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Project:	IMPLEMENTATION OF A CENTRAL LABORATORY AND AN AIR QUALITY MONITORING NETWORK IN DAKAR
Agreement:	NO 003/C/FND/05

Air Quality Monitoring Programme for Dakar

Result of the design study

Bjarne Sivertsen

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Contents

Air Quality Monitoring Programme for Dakar

1 Introduction

This report covers 3 Sub-tasks of the project, namely: 4.1-Define monitoring objectives, 4. 2-Design the monitoring network and 4.3-Perform site studies and site evaluation; and corresponds to the deliverables 4a “Monitoring objectives and design of monitoring network” and 4b “Sighting report for the final measurement network”.

An important part of the development and design of an urban air quality monitoring programme is to identify possible air pollution problems from sources to impacts. Ambient air pollution data have been collected in order to obtain necessary information to enable the design of an air quality monitoring programme for Dakar. The data that have been used:

- Previous measurements of air quality
- Meteorological data for Dakar
- Some information about air pollution sources
- A pre-screening study of air pollution
- A screening study including measurements of selected air pollutants in Dakar.

The selection was also based on the ambient air pollution screening studies (Sivertsen et al., 2006) and background documents on air quality monitoring design (see Memo dated 25 February 2006). The screening studies included measurements of a number of pollutants in Dakar.

The final selection of sites for permanent monitoring of air quality in Dakar were decided during field studies performed on 28 February and 1 March 2006. An important part of the design has also been to clearly define the objectives of the air quality monitoring programme. To meet the objectives defined below the sites selected will have to be permanent and operated for a number of years. Five permanent air quality monitoring stations have been defined already in the Terms of Reference.

2 Monitoring objectives

The air quality monitoring programme design will be dependent upon the objectives specified for air quality management programme in Dakar. What are the expected outputs of the monitoring activity? Which problems do we need to address?

Defining the output will influence the design of the network and optimise resources used for monitoring. It will also ensure that the network is specially designed to optimise information on the problems at hand.

Based on the results of screening studies undertaken in Dakar, as well as the terms of reference provided for the project, a general objective for the air quality measurement programme is to adequately characterise the air pollution situation for the Dakar area and to quantify the relative importance of traffic emissions relative to all other sources in the area.

In more details we have defined some of the objectives for the air quality monitoring programme in Dakar as to:

- Facilitate background concentrations measurements,
- Monitor current levels as a baseline for air quality assessment,
- Check the air quality relative to standards or limit values,
- Detect the importance of individual sources,
- Enable comparison of air quality data from different areas and countries,
- To collect data for air quality management, traffic and land-use planning purposes,
- Observe trends (related to emissions),
- Check the impact of actions taken to reduce the pollution,
- Develop abatement strategies,
- Determine exposure and assess effects of air pollution on health, vegetation or building materials,
- Informing the public about air quality and raising awareness,
- Facilitate source apportionment and identification;
- Support legislation in relation to air quality limit values and guidelines

The users such as DEEC and CETUD, who will need the information to be collected in Dakar, will have the possibility to take part in the final design not only to ensure that the surveys are appropriate to their needs but also to justify committing the resources.

3 Design of the monitoring network

The number of monitoring stations and the indicators to be measured on each station has been decided based on the knowledge of sources and prevailing winds. The main pollutants measured during the screening studies have also been used as background for the design.

Now that the objectives of ambient air pollution monitoring and sampling are well defined, a certain operational sequence has to be followed. A best possible definition of the air pollution problem together with and analysis of available personnel, budget and equipment represent the basis for decision on the following questions:

1. What spatial density of sampling stations is required?
2. How many sampling stations are needed?
3. Where should the stations be located?
4. What kind of equipment should be used?
5. How many samples are needed, during what period?

6. What should be the sampling (averaging) time and frequency?
7. What additional background information is needed:
   - Meteorology,
   - Topography,
   - Population density,
   - Emission sources and emission rates
   - Effects and impacts, on what? etc.?
8. What is the best way to obtain the data (configuration of sensors and stations)?
9. How shall the data be accessible, processed and used?

The answers to these questions will vary according to the particular need in each case. Most of the questions were addressed in the screening site studies (Sivertsen et al., 2006).

3.1 Background information

Before starting the design of the monitoring network it has been important to collect existing information on air quality and meteorology in Dakar. The monitoring sites for the future ambient Air Quality monitoring programme will be evaluated based upon available information from:

- Screening studies
- Monitoring objectives,
- Emission sources,
- Meteorological conditions, prevailing winds,
- Other types of existing data.

The ambient measurement sites may cover different areas including microenvironments such as background stations, residential areas, urban areas, streets and a maximum impact area.

3.1.1 Prevailing winds

Wind data have been collected from CERER in Dakar and from weather prognoses for Western Africa.

Wind frequency distributions from CERER during the winter months 2005 show a prevailing northerly wind over DAKAR.

During the summer season the winds are more from westerly directions as demonstrated in Figure 2 based on data from a meteorological forecast model.

Vertical temperature profiles are being measured by the Weather service, and Figure 2 demonstrates that a strong daytime inversion is presented above Dakar at the 3 June 2005. The height of this inversion is at about 500 m above the surface.

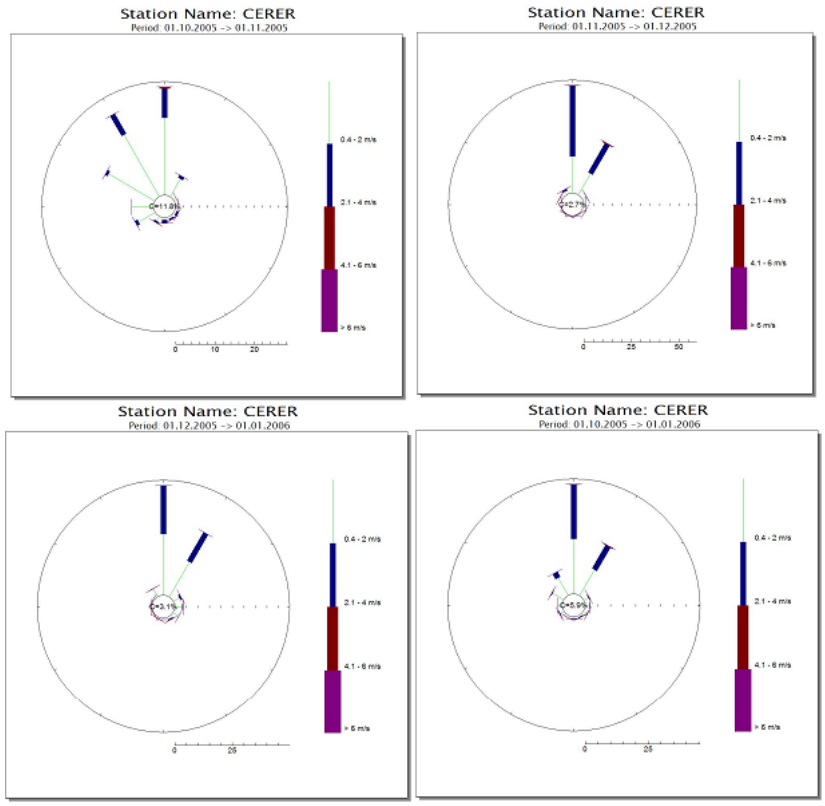

Figure 1: Wind frequency distributions based on data collected at CERER in Dakar from 1 October to 31 December 2005.

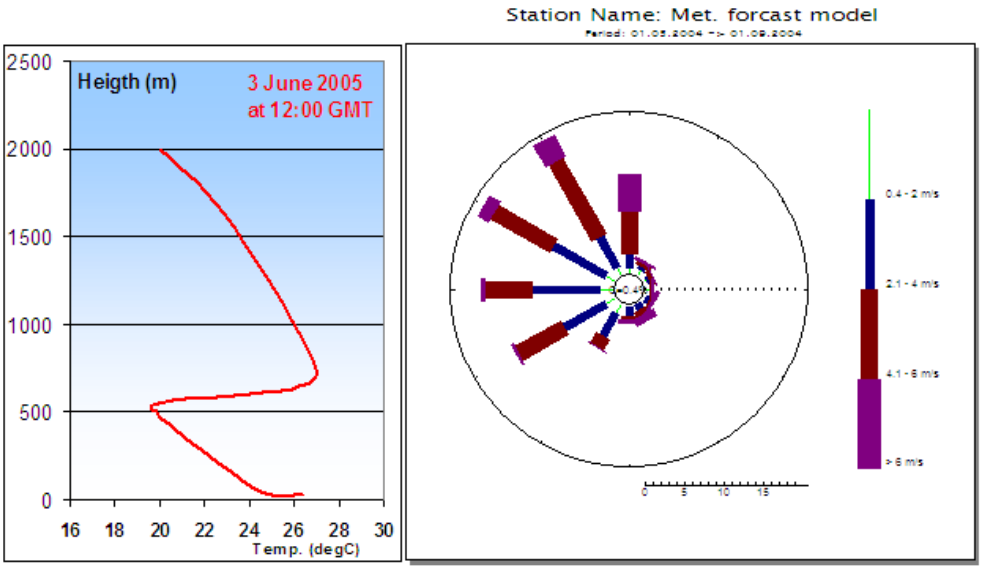

Figure 2: Vertical temperature profile as measured at the Weather service in Dakar and the wind frequency observed from 1 May to 1 September based on weather forecast models.

3.1.2 Sources

The main air pollution sources in Dakar seem to be traffic, industries and background generated dust.
The sources may be divided into three categories.

- Emissions from road traffic are treated as line sources.
- Emissions from single activities of some size, like industries, energy production etc., that are linked to single stacks, are treated as point sources.
- Emissions from open air waste burning; public and private services and agricultural activities are treated as area sources.

A major part of the emissions inside Dakar is coming from traffic. On a general basis it seems that traffic jams on some of the main roads produce high emissions of CO. High traffic density on the main roads also lead to large emissions of NOx and particles. The emissions from traffic will have to be treated as line sources based on physical descriptions of the roads and information about traffic flow and traffic emission factors. The traffic flow will be collected as number of vehicles and vehicle distribution for different vehicle classes. Some of this work has started in Dakar.

The industrial areas, especially located in the eastern part of the city (e.g. Grands Moulins area) causes emissions of PM, SO_2, VOC and NOx. The general activities in the city seem to produce high background levels of suspended particles. From the preliminary data collected we have seen that open air burning and general polluting activities inside and outside the city of Dakar may contribute to the general pollution level. In some cases also transport of dust from sources outside Senegal (wind blown desert dust) may contribute to high PM concentrations in the city. It will be important in the design of the measurement programme to catch the relative importance of these sources.

3.2 Site selection

3.2.1 Permanent sites

The air quality monitoring programme for Dakar shall provide information to support and to facilitate the assessments of air quality in Dakar and to meet the objectives defined in Chapter 2. Many objectives as described above require that the monitoring sites selected for Dakar will have to be fixed permanent sites. If they are being changed or moved around they will not provide information about trends and they cannot report the impact of actions or changes in the emissions over time.

There will also be a limited amount of permanent sites within the budget made available. We will thus have to plan carefully and see that the fixed sites will cover different types of microenvironments. To meet the objectives of assessing the impact on health they will also have to represent air pollution in areas where people live and stay. All these matters have been taken into account in the design presented below.

To verify that the selected fixed sites meet the required objectives it may be possible in the future to undertake specific field studies using simple inexpensive passive samplers to map the concentration distribution in Dakar. This has also been done ahead of the monitoring programme design (Sivertsen et al., 2006).

3.2.2 Site representativity

This means that for designing a monitoring programme in an urban area several monitoring stations are needed for characterising the air quality in the total region. The areas are generally divided into urban, suburban and rural/background areas. Measurements should be undertaken in different microenvironments within these areas, where people are living, staying and moving. In a typical urban air pollution measurement programme the microenvironments selected are often classified as:

- Urban traffic,
- Urban commercial,
- Urban background,
- Suburban (traffic and industrial)
- Rural sites (background areas).

When considering the location of individual samplers, it is essential that the data collected are representative for the location and type of area without undue influence from the immediate surroundings. It is important to bear in mind, when measuring air quality or analysing results from measurements that the data you are looking at represents the sum of impacts or contributions originating from different sources on different scales.

In any measurement point in the urban area the total ambient concentration is a sum of:

- A natural background concentration,
- A regional background,
- A city average background concentration (kilometre scale impact),
- Local impact from traffic along streets and roads,
- Local impacts from small area sources like open air burning (waste and cooking),
- Impact from large point sources such as industrial emissions and power plants.

To obtain information about the importance of these different contributions it is therefore necessary to locate monitoring stations so that they are representative for the different impacts. We will, in addition to air pollution data, often need meteorological data to identify and quantify the sources contributing to the measurements. It is also important to carefully characterise the representativeness of the monitoring sites, and to specify what kind of stations we are reporting data from.

The classification of measurement stations is divided into 3 types of areas; urban, suburban and rural. In each of the areas there may be 3 types of stations; traffic, industrial and background. The background stations are divided into; near-city background, regional and remote background stations.

Descriptions of the areas are given in the Table below:

Table 1: Typical area classification of micro-environments for air quality monitoring programmes (EU, 2001, Larssen et al., 1999).

Type of area	Description	Type of station
Urban	Continuously built-up area	Traffic Industrial Background : - Near city - Regional - Remote
Suburban	Largely built-up area: continuous settlement of detached buildings mixed with non-urbanized areas	
Rural	Areas that not fulfil the criteria for urban/suburban areas	

When considering the location of individual samplers, it is essential that the data collected are representative for the location and type of area without undue influence from the immediate surroundings.

3.3 Air pollution indicators and parameters

It is normally not possible to measure all the air pollutants present in the urban atmosphere. We therefore have to choose some indicators that should represent a set of parameters selected to reflect the status of the environment. They should enable the estimation of trends and development, and should represent the basis for evaluating human and environmental impact. Further, they should be relevant for decision-making and they should be sensitive for environmental warning systems.

The selected parameters for air quality are related to air pollutants for which air quality guideline values are available. The interrelationships between the indicators and other related compounds might vary from region to region due to differences in emission source profiles.

Local and regional authorities are using the selected sets of environmental indicators as a basis for the design of monitoring and surveillance programmes and for reporting the state of the environment.
Air quality indicators should:

- Provide a general picture,
- Be easy to interpret,
- Respond to changes,
- Provide international comparisons,
- Be able to show trends over time.

3.3.1 Air quality limit values for Senegal

Air quality limit values presented by the government of Senegal will have to be considered in the design of the air quality monitoring programme.

Table 2: Air quality limit values given by WHO and Senegal.

Pollutant	Averaging time	Maximum Limit Value	
		WHO	Senegal
Sulphur Dioxide (SO_2)	1 hour 24 hours Year	500 (10 min) 125 50	- 125 50
Nitrogen Dioxide (NO_2)	1 hour Year	200 40-50	200 40
Ozone (O_3)	1 hour 8 hours	150-200 120	- 120
Carbon Monoxide (CO)	1 hour 8 hours	30 000 10 000	- 30 000 (24h)
Particles <10 µm (PM10)	24 hours Year	50 * 20 *	260 80
Lead (Pb)	Year	0.5-1,0	2

** EU limit values*

3.3.2 Selected indicators for Dakar

The compounds or indicators selected for Dakar have been:

- Nitrogen dioxide (NO_2),
- Sulphur dioxide (SO_2),
- Carbon monoxide (CO),
- Particles with aerodynamic diameter less than 10 µm (PM_{10}) and 2,5 µm ($PM_{2,5}$),
- Ozone (O_3).
- BTEX (recommended instead of VOC)

The US EPA refers to the five first compounds listed above as the priority pollutants (US EPA, 1990). They are also given in the Air Quality Daughter Directives of the European Union with specific limit values for the protection of health and the environment (EU, 2005). The first three are also given in the World Bank limit values for ambient air pollution. The World Health Organisation guideline values also include the above indicators (WHO, 2005).
In the Terms of Reference for the project other indicators were suggested such as:

- Volatile organic compounds (VOC)
- Polycyclic Aromatic Hydrocarbons (PAH)
- Lead (Pb)

Instead of sampling of VOC for analyses by gas chromatography in the laboratory, BTEX are often measured with automatic monitors. We have selected this option. PAH need specific high volume samplers and can only be sampled intermittently. One of the PAH compound of specific interest may be benzo[*a*]pyrene (BaP). However, in this case filters will have to be brought to a chemical laboratory for separate analyses.

3.4 Meteorological measurements

An air pollution monitoring and management programme is not complete unless there are also meteorological data available. In the urban air quality monitoring programme for Dakar at least one meteorological station for local and micro meteorological data will be needed. These data will be used for air quality assessment and explanation as well as for input to air quality modelling and source impact identification.

Continuous measurement of meteorological data will be undertaken at one station with a ten metre high mast in the Dakar area. This will include sensors for the most important parameters such as:

- Wind speed and direction,
- Temperatures or vertical temperature gradients,
- Net radiation,
- Wind fluctuations or turbulence,
- Precipitation,
- Relative humidity, and
- Atmospheric pressure

4 The sites and indicators selected for Dakar

Based on the two screening campaigns preformed by NILU (Laupsa et al., 2005 and Sivertsen et al., 2006) and previous studies, we have obtained a fair knowledge of the typical air pollution problem in Dakar.

From the specifications given in the Terms of Reference we have been limited to using only five air quality monitoring stations for Dakar. The goal has thus been to apply these stations in the most optimal way. In addition to the five automatic monitoring stations we will thus have to also include some manual operated or semi automatic samplers in order to map the air pollution situation in additional micro-environments and densely populated areas. One other reason for this choice is that suspended particles have shown to represent a major problem in Dakar. Fairly inexpensive samplers are available to meet these objectives.

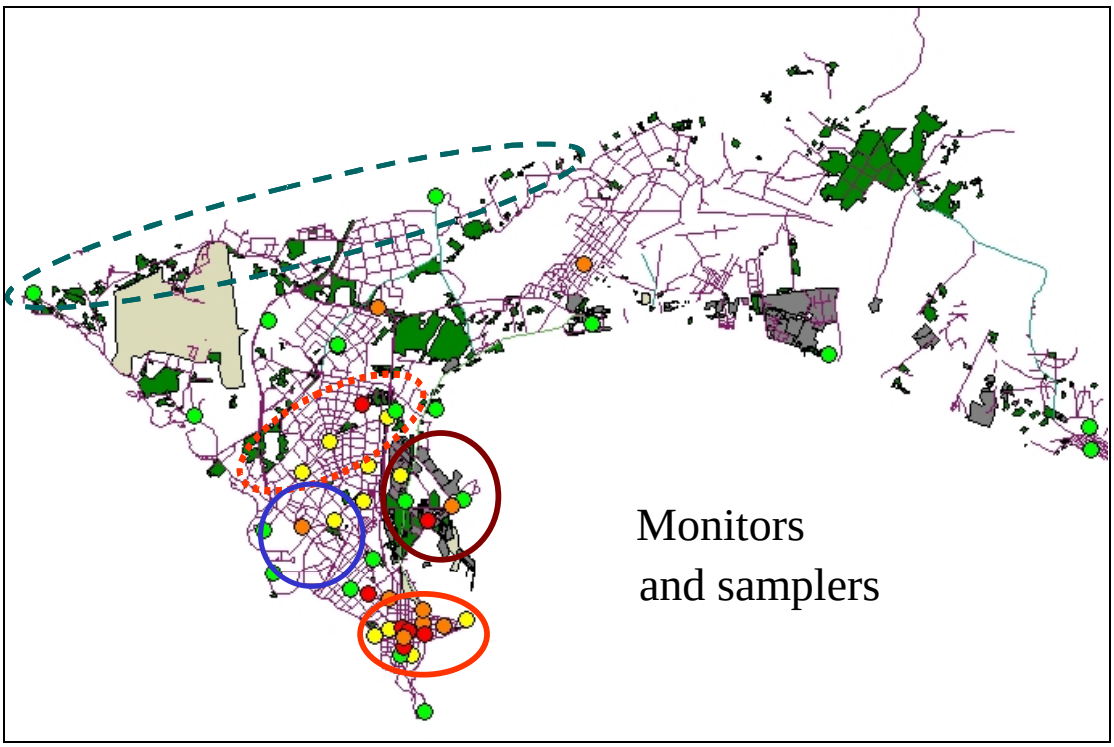

Figure 3: Areas for air quality monitoring stations.

Based on the preliminary studies we have selected five general areas in Dakar, where monitoring data should be collected in the future. The five general areas are indicated in Figure 3:

- The commercial city centre of Dakar, road side station
- An urban road side station in the Medina area
- An urban background station in the northern Dakar city area
- One industrial station in the eastern Dakar, close to the BelAir area
- One regional background station, upwind from the city along the northern coast

We have thus proposed to transform the "mobile station" as indicated in the ToR to a permanent station in order to strengthen the continuous and consistent air quality measurements in Dakar.

Based on the findings from the screening studies indicating that PM is the major air pollution problem in Dakar, we have added two or three PM_{10}/$PM_{2,5}$ samplers to the monitoring network (one sequential and two manually operated).

4.1 Urban road side station, City centre of Dakar

4.1.1 Alternative 1: Boulevard de la Republique

The first priority location for a permanent monitoring station in the urban city centre of Dakar may be located next to the Cathedral (La Vierge Marie Mere de Jesus le Sauviour) on the Boulevard de la Republique.

Figure 4: The first priority monitoring station position in the urban centre of Dakar.

The station will be placed inside the fence east of the Cathedral, about 7 m from the street. The site is characterised as an urban traffic station (UT). The indicators measured here will be:

NO_2, SO_2, CO, Ozone, PM_{10} and $PM_{2,5}$.

A letter will be prepared to the head of the Church for the application to use the ground.

4.1.2 Alternative 2: Place de Soweto

As a second priority site for an urban air quality monitoring station has been selected inside the Musée de Dakar (Université de Dakar). The shelter may be placed inside the fence about 5 m from the gate. The site here is also urban traffic (UT).

The indicators measured here will be:

NO_2, SO_2, CO, Ozone, PM_{10} and $PM_{2,5}$

A letter will have to be prepared for the IFAN de Dakar.

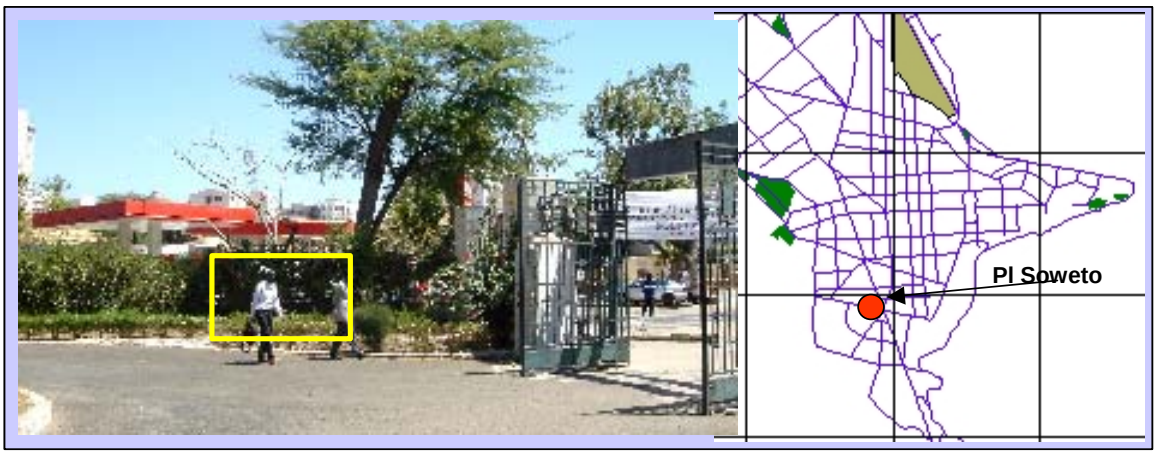

Figure 5: The second priority position in the urban centre of Dakar.

4.2 Urban road side station, Medina area

An urban background/roadside station has been identified near the gate at the Douta Seck Cultural Centre in the Medina area on the southern side of the Avenue Blaise Diagne.

Figure 6: The urban background/road side station located in the Medina area of Dakar, placed east of the gate entrance inside the fence.

Two positions were selected inside the fence of the centre; one east of the gate (see Figure 6) and the other one 3m west of the gate. The site is characterised as an urban traffic station (UT).

The indicators measured here will be:
NO_2, CO, and PM_{10}

A letter will have to be prepared for the Ministry of Culture. The contact person in the centre is Mr Kebe.

4.3 Urban background area, Northern Dakar

An urban background station was identified inside the ground of the Eglise St Maurice in the HLM4 area.

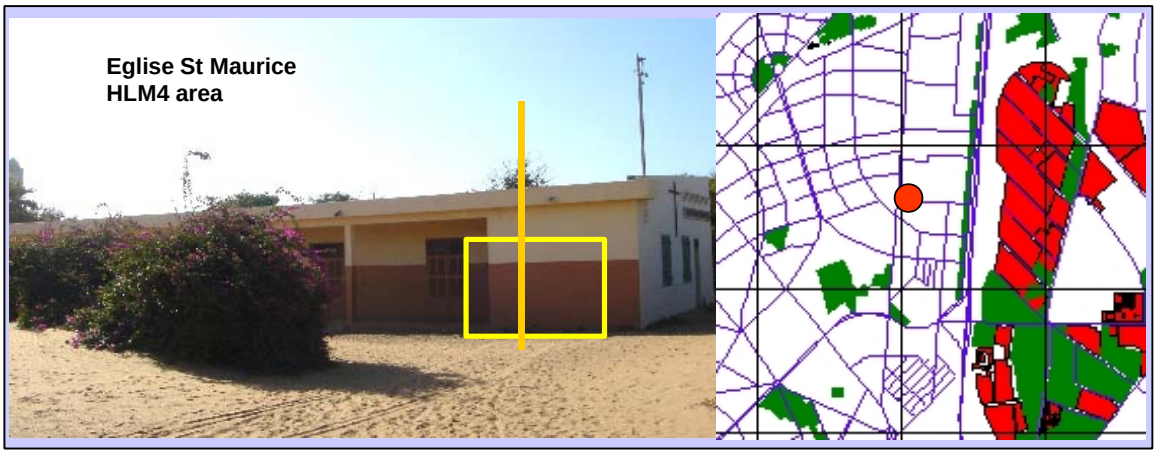

Figure 7: An urban background station with a meteorological tower located inside the Eglise St Maurice church ground at the HLM4 area.

The shelter with the ten meter meteorological mast will be placed next to a 4 m high building, about 100 m from the Cheikh Ahmadou Bamba Mbacke road running outside the area. The area seems to be a secure place and guards are always present. The site is characterised a san urban background station (UB).

The indicators measured will be:
PM_{10}, NO_2, SO_2 and ozone.

In addition the meteorological parameters measured on a 10 m mast will be, wind speed and direction, temperature, vertical temperature difference, turbulence, relative humidity, pressure, precipitation (and optional net radiation).

The contact person is Abbé Joseph Touré, tel: 825 2211.

4.4 Urban industrial station, near Bel-Air area

Two alternative sites were selected for location of the monitoring station in the industrial area. Both of these locations are situated closed to the Bel-Air area in eastern Dakar and are characteristic for an urban industrial site (UI).

The indicators measured at this station will be:
PM_{10}, $PM_{2,5}$, NO_2, SO_2, BTEX and ozone.

4.4.1 Alternative1: Gendarmerie at Av. Felix Ebou

A well-suited building belonging to the Gendarmerie du Port Authority was identified for placing a shelter is on top of the building. The intake of air would then be about 7 m above the surface. The location is downwind from the entire industrial area of Bel-

Air, downwind the Senelec power plant and also about 15 m downwind the Avenue Felix Ebou. It will thus be important to place the air intake on top of the shelter. In this way we will detect the general plume of pollutants from the industrial area and to a less degree catch the micro scale impact of emissions from cars on the street.

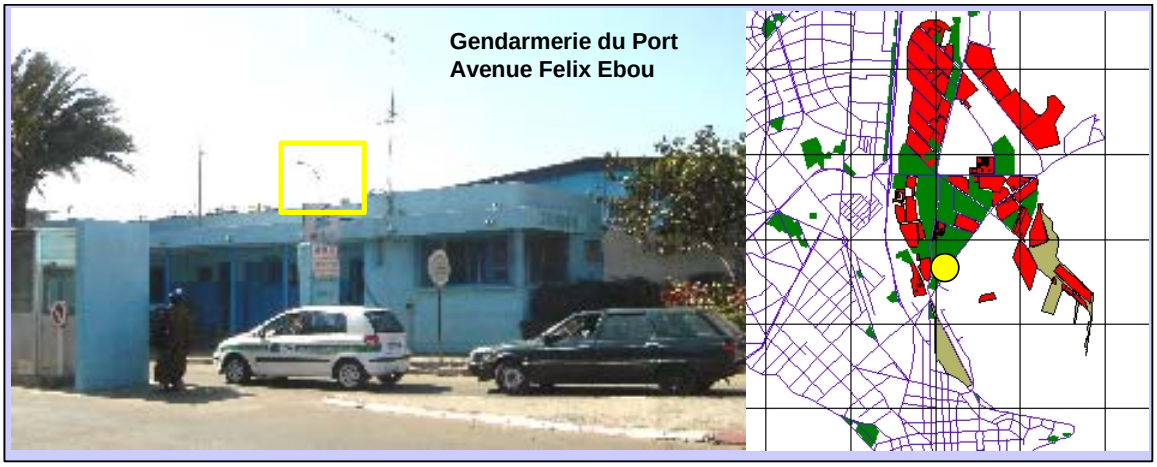

Figure 8: An industrial station (road side) at the roof of the police station on Avenue Felix Ebou.

The site will be characteristic for an urban industrial site (UI). A letter will have to be addressed to the Authorities. A contact person is Commandant Ambroise Sarr, tel: 8094545.The indicators measured here will be:

PM_{10}, $PM_{2,5}$, NO_2, SO_2, BTEX and ozone.

4.4.2 Alternative 2: Caserne du Potou de Bel-Air

An alternative location of the monitoring station in the industrial area may be at the roof of the security building, close to the gate of Caserne du Gendarmerie Poyou de Bel-Air.

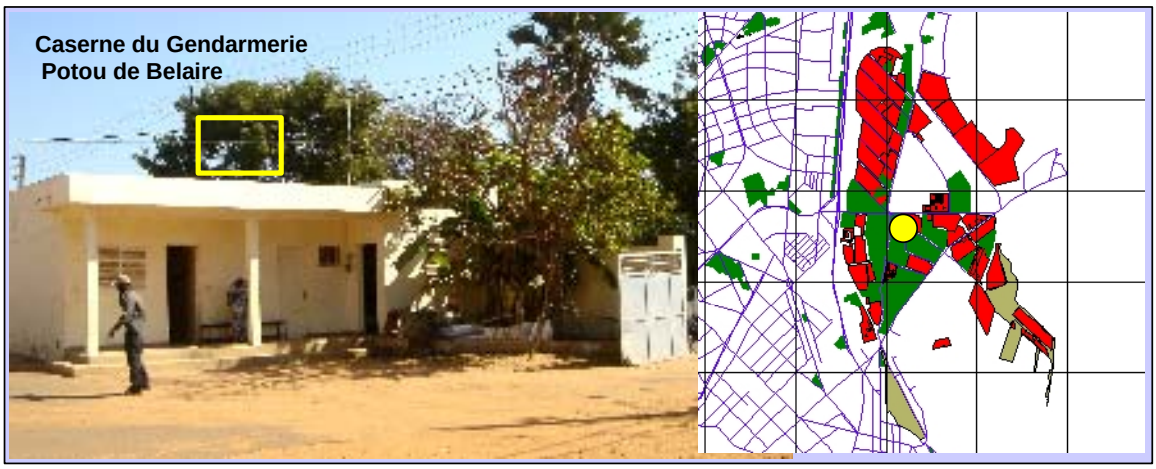

Figure 9: The alternative industrial station at the roof of the security room inside the gate of the Caserne Gendarmerie Potou de Belaire.

The responsible person for the Caserne is Mr Kane. A letter has to be addressed to the Gendarmerie attention The Captain Mr. Ndao located at Mole 1 service du port.

The indicators measured here will be:
PM_{10}, $PM_{2,5}$, NO_2, SO_2, BTEX and ozone.

4.5 Regional background station, northern coast

Two alternatives for a regional background station have been identified along the northern coast in areas usually not influenced by local emissions from Dakar area.

The indicators to be measured at the background station will be:
Ozone, PM_{10}, and NO

4.5.1 Alternative 1: Club BCEAO in the Yof area

The first priority area was found inside the club of the BCEAO bank in the eastern Yof area. The area seemed clean and well protected, and the shelter may be placed just inside on of the gates on the northern side of the complex.

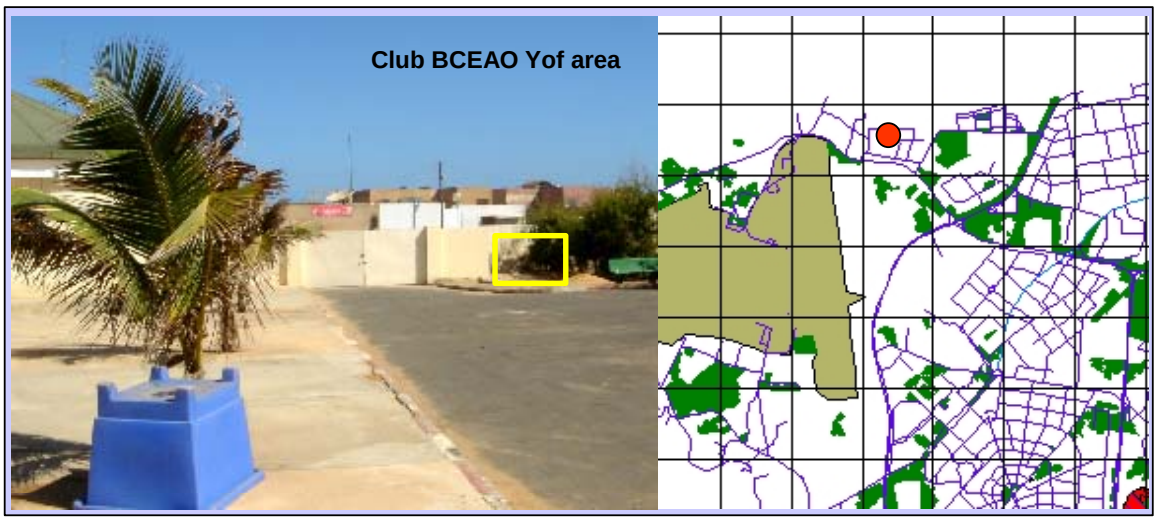

Figure 10: The first priority location of a regional background station for Dakar located at the northern coast of the Yof area inside the protected club of BCEAO bank.

The site is characteristic for a rural background station (RB). A letter has to be addressed to the Patrimoine at the head office of BCEAO bank. The telephone number was given: 8390500.

4.5.2 Alternative 2: The Meridien Golf club

An alternative location to the Yof area will be to locate the shelter inside the Meridien golf club area. We found a suitable place next to the driving range, close to a small brick shelter that was half way built. The site is characteristic for a rural background station (RB).

The golf club is an independent organisation from the Meridien hotel, and a request letter asking for permission to use the ground has to be addressed to the Director Mr. Osmand Diallo.

Telephone: 206704, Fax no: 8203956.

Figure 11: An alternative location of a regional background station for Dakar located at the northern coast inside the Meridien golf course.

The indicators to be measured at the background station will be:
Ozone, PM_{10}, and NO_2.

4.6 Possible locations for PM_{10}/$PM_{2,5}$ samplers

The main air pollution problem in Dakar is suspended dust. To improve the information collected concerning the air quality, it may be necessary to add two or three sampling sites for PM_{10} and/or $PM_{2,5}$. This will at the end be a question of available funds within the budget given to the project.

We have at this moment identified a few locations, which may be used for the purpose. These sites are described below.

We will for this purpose propose to use small "MiniVol Portable Ambient Air Samplers", which enable sampling of particulates (PM_{10} and $PM_{2,5}$). This is low-cost, portable battery-operated sampler. It is programmable using a 7-day programmable timer, easy to site, and does not require a power source. The "MiniVol" measures 64 cm high, and weighs 8.5 to 11 kg

Filters will have to be collected manually and analysed by gravimetric methods. The gravimetric analysis of particles collected on a filter is a simple, accurate and widely used method for determination of particle mass concentration. It requires accurate measurement of the sampling flow rate, and measurement of the net mass collected on a filter. This is done by weighing the filter before and after sampling with a balance located in a temperature and relative humidity-controlled environment. We may also introduce simple reflectrometic methods to estimate black smoke concentrations. The laboratory at DEEC will have to be equipped with the adequate instruments for these analyses.

4.6.1 Sandaga marked

The balcony of Pharmacie Guigon, which is located at the end of Avenue Pompidou across the square in front of the Sandaga Marked, would be a perfect place for a MiniVol sampler.

The sampler may be brought to the balcony every week or the filter may be changed manually every week while the sampler is permanently located at the balcony. The owner will have to be contacted in order to get permission to place the sampler there.

4.6.2 University

Another possible location for a MiniVol sampler may be on the roof of a small office building close to the gate of the University. This location was also used for the passive sampling campaign.
It will, however, be a question of security during the few days when the sampler will have to be exposed in field. Bruno Legendre may contact the owner of this building.

4.6.3 Gibraltar area

A sequential $PM_{10}/PM_{2,5}$ sampler may be placed close to the Performances building in the Gibraltar area to monitor the Dakar (sub)urban background concentrations measured as 24 hour average concentrations.

At this site we will try to use a dichotomous sampler (single of sequential) to sample PM_{10} and $PM_{2,5}$ simultaneously as 24-hour average concentrations. One type of these samplers may be the SA241 Dichotomous Sampler RFPS-0789-073 (Virtual Impactor). This sampling module has Size Selective Inlet with 10 micron cut-point; virtual impactor head has single-stage EPA design with 2.5 microns cut-point. The filter holders are clearly marked "Coarse" and "Fine" and sealed with separate hand nuts. Filters have to be changed manually once a week.

4.6.4 The Pikine area

The Pikine area in the north-eastern part of Dakar is one of the most polluted areas in the region. We have not selected a specific point for measurements in this area, but we will propose that intermittent measurements using the MiniVol samplers will be undertaken in this area. The purpose will be to identify the typical air pollution concentrations and compare them with other areas of Dakar.

4.6.5 Place de OUA

The last of the possible locations for MiniVol samplers are at the post office close to the Place de l'Unite Africaine. We discussed the possibility to place a MiniVol sampler at the roof of the Post Dakar Liberty building, and the local representative was positive to this.

However, this is only an option and we will have to send an application letter to Mr Moussa Ndaye, tel: 825 3862 to have a general permission to place the sampler on the roof of the post office

4.7 The monitoring network in summary

In order to meet the objectives defined for the monitoring program, we have designed a monitoring network for Dakar with 5 permanent automatic air quality stations, one meteorological station and two or three sampling stations for PM_{10} and/or $PM_{2,5}$. The following instruments are assigned to the automatic air quality monitoring 5 NOx monitors,

- 5 PM_{10} monitors,
- 2 $PM_{2.5}$ monitors,
- 3 SO_2 monitors
- 2 CO monitors
- 3 Ozone monitors
- 1 BTEX monitor

In addition there will be one automatic weather station, 3 manually operated MiniVol Samplers and one sequential PM sampler. The monitoring programme is presented in the following table and in Figure 12.

Table 3: The continuous air quality monitoring programme for Dakar, considering the first alternative for the location of each permanent station.

Site	Name	Type	NO2	SO2	CO	PM10	PM2,5	O3	BTEX
1	**Boul. Rep**	**UT**	**X**	**X**	**X**	**X**	**X**	**X**	
2	**Medina**	**ST**	**X**		**X**	**X**			
3	**HLM4**	**UB**	**X**	**X**		**X**		**X**	
4	**BelAir**	**UI**	**X**	**X**		**X**	**X**		**X**
5	**Yof**	**RB**	**X**			**X**		**X**	

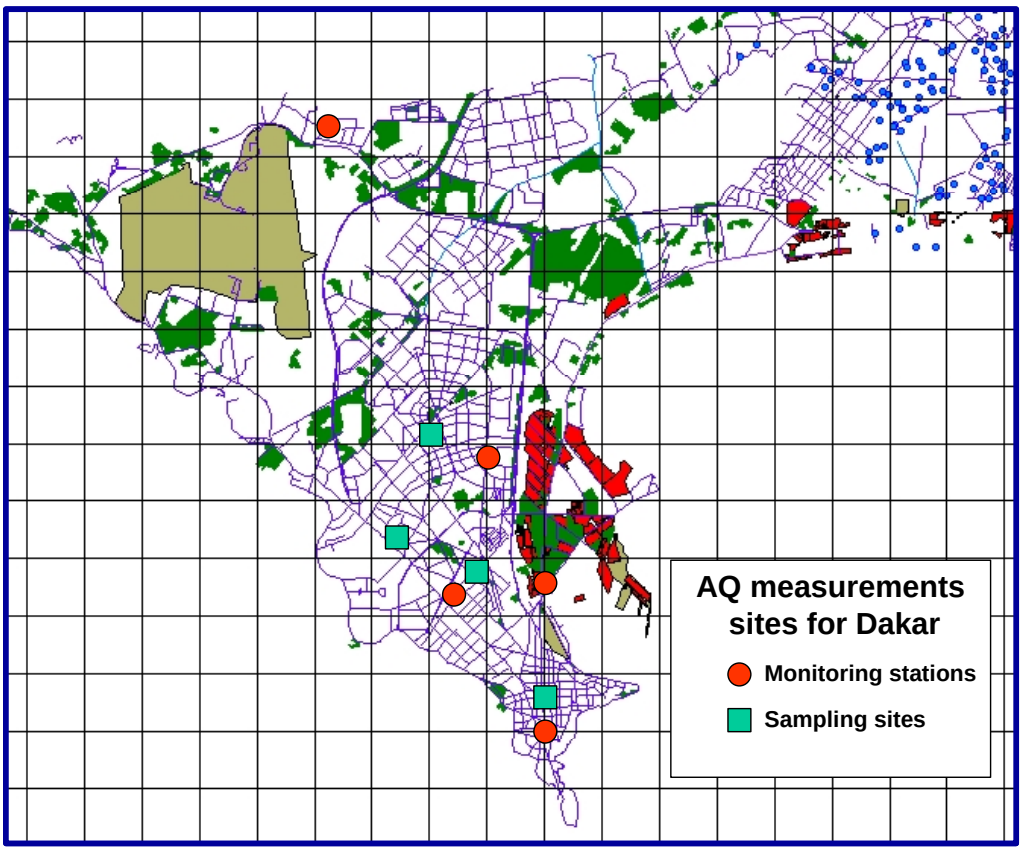

Figure 12: A summary of measurement sites selected for the air quality monitoring programme in Dakar.

A summary of the locations of monitors and samplers selected for the Dakar air quality monitoring programme is presented on the map in Figure 12.

The Dakar city is well covered, but it remains to receive feedback from the landowners concerning permissions to locate the monitoring station shelters or the samplers at the identified locations.

After permissions have been given the sites will have to be prepared with adequate platforms, which will be specified by the selected instrument providers. Power and telephone lines will also have to be prepared at all sites for monitoring (shelters).

The picture shows a typical shelter for monitoring stations. The dimensions is about 3x2x2,5 m.

5 Technical requirements of equipment

The full list of technical specifications of the instrumentation will be provided in the tender documents. This list will include instrument requirements, data transfer, shelters and necessary infra structure. Technical requirements of monitors, instruments and calibration gases will also be included.

Automatic air quality monitors will be located inside an air-conditioned shelter at the permanently located automatic air quality measurement station

5.1 Shelter

The shelter will include necessary power requirements (220 - 240 V) and an option for stabilization of the electric power supply. It will have a minimum number of electric circuits: 3, each protected with switch breakers. The shelter will be fully air conditioned to meet a requested indoor temperature of 25 to max 30 °C, preferably stable within ± 1 °C. It may be necessary to use split unit air condition. Rack for monitors will be installed and equipment for securing calibration gas cylinders to the shelter wall inside the shelter.

The shelter should be steel plated, painted white, with no windows and door lock. It should be isolated sufficient to maintain the requested indoor temperature in Dakar. Excess air from the air intake manifold and monitors must be ventilated outside the shelter.

The air quality instruments inside the shelter will be based on available automatic monitors. All information collected at each station will thus be available on-line at a central database or via Internet solutions to the different users which may be interested in this information.

5.2 Automatic monitors available

Methods and instruments for measuring air pollutants continuously must be carefully selected, evaluated and standardised. Several factors must be considered:

- *Specific*, i.e. respond to the pollutant of interest in the presence of other substances,
- *Sensitive* and range from the lowest to the highest concentration expected,
- *Stable*, i.e. remain unaltered during the sampling interval between sampling and analysis,
- *Precise*, *accurate* and representative for the true pollutant concentration in the atmosphere where the sample is obtained,
- *Sampling time* should be adequate for the required needs,
- *Reliable and feasible* relative to man power resources, maintenance cost and needs,
- *Zero drift* and calibration (at least for a few days to ensure reliable data),
- *Response time* short enough to record accurately rapid changes in pollution concentration,

- *Ambient temperature and humidity* shall not influence the concentration measurements,
- *Maintenance time* and cost should allow instruments to operate continuously over long periods with minimum downtime,
- *Data output* should be considered in relation to computer capacity or reading and processing.

If one consider the typical air concentrations of some pollutants of interest in air pollution studies, it is seen that as we go from background to urban atmosphere and from urban into the down wind area of an industrial complex the concentration for the most common pollutants may increase roughly by a factor 1000. In the next step from ambient air pollution to emission measurements we see another factor of about 1000. The selections of instruments have therefore to be set to measure over the "correct" range of pollution levels.

Analytical principles or measurement methods used in automatic air pollution monitors are:

- UV fluorescence for SO_2
- Chemiluminescence for NO_2
- Non-dispersive infra-red spectrometry for CO
- Gas chromatograph for benzene and VOC
- UV photometry for ozone
- Atomic absorption spectroscopy for lead

In more details the commonly used methods for automatic monitoring of some of the major air quality indicators are discussed in the following:

Sulphur dioxide (SO_2)

SO_2 should be measured from the fluorescent signal generated by exciting SO_2 with UV light.

Nitrogen oxides (NO and NO_2)

The principle of chemiluminescent reactions between NO and O_3 will be used for measuring NO_X. NO and total NO_X is being measured.

Ozone (O_3)

An ultraviolet absorption analyser is being used for measuring the ambient concentrations of ozone. The concentration of ozone is determined by the attenuation of 254 nm UV light along a single fixed path cell.

Suspended particles; TSP, PM_{10} and $PM_{2.5}$

Gravimetric methods including a true micro weighing technology have been used to measure ambient concentrations of suspended particulate matter. For automatic monitoring an instrument named "Tapered Element Oscillating Microbalance (TEOM)" has been most frequently used. Using a choice of sampling inlets, the hardware can be configured to measure TSP, PM_{10} or $PM_{2,5}$.

Measurement on filter tape using the principles of beta attenuation for estimating 30 minute or one hour average concentrations of PM_{10} or $PM_{2,5}$ have been operated with an air flow of about 18 l/min.

Carbon monoxide (CO)
The CO analyser often used in urban air pollution studies is a non-dispersive infrared photometer that uses gas filter correlation technology to measure low concentrations of CO accurately and reliable by use of state-of-the-art optical and electronic technology.

BTEX monitor
A multipurpose gas chromatograph has been designed to continuously monitor single or multiple gas components in a wide range of applications. The BTEX analyser provides direct measurement of Benzene, Toluene, Ethyl benzene and Xylene's in ambient air. It employs a photo ionisation detector (PID) as the sensing element. This detector is specific to volatile organic compounds. The Benzene, Toluene, Ethyl benzene and Xylene's in the gas sample are physically separated using proprietary GC columns.

5.3 Data transfer systems

All data from the instruments mentioned above may be collected by a data logger and transferred directly to a database for processing, control and presentations.

There are many different options existing on the market for efficient data communication from monitors to a database. The various conditions at the locations decide the best solutions. Several factors influence the final decision such as availability of telephone networks, quality and speed of the network, the amount of data to be transferred and the frequency of transfer.

5.4 Calibration laboratory

To ensure that the air pollution data collected meet the national and international requirements for quality assurance and quality controls (QA/QC) it will be necessary to establish a maintenance and calibration laboratory in Dakar. This laboratory is of crucial importance for keeping up a good quality monitoring system and will, after adequate training, also serve a maintenance and service laboratory for DEEC.

The maintenance and calibration laboratory should be equipped with gas monitors in addition to the multipoint calibration units, to enable calibrations of gas standards. Expert personnel have to be trained locally in Dakar to operate the monitors for calibration reasons. Some experts will also have to be prepared and trained to carry out systematic site visits, checks and audits of the monitoring programme.

A number of monitors for the purpose of standards controls and calibrations should be placed in a rack in the calibration laboratory. The complete set-up includes the following instruments:

- NO_x monitor
- SO_2 monitor
- O_3 monitor
- CO monitor
- Data acquisition system, Data logger and PC
- Zero air, two point calibration unit
- Calibrator, Multipoint calibrator
- Accessories
- Gases

NILU will establish the necessary expertise to operate the whole system in the laboratory at DEEC. If necessary NILU could be contracted to perform Audits once a year in the future.

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ABSTRACT
This report covers 3 Sub-tasks of the project: 4.1-Define monitoring objectives, 4. 2-Design the monitoring network and 4.3-Perform site studies and site evaluation; and corresponds to the deliverables 4a "Monitoring objectives and design of monitoring network" and 4b "Sighting report for the final measurement network". The monitoring objectives and the design of the monitoring network for Dakar are presented in this report. The number of monitoring stations and the indicators to be measured on each station are also presented. The representativity of the different stations is defined and the general area of where to establish the individual stations are stated. The sites are characterised according to standard reporting procedures.

NORWEGIAN TITLE

KEYWORDS Air quality monitoring	Air quality assessment	Senegal

ABSTRACT (in Norwegian)

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B Restricted distribution
C Classified (not to be distributed)