

Ill-defined boundaries

While it was agreed that the geographic scope of the environmental assessment be limited to Ogoniland, there is no clearly agreed official definition of what constitutes Ogoniland. Boundaries, even between local government areas in Ogoniland, are not well defined and always disputed. Consequently, the UNEP study may have captured some information from outside Ogoniland while inadvertently leaving out areas that may be perceived by some as part of Ogoniland. At all times, the project team tried to err on the side of caution. Whenever there were people living in an area, their opinion on whether or not the area lay within Ogoniland was taken as correct. Greater difficulty was experienced in areas where oil industry operations were apparent but there was no community presence, such as at Bodo West.

Vertical delineation of contamination

While the horizontal delineation of contamination was challenging (no visible signs on the surface), vertical delineation was even more difficult given the wide fluctuations in groundwater levels. On reaching groundwater, any contamination can penetrate to considerable depths. The UNEP survey used only shallow augers for groundwater analysis, with a maximum sampling depth of 5 metres. At a number of locations, chemical analyses revealed that contamination may have gone deeper.

Time frame

The assessment of contaminated sites always calls for decisions on the number of samples to be taken at a particular location. In general, this is primarily driven by the cost of subsequent analysis of the samples. However, in Ogoniland there was an additional variable to be dealt with: the amount of time available to the UNEP team to work safely at a site, with the added consideration that a second visit, while highly desirable, might not prove feasible. Consequently, the sampling approach had to be tailored to capture the breadth, depth and intensity of contamination from the lowest feasible number of samples. However, whenever access was more freely available, the opportunity was always taken to supplement initial sampling.