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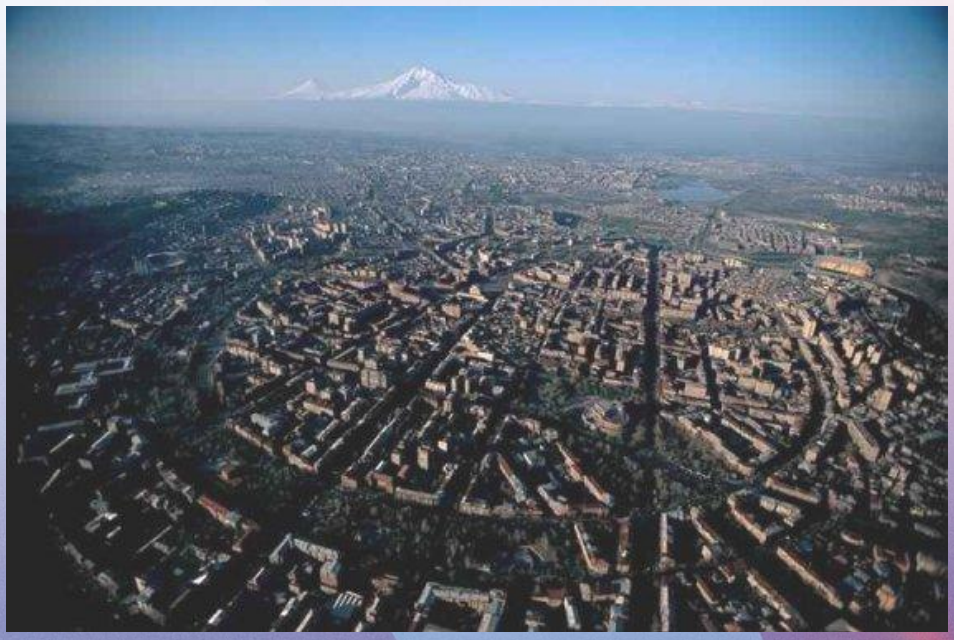
Mission report: Air quality management feasibility study for Yerevan, Armenia

1-5 February 2010

Li Liu and Dag Tønnesen



Norsk institutt for luftforskning
Norwegian Institute for Air Research
NILU

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Summary

A mission to Yerevan, Armenia, has been carried out within the project "Air quality management feasibility study for Armenia". The project is financed by Norwegian Ministry of Foreign Affairs. The objectives of the feasibility study were to initiate the project activities, including a kick-off meeting in Yerevan with local experts, to evaluate the existing air quality monitoring system, and to perform a screening study in Yerevan based on passive samplers for NO_2 and SO_2, as well as to understand the air quality management structure in Yerevan.

The mission took place in the period 1-5 February 2010. It was carried out by two scientists from NILU – Norwegian Institute for Air Research, Dag Tønnesen and Li Liu. Kick-off, information meetings and field survey have been carried out covering the existing monitoring system and pollution sources in Yerevan. Recommendations and adjustment have been made based on the actual state of air quality monitoring and management in Yerevan. It was agreed to change the planned screening study into an inter-comparison experiment with passive samplers in Yerevan, because a passive sampling network already was running at Yerevan with good spatial coverage. It was also identified that technical support and instruments maintenance for automatic monitors should be prioritised, because the existing system was in a very poor situation for operation due to lacking technical support.

The main conclusions were that the Armenia authorities needed support in establishment of a complete air quality management system containing automatic data acquisition, data storage, data statistics and evaluation tools, as well as a tool to present GIS based data on the internet. A review of the existing network regarding both locations of stations and parameters to be measured in Yerevan should also be carried out to find out how many stations and which instrument types were needed.

This mission report includes facts from meetings and information from relevant references. The documents and materials received through the mission are presented in the appendixes.

Mission report: Air quality management feasibility study for Yerevan, Armenia

1-5 February 2010

1 Background and objectives

The background for the mission was to prepare a project proposal for establishing an Air Quality management system (AQMS) for Yerevan, Armenia. A feasibility study for establishing such a system was financed by the Norwegian Ministry of Foreign Affairs, and this mission to Yerevan was conducted to initiate the feasibility project.

The objectives of the mission were to:

1. have a kick-off meeting in Yerevan with participation from NILU and local experts
2. evaluate the existing local monitoring network and institutions
3. perform a screening study in Yerevan based on passive samplers for NO_2 and SO_2

In addition, the mission was also aimed to understand the official structures and responsibilities for local air quality in Yerevan, to get information of local capacity for operating and maintaining monitoring equipment, and to find out information on which institutions are processing data concerning local emissions and meteorology.

2 General information of Yerevan

2.1 Location and geographical conditions

Yerevan is the capital and the largest city in Armenia. It is located in the centre-west of Armenia (Figure 1). The coordinates are approximately 40°11'N/44°31'E. The northern part of the city is surrounded by mountains on three sides, and the southern part of the city descends to the bank of Hrazdan River. According to the existing borderlines, the city occupies 227 km^2. The extension from the north to the south is about 16 km, and from the west to the east is about 13.5 km.

The elevation of Yerevan ranges from 850 to 1420 meters above sea level, and the climate is typically a dry continental climate. It has characteristics of hot long-lasting summers, short cold winters, very short spring and long-lasting and mild autumn. The average temperature in Yerevan varies from +8.8°C to +11.6°C. The highest temperature ever registered was 41.8°C, and the winter temperature can reach -20°C or -30°C. The annual solar radiation reaches 2700 hours, about 142 $kcal/cm^2$, which is favourable for photochemical smog when precursors are present. The annual precipitation varies from 300 to 350 mm. Most of the precipitation occurs in spring and in autumn. The summer precipitation is characterised by short cloudbursts. Since a large part of the city is surrounded by

mountains, long lasting fog and inversions are often observed in autumn and winter.

Figure 1: Geographical location of Yerevan and Yerevan from space.

2.2 Population

The population in Yerevan made up to 1 102 900 people in 2005, and the density of the population is 4859 inhabitants per square km. Yerevan occupies 0.76% of the territory of the country with 34% of the whole population.

The urbanisation process in Yerevan was intensive during the Soviet period. The population in Yerevan was 6.5% of the total population of Armenia in 1920, and the number increased to 36.5% in year 1990, as results of large migration into Yerevan city. After the Soviet period, the population growth slowed down and even decreased. The registered population in 1989 was 3 287 700 inhabitants, and that reduced to 1 102 900 in 2005. The changes were mainly caused by labour migration and reduced birth rate. In the last 20 years, the birth rate in Yerevan has decreased 2-2.5 times. The decrease in the birth rate was caused by the economic decline in Armenia and the labour migration of men of reproductive age.

2.3 Economic activities and the urban development

Yerevan is the centre of economic activities of the country, and the restructuring of industrial sectors took place after the Soviet period. During the Soviet period, the city was highly polluted with emissions from industries, especially from chemical and construction industries. Those factories were often in operation without necessary treatment of emissions. Before the 1990ies, the major industries

in Yerevan were mechanical engineering, chemical and building industries. After the restructuring, light manufacturing and food industries became prevailing sectors. With the change of industries in Yerevan, up to 51% of industrial emissions were eliminated.

According to data from 2005, there were 1595 enterprises in Yerevan, of which 87.7% were processing industries, including food, drinks, paper, metallurgic, as well as wood production. A large part of the enterprises (584 of them) was in the food and beverage industry, about 239 enterprises were in paper industry and 131 enterprises in metallurgic production, some in timber and wood processing industry. Table 1 shows the emissions from stationary sources in Yerevan in 1990 and from 2000 to 2005. The data were collected by the UNEP project "GEO Yerevan" (Daneilayan et al., 2007).

Table 1: Emission in Yerevan from stationary sources for1990 and 2000-2005. (unit: tons).

Pollution/year	1990	2000	2001	2002	2003	2004	2005
SO_2	23269	302	263	274	299	407	474
NO_2	14783	1021	766	507	581	573	854
CO	124826	512	476	428	530	462	423
Dust	3755	176	156	281	273	301	651

Source: UNEP GEO Yerevan, 2004-2006 summary report (Daneilayan et al., 2007).

Yerevan has 12 administrative districts, as indicated in Figure 2. The industries are mostly located in the south of the city, in the districts Sengavit and Erebuni.

Figure 2: Administrative districts in Yerevan.

2.4 Energy consumption in Yerevan

The electricity supply for Yerevan consists of the following units: electric power production by thermo-power stations (27%), hydropower stations (33%), and Armenia nuclear power station (40%).

Yerevan thermo-power station is positioned in the south of Yerevan. The production of electricity in the Yerevan thermo-power station has been reduced about four times compared to what it was in 1990. Since 1998, the majority of electricity consumption units in Yerevan have been converted to be using gas, and the gas supply system of the city has been fully restored before 2005.

When Armenia was separated from the Soviet Union, the system for heating and hot water supply was in a very difficult situation, and some of them have been partially restored and are running. A survey carried out in 2000 showed that the heating in Yerevan was segmented as follows: electric heaters (50.1%), district heating (27.5%), wood fuel (15.4%), natural gas (4.4 %), kerosene (2.3%) and coal (0.3 %).

After the year of 2000, the number of buildings in Yerevan supplied by central heating were decreased drastically. In 2004, only 112 buildings in Yerevan were heated by centralised heating. As a result, the apartment owners use hot water heaters of various types. Since 2002, natural gas appliances were widely introduced on the market. A survey in December 2006 for three districts in Yerevan including Avan, Shengavit and Erebuni showed that about 46.8% of the apartments were using natural gas for heating and cooking. Presently, heating in Yerevan is mostly depending on gas and electricity.

All sources of energy used in transport in Armenia are imported, and there is no fuel production in the country. Petrol, diesel and compressed gas are the major fuels used in Armenia. Between 2001 and 2005, the fuel consumption in transport has increased by 40%, with a clear trend of increased use of compressed gas. Table 2 shows the fuel consumption in Armenia from 2001 to 2005.

Table 2: Fuel type and consumption in transport sector in Armenia, 2001-2005.

Years	**2001**	**2002**	**2003**	**2004**	**2005**
Petrol	66%	57%	52%	54%	47%
Diesel oil	24%	28%	30%	26%	29%
Compressed gas	10%	15%	17%	20%	24%
Total consumption (1000 tons)	285	312	366	401	391

Source: Sustainable urban transport in the city of Yerevan, Ministry of Nature Protection of Armenia (Tsarukyan et al. 2006).

2.5 Transportation in Yerevan

The most important transport means for passenger transport in Armenia are railway, motor vehicles, air, and electric transport. Approximately 50% of Armenia's vehicles are registered in Yerevan and about 70% of passenger transport in Armenia occurs in the city of Yerevan.

The transport in Yerevan is supplied by buses, trolleybuses, minibuses, metro, and private cars. According to Mr. Arman Vermishyan from Burg Youth Environmental Centre, Armenia, there were 48 bus routes, 9 trolleybus routes and 119 microbus routes in 2008, plus one underground line for public transport in Yerevan. On average, there are about 90 buses (state-owned and private), 50 trolleybuses and more than 2600 microbuses operating daily on the different routes in Yerevan. The main part of the passenger transportation, nearly 80%, is carried out by microbuses. There are also about 120 000 private cars registered in Yerevan. Almost one third of the private cars and buses use compressed gas, which is 2-3 times cheaper than petrol. The vehicle fleet increases by 9-10% every year.

The major population of the cars in Yerevan were produced before 1990, i.e. during the Soviet period, and are not equipped with emission after-treatment devices. Cars imported from other countries represented only about 5% of the vehicle fleet in 2005, although their number increased rapidly in the last years.

Transport is considered the biggest polluter in Yerevan. Pollutants of concern in Yerevan include: NO_2, CO, SO_2, dust, benzene, aromatic hydrocarbons, ozone and lead. A statistic number (Table 3) shows that emissions from transport in Yerevan are the largest compared to other emission sources in Yerevan. The conclusion is based on summing up all considered pollutants, although this is an

improper approach to estimate the real contribution of transport for different pollutants. However, to a certain extent, it indicates the large amount of emission from transport in Yerevan, Table 3.

Table 3: Total of harmful substances emitted to the atmosphere in Yerevan (unit: 1000 tons/yr).

Year	Industry	Energy	Transport	Total
1987	46.7	26.1	175.2 (71%)	248.0
1998	0.7	1.0	74.8 (98%)	76.5
2000	0.8	1.8	67.3 (96%)	69.9
2001	1.5	0.5	67.4 (97%)	69.4
2002	1.2	0.35	66.8 (98%)	68.4
2003	1.4	0.4	73.9 (98%)	75.7
2004	1.8	0.4	82.2 (97%)	84.4
2005	2.1	0.7	73.4 (96%)	76.2

Sources: Sustainable urban transport in the city of Yerevan, Ministry of Nature Protection of Armenia (Tsarukyan et al., 2006).

3 Nature of the air quality problems in Yerevan

3.1 Air quality in Yerevan

Yerevan was heavily polluted in the Soviet period with emissions from various industries, especially from chemical and construction plants. The city is surrounded by mountains on three sides, which is unfavourable for dispersion of air pollutants, since the emissions often are trapped by inversion layers, especially in the winter time. High temperatures in summer and autumn, in addition to strong irradiation in Yerevan provide suitable conditions for photochemical processes. Existing measurements of ozone and formaldehyde levels (Table 5) indicate the problem of photochemical smog episodes in Yerevan.

After the Soviet period, the industrial activities in Yerevan have decreased because of the economic crisis and restructuring of the country. The emissions from the industry sector were reduced considerably, however the air quality in Yerevan has not improved to the same degree as the decrease of emissions. The increased emission from the transport sector in the last years has been a major contributor for air pollution in Yerevan. Table 4 shows the drastically reduced emissions from industries and the actual improvement of the air quality.

Table 4: Emission reduction from industries and improvement of air quality in Yerevan for 1990 and year 2004-2005, in %.

Pollutants	Reduction of emissions	Improvement of concentration levels
NO_2	96	8
SO_2	98	31
Dust	72	44

Table 5 presents a summary of air quality measurements for 2008 and 2009. The data were provided by the Environmental Impact Monitoring Centre (EIMC). The major air pollution problems in Yerevan apply for dust, NO_2 and ozone. The problems are mostly linked to traffic emissions.

Concerning NO_2, the number of exceedances of the Armenia air quality standard (24 hours limit value: 400 µg/m^3) in 2009 was 115. While comparing with the WHO guideline value (2005) for one hour averaged concentrations of 200 µg/m^3 for NO_2, the number of exceedances for NO_2 would be high.

The measured ground level ozone concentration had a monthly average of 48 µg/m^3 in 2009. The monthly average in July 2009 reached at 120 µg/m^3, and the monthly averages from April to September were all above 90 µg/m^3 in Yerevan. These measurements indicate that the probability of frequently occurring ozone episodes in Yerevan is large. Considering the WHO guideline value (2005) for 8 hours ozone averages of 100 µg/m^3, the high ozone levels in Yerevan are expected to have rather large impacts both on human health and on the ecological system.

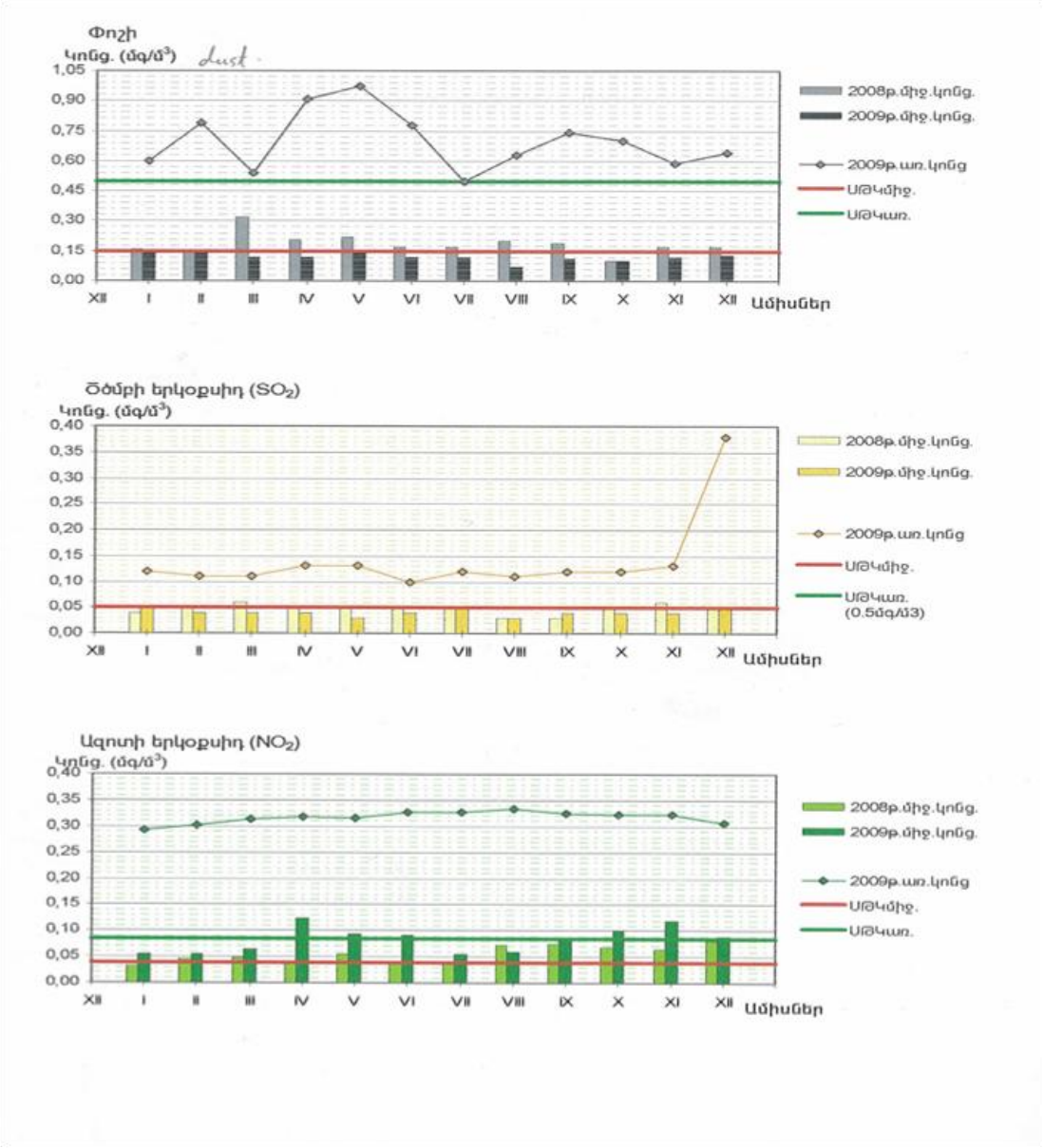
The particulate matter levels found in Yerevan are difficult to evaluate. Particulate matter in Yerevan is measured as particles larger than 0.95 µm, therefore the measurement of "dust" represents the total mass concentration of suspended particles with an particle size larger than 0.95 µm. The Armenia government has defined a 24 hours limit value of 150 µg/m^3 for dust, which often is exceeded. The monthly average levels of dust in Yerevan in 2009 vary between 60 µg/m^3 and 320 µg/m^3, and peaks are found in springtime. International limit and guideline values for particles are usually defined for PM_{10} and $PM_{2.5}$ (i.e. particles with aerodynamic diameters below 10 µm and below 2.5 µm, respectively), since these size fractions are easy to sample and can be addressed to certain adverse effects on human health. The lack of measurements of PM_{10} and $PM_{2.5}$ makes it difficult to quantify the sources of particles and also the effects on human health in Yerevan.

SO_2 concentrations (Table 5) are below the Armenia limits of air quality (24 hours limit value is 50 µg/m^3), but still much higher than the WHO guideline value (2005) of 20 µg/m^3.

Table 5: Overview on concentrations of air quality parameters in Yerevan, 2008-2009.

Criteria components, (Number of stations)	Maximum concentration (µg/m^3) and (Number of stations)	Average monthly concentration (µg/m^3)	Armenian Limit value (µg/m^3)
			24-hours
Dust (4)	640 (8)	130	150
Sulfur Dioxide (4)	380 (2)	50	50
Carbon Monoxide (1)	-	2350	30000
Nitrogen Dioxide (4)	307 (7)	900	40
Nitrogen Monoxide (4)	190 (8)	40	60
Ground Level Ozone (4)	70 (2)	48	30
Benzene (4)	178 (1)	15	100
Toluene (4)	679 (8)	8	600
Xylene (4)	157 (7)	13	200

Source: Air quality annual report 2009, Environmental Impact Monitoring Center (EIMC), Ministry of Nature Protection, Armenia.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Կոնց. (մգ/մ³)
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Կոնց. (մգ/մ³)
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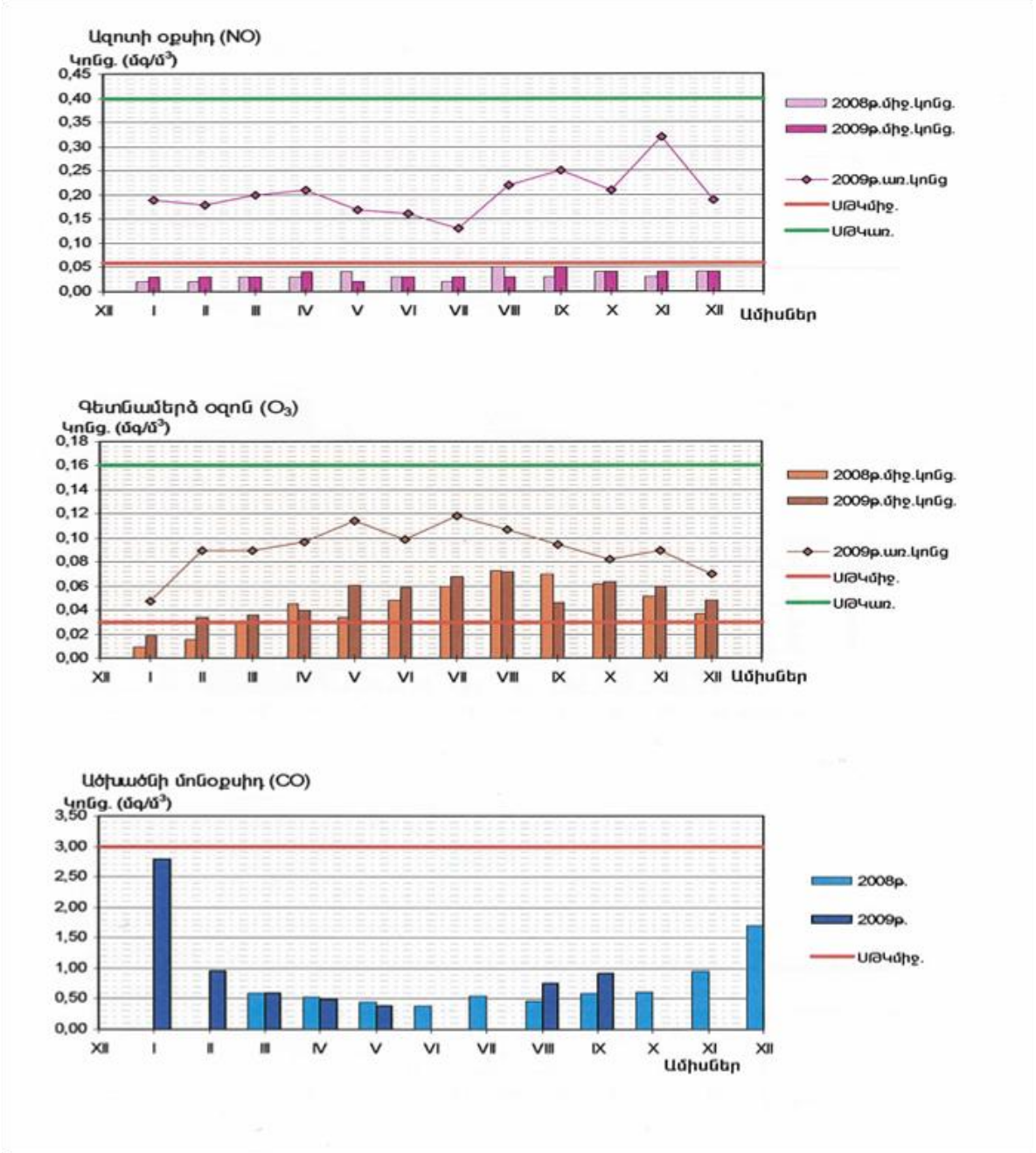

Figure 3: Monthly concentration of Dust, SO_2, NO_2, NO, O_3 and CO in Yerevan, 2008-2009. Unit: mg/m^3.

3.2 Emission sources in Yerevan

The major emission sources in Yerevan include:

1. Stationary sources (point sources)
   - Power plants
   - Enterprises
   - Heat Only Boilers (HOBs)

2. Transport
   Direct emissions from:
   - public transport
   - airplanes
   - private cars

   Indirect emissions of dust from resuspension

3. Emissions from stoves in apartments and public buildings

It was said during the meeting with EIMC that the emission data could be acquired through departments of the Ministry of Nature Protection.

4 The state of the air quality monitoring network in Yerevan

The air quality monitoring system in Armenia started operation in 1960. The Environmental Impact Monitoring Centre (EIMC) is the institution responsible for operating the monitoring system in Armenia, and reporting to the Ministry of Nature Protection. It has not stopped its activity after the independence, but it has been operating in very poor conditions. In the last 3 years, the air quality monitoring system has been equipped with new methods and new equipment through national or international projects, but faced many problems and challenges due to the lack of knowledge and funding. The cooperation with the EMEP program has continuously contributed to capacity building at EIMC, since the EMEP station in Armenia is run by EIMC.

The air quality monitoring network in Yerevan is measuring the concentrations of air quality parameters based on three different monitoring methods:

a. Air quality monitoring with passive sampling
   The passive samplers used have been developed by EIMC, and are produced locally. The components include SO_2 and NO_2.

b. Air quality monitoring with chemical solutions, active sampling
   The method is based on the absorption of a specific component from the ambient air in a solution. EIMC prepares the solution. The method is applied for SO_2, NO, NO_2, O_3, benzene, xylene, and toluene.

c. Continuous monitoring with automatic monitors
   EIMC has now 25 instruments for measuring CO, SO_2, $NO/NO_2/NO_x$. The instruments are positioned at 4 monitoring stations. Due to technical failures only 5 of the instruments were running at the time of the mission.

A passive sampling network in Yerevan started from 2008. Weekly sampling with passive samplers is carried out at 40 locations in Yerevan, with an exposure time of one week. The passive sampler was designed by EIMC and is produced locally at EIMC. The results from passive sampling were used to produce trend calculations with statistical methods and to produce concentration distribution maps. The instruments used for particulate matter are sampling "dust" (as defined above), and are inherited from the Soviet time, with no possibility to having the damaged or aged components repaired. It is urgent to replace the instruments with internationally recognised PM_{10} and $PM_{2.5}$ monitors.

Originally, 5 automatic monitoring stations have been established in Yerevan. One station ('No.18') was burned down and was not being rebuilt. Presently, 4 stations are equipped with automatic monitors. In total 25 monitors for SO_2 and NO/NO_x are operated at the four stations. The problem for EIMC is the lack of means or funding to maintain and run the system properly.

Since the instruments were not purchased directly by the end user (EIMC in Yerevan), and the company which acted as intermediary meanwhile disappeared, the EIMC does not get any technical support from the instrument producer. The monitors running in the air quality monitoring system were produced by the US company *Teledyne Analytical Instruments.* Due to the lack of technical support and proper maintenance, 20 out of the 25 monitors are out of operation. Although most of the instruments were purchased in 2008 or 2009, the actual operation time was mostly less than a year before they failed to run.

Figure 4 shows the location of the automatic monitoring sites in Yerevan. Station No.1 is located in front of the EIMC building, representative for residential area. Station No.7 which is located in the centre of Yerevan, at the side of a busy road, can be representative as a traffic site. Station No.8 is located in the northeast of the city, at the side of a road, surrounded by apartment buildings and close to a busy road connecting Yerevan and the outskirt area of the city. Another station, No.18, is located in the south of central Yerevan; the station was burned. Station No.2 (marked in red colour) is located in the south of the city, in an industrial area. There is a large chemical factory nearby.

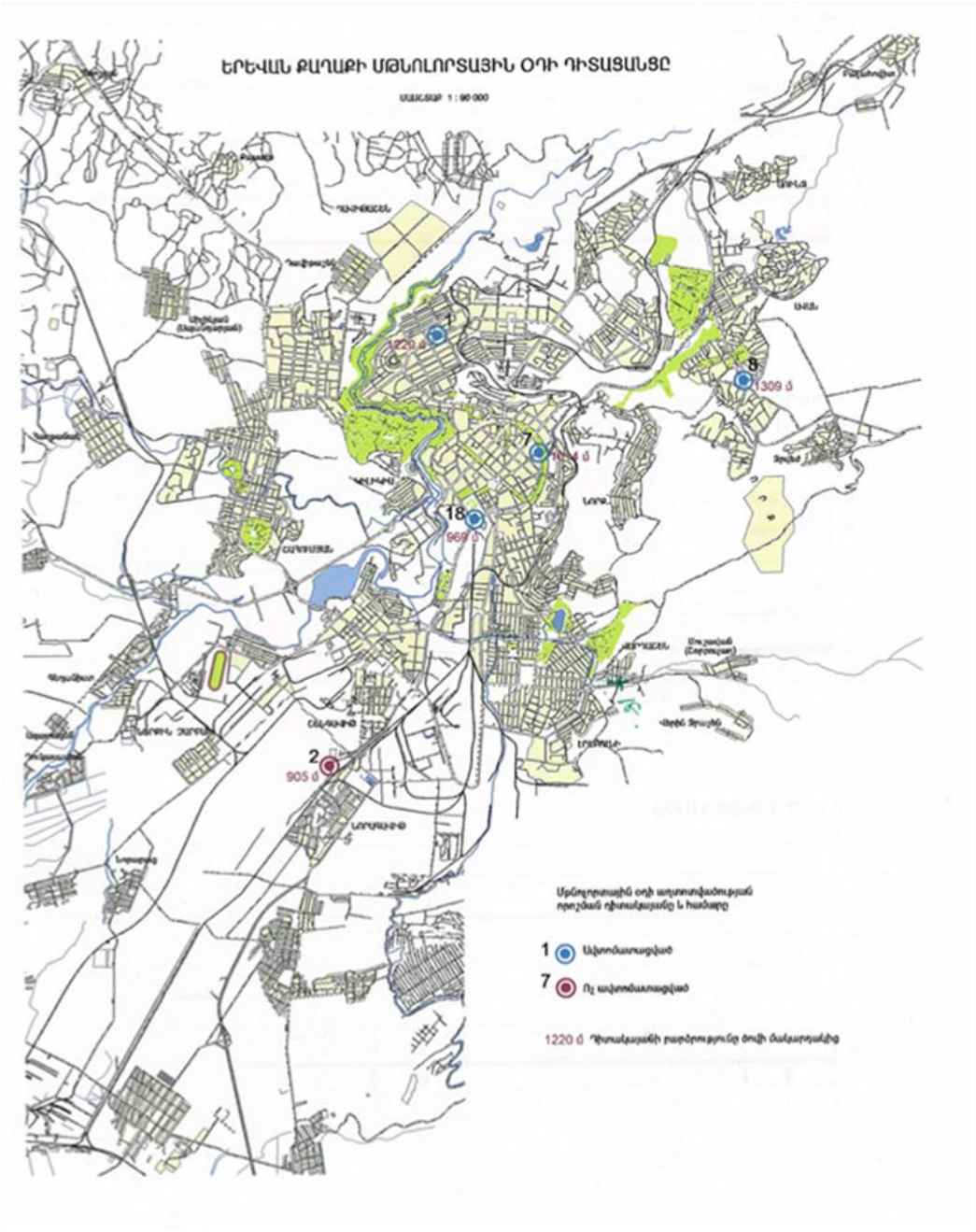

Figure 4: Locations of automatic monitoring stations in Yerevan.

The data measured by automatic instruments are collected manually from the stations and are then transferred into the database at EIMC. EIMC has been working on developing a system to process the data.

Tables 6, 7, 8, 10 give information about stations, including locations, representativity, starting dates, measurement methods, and state of instruments. Regarding the ID number of the stations, it was explained by EIMC that the ID numbers from Soviet time are still being used for the air quality monitoring system. The photos below show a station and instruments in the station in Yerevan.


TELEDYNE INSTRUMENTS
GAS FILTER CORRELATION CO ANALYZER

Table 6: Station No.1, location, measurement methods and instruments.

Station code and name	No.1 Ambient Air Sampling Station, Environmental Impact Monitoring Center	
Location	Address: 29 Komitas str., Yerevan, Armenia Location: N 40°12'21.47", E 44°31'19.04"	
Representativity of the station	Residential area	
Start date	From 1970s; there are results from 1987	
Measurement type	Components	Analysis methods
Passive samplers	NO_2 SO_2	Spectrophotometric Spectrophotometric
Active sampling	NO NO_2 SO_2 O_3 Dust Benzene Toluene Xylene	Spectrophotometric Spectrophotometric Spectrophotometric Spectrophotometric Gravimetric Chromatographic Chromatographic Chromatographic
Automatic monitors	CO SO_2 $NO/NO_2/NO_x$	IR non Dispersion, Not Working Fluorescence, Not Working Chemiluminescence, Not Working

Table 7: Station No.2, location, measurement methods and instruments.

Station code and name	No.2 Ambient Air Sampling Station, Environmental Impact Monitoring Center	
Location	Address: 135 Arshakunyac str., Yerevan, Armenia Location: N 40°07'41.90", E 44°28'42.16"	
Representativity of the station	Residential area	
Start date	From 1970s; there are results from 1987	
Measurement type	Components	Analysis methods
Passive samplers	NO_2 SO_2	Spectrophotometric Spectrophotometric
Active sampling	NO NO_2 SO_2 O_3 Dust Benzene Toluene Xylene	Spectrophotometric Spectrophotometric Spectrophotometric Spectrophotometric Gravimetric Chromatographic Chromatographic Chromatographic
Automatic monitors	-	-

Table 8: Station No.7, location, measurement methods and instruments.

Station code and name	No.7 Ambient Air Sampling Station, Environmental Impact Monitoring Center	
Location	Address: 51/7 Khanjyan str., Yerevan, Armenia Location: N 40°10'57.77", E 44°31'24.28"	
Representativity of the station	Residential area	
Start date	From 1970s; there are results from 1987	
Measurement type	Components	Analysis methods
Passive samplers	NO_2 SO_2	Spectrophotometric Spectrophotometric
Active sampling	NO NO_2 SO_2 O_3 Dust Benzene Toluene Xylene	Spectrophotometric Spectrophotometric Spectrophotometric Spectrophotometric Gravimetric Chromatographic Chromatographic Chromatographic
Automatic monitors	CO SO_2 $NO/NO_2/NO_x$	IR non Dispersion Fluorescence, Not Working Chemiluminescence, Not Working

Table 9: Station No.8, location, measurement methods and instruments.

Station code and name	No.8 Ambient Air Sampling Station, Environmental Impact Monitoring Center	
Location	Address: 32 Gay avenue., Yerevan, Armenia Location: N 40°11'27.02", E 44°34'01.49"	
Representativity of the station	Residential area	
Start date	From 1970s; there are results from 1987	
Measurement type	Components	Analysis methods
Passive samplers	NO_2 SO_2	Spectrophotometric Spectrophotometric
Active sampling	NO NO_2 SO_2 O_3 Dust Benzene Toluene Xylene	Spectrophotometric Spectrophotometric Spectrophotometric Spectrophotometric Gravimetric Chromatographic Chromatographic Chromatographic
Automatic monitors	CO SO_2 $NO/NO_2/NO_x$	IR non Dispersion Fluorescence, Not Working Chemiluminescence

4.1.1 Meteorology measurements

In 1992, Armenia became a member of World Meteorological Organization. The Ministry of Emergency holds the meteorological data. The data can be made available for the Ministry of Nature Protection upon request.

There are also meteorological instruments installed at each air quality monitoring station run by EIMC, on the rooftop of each station. At each site, there is a ~3 metres high mast. Thus, the sensors are placed at about 6 meters above ground. However, the meteorological instruments at those stations are not practically running, since some are broken. Only the one installed on the top of the four-floor building, where EIMC is located, is running and data are stored. There is a plan to replace all meteorological instruments at each of the stations, with equipment produced by a French company (La Crosse Technology).

4.1.2 Information for the Public

The air quality situation and data is published on the website of EIMC: http://www.armmonitoring.am/ in Armenian language.

5 Passive sampling in Yerevan and inter-comparison experiment with NILU passive samplers

There are 40 passive sampling sites in Yerevan, measuring NO_2 and SO_2 with a one-week exposure time; from Friday to Friday.

One of the major tasks of the first mission to Armenia was to evaluate the existing monitoring network, find suitable locations, and carry out a screening study for Yerevan with NILU passive samplers. Because of the barriers in language and communication, the existing passive sampling network is still rather unknown to the Norwegian project partner. It is obvious that a short-term screening study is unnecessary, but that an inter-comparison of the results of two types of passive samplers was useful.

Together with EIMC it was decided to carry out an inter-comparison experiment for NO_2 with passive samplers. For the existing 40 sampling sites in Yerevan, three NO_2 passive samplers were exposed in parallel at each site. One passive sampler from Armenia and two samplers from NILU were exposed for the same period, and EIMC carried out the analysis in the laboratory for their own samplers and applied the same method for one of the NILU samplers. The other NILU sampler was sent back to NILU and was analysed at the NILU chemical laboratory. The results were expected to be valuable for evaluation of the results obtained locally and of the chemical analysis methods carried out in Armenia.

80 NO_2 passive samplers and 4 blanks from NILU were delivered to EIMC.

It was also requested by EIMC to carry out the inter-comparison for 35 sites in Yerevan and 5 sites in another city. These 5 sites were selected by EIMC.

Passive sampler used in Yerevan

NILU passive sampler

Figure 5: Passive samplers from EIMC and NILU.

6 Recommendation regarding the air quality monitoring and management in Yerevan

The following recommendations are based on the state of the existing system. EIMC requested to support the operation of the monitoring network, and to integrate the Norwegian aid project to strengthen the future long-term air quality management in Yerevan:

- Changing the planned screening study into an inter-comparison experiment with passive samplers in Yerevan, since a passive sampling network with a good spatial coverage already was running at Yerevan.
- Emergency: 'First aid' in the laboratory directed to operation and maintenance of the automatic monitors. NILU suggests to have a NILU technical expert to visit Yerevan to help repairing the monitors and provide on-spot training.
- Building up a preliminary project for Yerevan with the air quality management system AirQUIS, developed by NILU.
- On-spot training of the staff in the instrument laboratory, establishing a QA/QC routine for the automatic monitoring network in Yerevan.
- Both a data acquisition and an air quality information distribution system are needed in Yerevan.
- Knowledge transfer would be essential. Knowledge of building up an integrated air quality management system can be transferred through the establishment of an AirQUIS system for air quality management in Armenia.
- Software, such as the AirQUIS system, for analysing both emission and measurement data and presenting data with GIS is needed for Yerevan.
- Instruments and software for data transfer are needed.
- More monitoring stations and instruments are needed at Yerevan and it is recommended to have a moveable station.
- NILU suggests to contribute with evaluation and review of the existing monitoring network and to recommend additional sites and parameters to be measured.

- It is possible and beneficial for EIMC to combine the project and existing EMEP activities in Armenia through the instrument maintenance and training.

7 References

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Environmental Impact Monitoring Center (2009) Air quality annual report for Armenia. Yerevan, Environmental Impact Monitoring Center, Ministry of Nature Protection of the Republic of Armenia.

Tsarukyan, M. (2006) Sustainable urban transport in the City of Yerevan. Yerevan, Ministry of Nature Protection of the Republic of Armenia. http://www.thepep.org/en/workplan/urban/documents/Tbilisi/Yerevan_sustainableurbantransport_en.pdf

Useful links:

Yerevan Municipality.
URL: http://www.yerevan.am/index.php?page_id=1&lang=3

Ministry of Nature Protection of Armenia.
URL: http://www.mnp.am/index_eng.htm

Armenia Environmental Impact Monitoring Center.
URL: http://www.armmonitoring.am/ (in Armenian)

Armenia State Hydrometeorological and Monitoring Service.
URL: http://www.meteo.am/

Climate Change Information Center of Armenia.
URL: http://www.nature-ic.am/en/index

The U.S. Agency for International Development (USAID) project: Water Management in the South Caucasus.
URL: http://chiqui.dai.com/wateriqc/default.htm

UNEP program: GEO-Cities.
URL: http://www.grid.unep.ch/activities/assessment/geo/geo_cities.php

UNDP project: Armenia-Improving the energy efficiency of municipal heating and hot water supply. URL: http://www.nature-ic.am/heating/eng/project.php

Appendix A

Brief minutes from meetings carried out

Day 1: Information meeting on structure of management concerning the air quality management in Yerevan, and finding out the data owner for emission, air quality and meteorological data in Yerevan.

Place: Ministry of Nature Protection

Participants:
Dag Tønnesen and Li Liu, NILU
Dr. Aram Gabrielyan, Head of Environmental Protection Department, Ministry of Nature Protection
Mr. Marzpet Kamalyan, Deputy Chief of State Inspection of Nature Defence, Ministry of Nature Defence
Mr. Asya Muradyan, Head of Land and Atmosphere Protection Division
Mr. Seyran Minasyan, Head of the Environmental Impact Monitoring Center (EIMC)**,** Ministry of Nature Protection
Mrs. Julieta Ghlichyan, Head of Normative Methodological Department

Brief minutes:
The air quality monitoring system in Armenia started working around 1960. It has been running on bad conditions after the independence of Armenia. The air quality monitoring system is improving with new methods and new equipments, but also facing many problems and challenges. The Environmental Impact Monitoring Center (EIMC) is the institution responsible for running the monitoring system in Armenia, and for reporting to the Ministry of Nature Protection. The cooperation with the EMEP program has been beneficial to local institutes. The EMEP station is run by EIMC, and the EMEP program has been continuously contributing to capacity building.

Presently, three methods are applied for measuring different pollutants, including passive sampling, active methods (pumping air to solution and gravimetric method for particles, and later analysis in the chemistry laboratory), and automatic instruments. The three methods are used for the various pollutants. Passive sampling covers a large area of the country. There are 10 residential areas in Armenia, where air quality is observed regularly (i.e. weekly) using passive sampling. The active measurements are carried out for SO_2, CO, NO_2, NO, O_3, benzene, xylene, toluene, and dust. In Armenia, particulate matter concentrations are measured as 'dust' with diameter larger than 0.95 µm. The internationally used particle size fractions PM_{10} and $PM_{2.5}$ are not measured, due to lacking instruments and funding.

The automatic monitors have been introduced into the monitoring system during the last 3-4 years. There are now 4 stations are equipped with 25 monitors for SO_2 and $NO/NO_2/NO_x$. The introduction of automatic monitors was based on projects, The biggest problem is maintaining and running the existing system.

According to Armenian regulations, institutes are not allowed to purchase instrument directly. Institutes send an application, which has to be approved, and the instruments have to be purchased through an intermediary. The monitors in Yerevan are products from the US company *Teledyne Analytical Instruments.* Since the instruments have not been purchased directly by EIMC, and the

company which acted as intermediary does not exist any longer, EIMC does presently not get any technical support from the instrument producer.

Air quality measurements in Yerevan:
Three stations in Yerevan are running with all methods, including continuous monitors, passive sampling, and active sampling. The passive sampling network in Yerevan started 3 years ago. Passive samplers for NO_2 and SO_2 are distributed at 40 locations in Yerevan, being exposed to ambient gas concentrations for one week. The passive sampler is locally designed and produced (by EIMC), and the methodology is based on scientific publications. The results from passive sampling were used for statistical analyses (e.g. trends) and to produce concentration distribution maps. The instrument for PM, which samples dust (analysed gravimetrically), is inherited from Soviet time, with no possibility to having the damaged or aged components repaired. It is urgent to replace the instruments with PM_{10} and $PM_{2.5}$ monitors.

Industry emissions and regulations:
Of the earlier existing industries, many have been sold or closed after Soviet time. The enterprises themselves are responsible for their emissions and once per year an on-site inspection is carried out by authority. The emissions of CO_2 are collected following the IPCC directive.

Transportation:
Data for transport and vehicles exist at the Ministry of Nature Protection.

Meteorological data:
The Ministry of Emergency obtains the meteorological data. The data can be made available to Ministry of Nature Protection upon request.

Fuel use in Yerevan:
No coal is used for domestic using, gas is used for heating and cooking. There is some wood burning in Yerevan. Central heating covers a part of the city.

Day 2: *Meeting for detailed information on existing air quality monitoring system*

Place: Environmental Impact Monitoring Center, Ministry of Nature Protection

Participants:
Dag Tønnesen and Li Liu, NILU
Mr. Seyran Minasyan, Head of the EIMC**,** Ministry of Nature Protection
Mr. Minas Belluyan. EIMC
Mr. Vardan, EIMC

Brief minutes:
The Environmental Impact Monitoring Center is located in the north of the city, in a residential area. EIMC rents about 10 rooms in a 4-floor building. The institute has about 70 employees.

The air quality monitoring system is running with three different measurement methods: passive sampling, active sampling, and automatic monitoring

instruments. The monitoring system started in 1960, when Yerevan was an industrialized city with many chemical industries.

The measurement of particulate matter (PM) is carried out with Russian instruments. The PM sampled consists of particles *larger* than 0.95 µm, thus the particle size fraction smaller than 0.95 µm is neglected. No study on source apportionment has been carried out. PM_{10} and $PM_{2.5}$ are not measured in Armenia to date. Dust, i.e. particles larger than 0.95 µm, is collected on filters three times per day, at 7:00, 13.00 and 19:00, for a period of 20 minutes each time. The average of the mass concentrations obtained from gravimetric analysis of the three filters is counted as daily average of the dust concentration.

There are 40 sites in Yerevan, where passive samplers for NO_2 and SO_2 are exposed for 1 week, from Friday to Friday.

There are 4 automatic monitoring sites at Yerevan. The ID numbers of the stations are inherited from Soviet time. Because of the lack of technical support and proper maintenance, 20 out of the 25 monitors are out of operation, although most of the instruments were purchased in 2008 or 2009. The actual operating time was less than a year.

Each station is equipped with meteorological sensors. The instruments at station No.1 were recently replaced, and the data are collected and saved at EIMC.

One of the major tasks of the first mission to Armenia was to evaluate the monitoring network, find suitable locations and carry out a screening study for Yerevan with NILU passive samplers. It became obvious that a screening study for a short period was not necessary, but that an inter-comparison of the two types of passive samplers would be valuable.

An inter-comparison experiment for NO_2 with passive samplers has been discussed. For the existing 40 sampling sites in Yerevan, three NO_2 passive samplers were decided to be exposed at each site. It was agreed that one passive sample from Armenia and two samplers from NILU would be exposed for the same period, and EIMC would carry out the analysis in the laboratory for their own sampler and apply the same method for one of NILU's samplers. The other NILU sampler would be sent back to NILU in order to be analysed at the NILU chemical laboratory. The results would be valuable for evaluating the results and the chemical analysis carried out in Armenia.

80 NO_2 passive samplers and 4 blanks from NILU were given to EIMC during the meeting.

EIMC requested the following points related to the running monitoring network and suggested how the Norwegian aid project can be integrated into long-term planning in the future:

- Emergency: first aid in the laboratory for running and maintaining the automatic monitors; best to have a NILU expert to visit Yerevan to help repairing the monitors and giving an on-spot training

- Training in the instrument laboratory; establishing a QA/QC system for the automatic network
- A data acquisition and air quality information distribution system is needed in Yerevan; knowledge and software (such as AirQUIS system) transfer would be useful,. The AirQUIS system can be applied to analyse data and present data with GIS for Yerevan
- More monitoring stations and instruments are needed at Yerevan; it may be beneficial to have a mobile station.

NILU received a map of the city of Yerevan and the air quality report for 2009 (in Armenian language).

It was agreed that NILU would start building up a preliminary project in AirQUIS at NILU for Yerevan.

Day 3: Summing up of the discussed points; priority was given to the possible support which could be supplied by NILU within the present feasibility study; a possible future project in Yerevan was discussed.

Place: Environmental Impact Monitoring Center, Ministry of Nature Protection

Participants:
Dag Tønnesen and Li Liu, NILU
Mr. Seyran Minasyan, Head of the EIMC**,** Ministry of Nature Protection
Mr. Minas Belluyan and Mr. Vardan, EIMC

Brief minutes:
List of the possible support and needs, containing those with the highest priority:

- Technical support/service for instrument laboratory, in order to make sure that the existing network and instruments are running
- Training on equipment and introduction of QA/QC system at instrument laboratory
- More stations and monitors
- Monitoring network design
- Knowledge on air quality modelling, data analysis
- Laboratory practice
- AirQUIS installation
- AirQUIS training

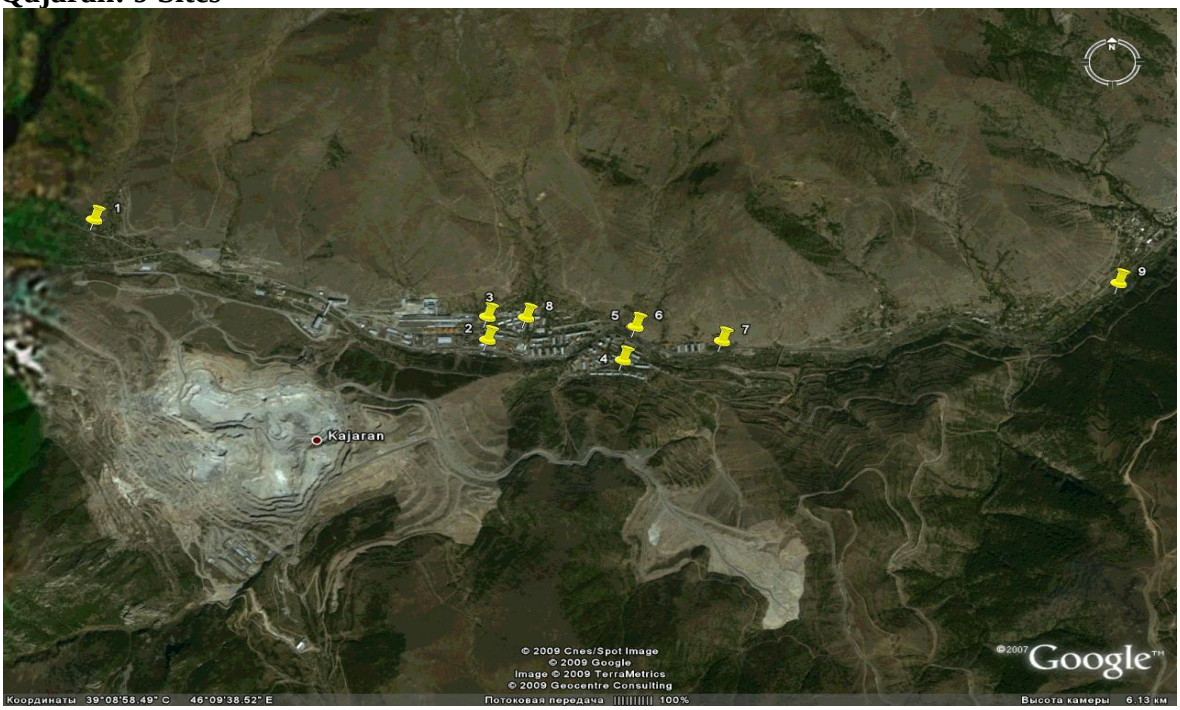
Methods for collection of emission data were discussed. Emission fluxes, population and meteorological data could be requested through the Ministry of Nature Protection.

It was suggested that 5 sites in one of the other cities would be chosen for the inter-comparison experiment, so that 35 of the sites involved in the experiment would be located in Yerevan.

Appendix B

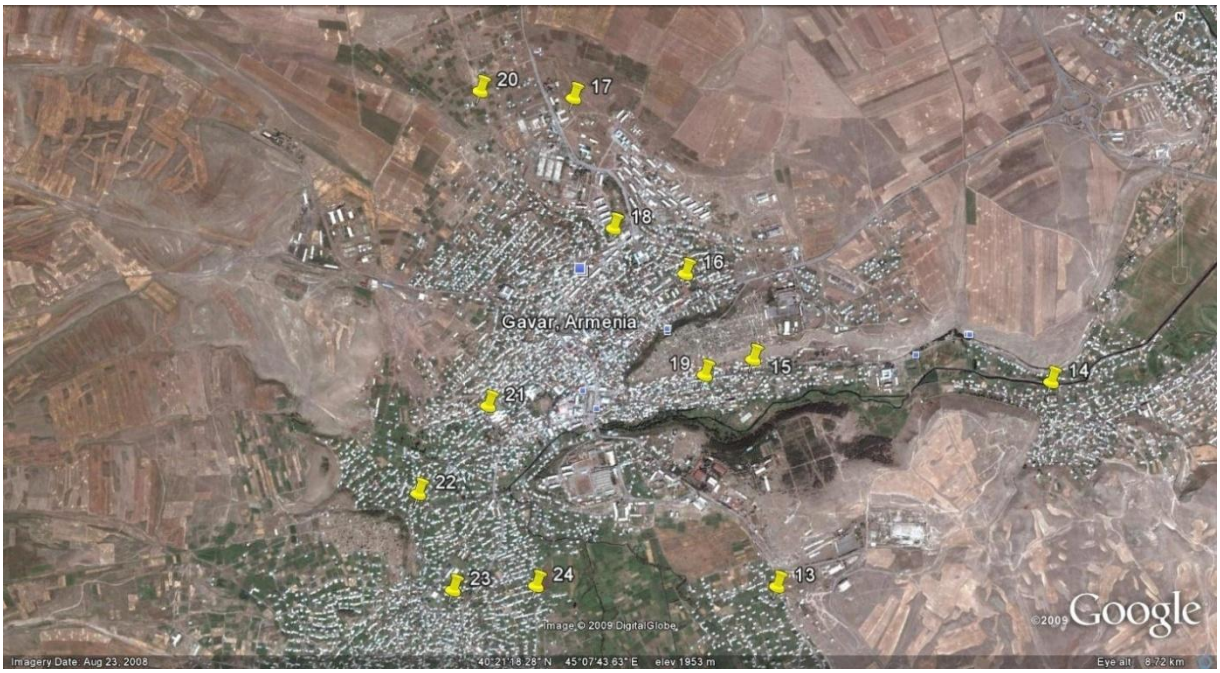
Air Quality Monitoring sites in 10 residential areas in Armenia

Qajaran: 9 Sites



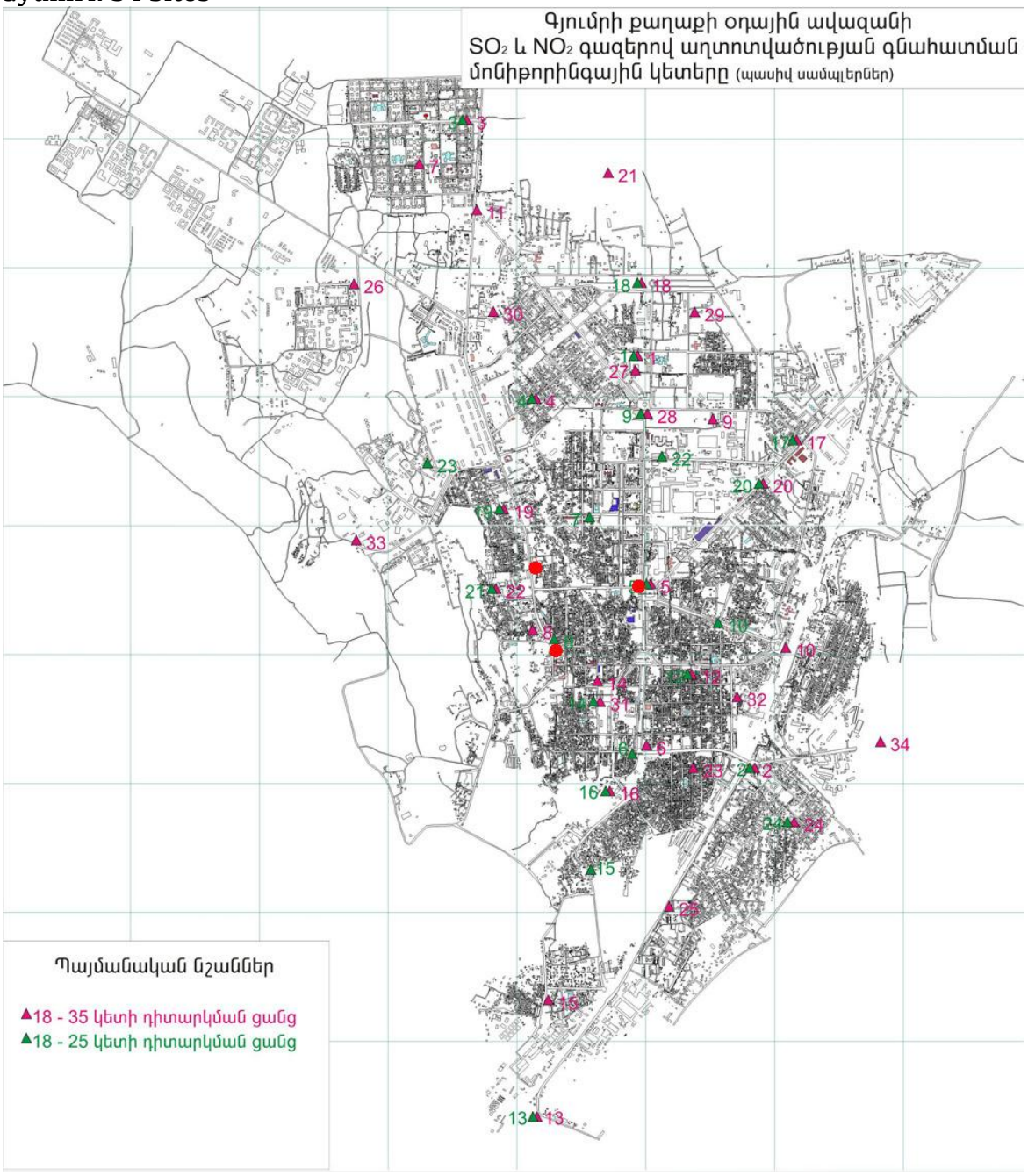
Kapan: 19 sites

Gavar: 12 Sites

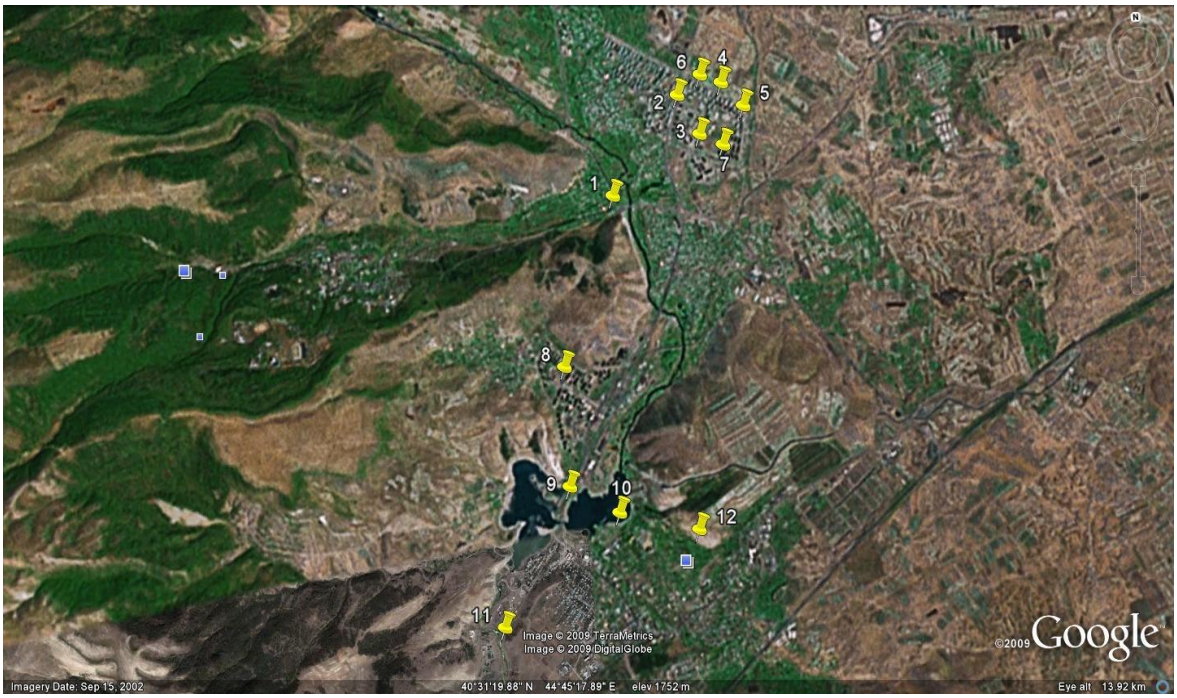


Alaverdi: 18 Sites

Gyumri: 34 Sites



Hrazdan: 12 Sites

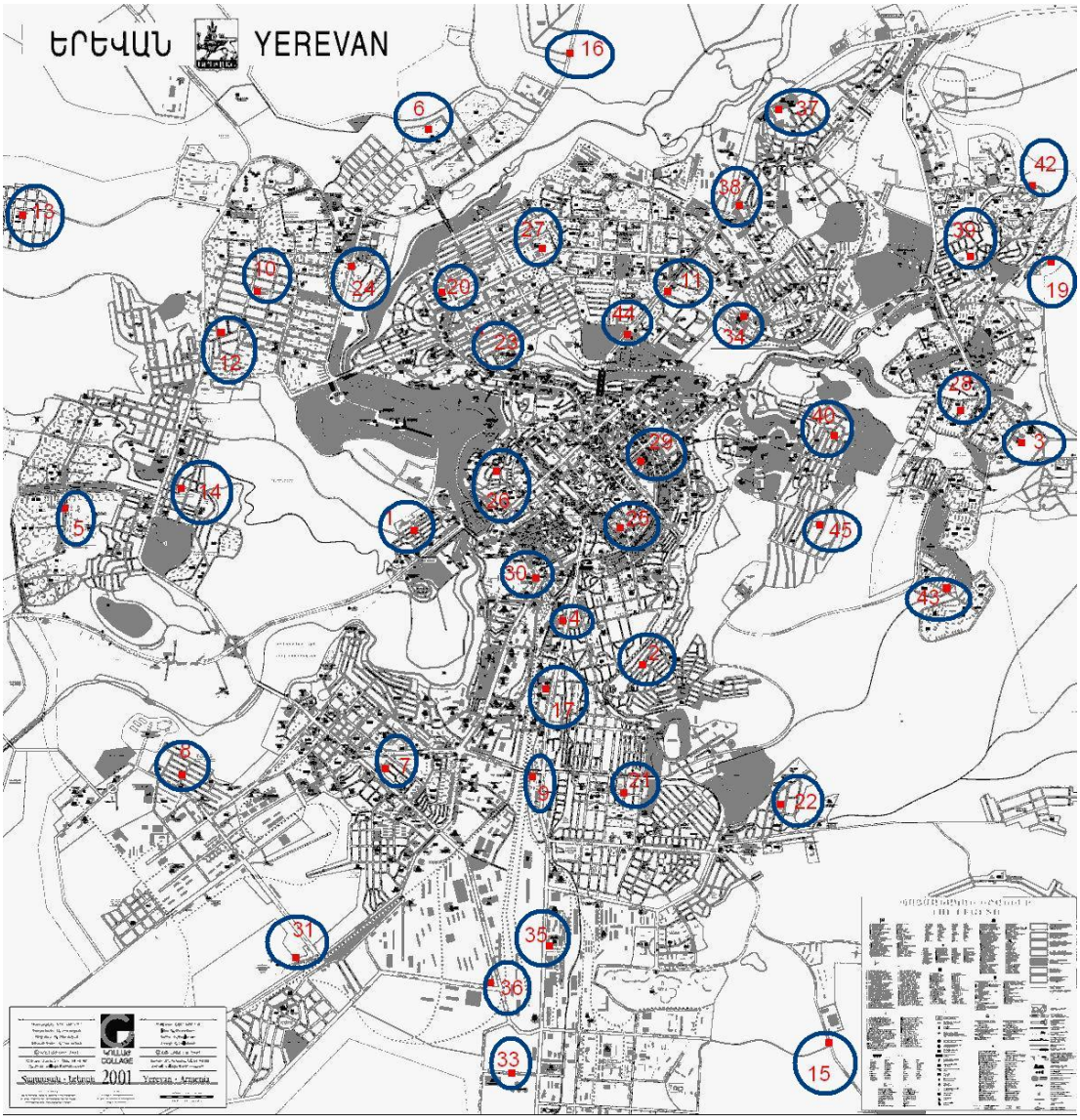


Ararat: 12 Sites

Vagharshapat: 16 Sites

Vanadzor: 24 Sites

Yerevan: 44 Sites

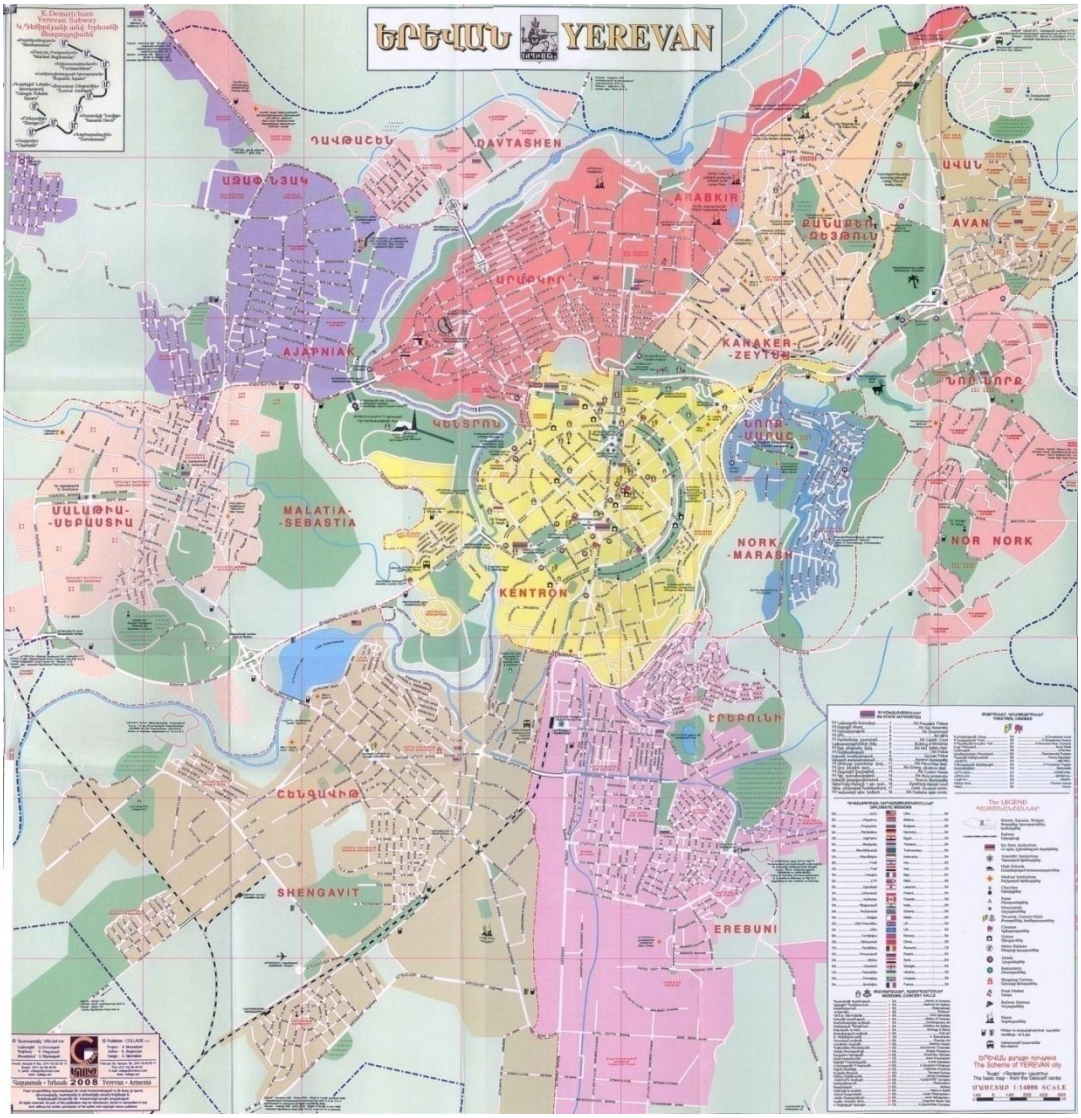


Appendix C
Air quality limit values in Armenia

Limit (LV) and Guideline (GV) values for some pollutants in Ambient Air
The text in the table in English (page 34, 2009 Air quality yearly Report)

Pollutant	AveragingTime	Armenia, ($\mu g/m^3$)	WHO, ($\mu g/m^3$)	EU, ($\mu g/m^3$)
Carbon Monoxide (CO)	15 minutes	-	100000	-
	30 minutes	50000	60000	-
	1 hour	-	30000	-
	8 hour	-	10000	10000
	24 hours	30000	-	-
Nitrogen Dioxide (NO_2)	1 hour	-	200	200 (not to be exceeded more than 18 times in one year)
	8 hours	-	-	-
	24 hours	40	-	
Nitrogen Monoxide (NO)	1 hour	-	-	-
	8 hours	-	-	-
	24 hours	60	-	-
Ground Level Ozone (O_3)	1 hour	-	-	-
	8 hours	-	120 (Maxmum daily 8 hourly mean)	-120 (Maxmum daily 8 hourly mean)
	24 hours	30	-	-
Sulfur Dioxide (SO_2)	10 minutes	500	500	-
	1 hour	-		0.350 (not to be exceeded more than 3 times in one year)
	8 hours	-	-	-
	24 hours	50	20	0.125 (not to be exceeded more than 3 times in one year)

Appendix D
Map of Yerevan city


ԵՐԵՎԱՆ
YEREVAN
ԴԱՎԱՇԵՆ
DAVTASHEN
ԱՐԱԲԿԻՐ
ARABKIR
ԱՎԱՆ
AVAN
ԱՋԱՓՆՅԱԿ
AJAPNIAK
ԿԱՆԱՔԵՌ-ԶԵՅԹՈՒՆ
KANAKER-ZEYTUN
ՄԱԼԱԹԻԱ-ՍԵԲԱՍՏԻԱ
MALATIA-SEBASTIA
ՆՈՐՔ-ՄԱՐԱՇ
NORK-MARASH
ՆՈՐ ՆՈՐՔ
NOR NORK
ԿԵՆՏՐՈՆ
KENTRON
ՇԵՆԳԱՎԻԹ
SHENGAVIT
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ABSTRACT
The report contains information of the air quality and the air quality monitoring system in Yerevan, Armenia. The state of the situation of air quality monitoring network in Armenia, including instruments in use, and the parameters measured is described. The capacity of the monitoring network is characterised and recommendations regarding air quality monitoring and management in Yerevan are given. The content of the reported resulted from a five-day mission to Yerevan in February 2010.

NORWEGIAN TITLE

Reiserapport. En studie om muligheten for å gjennomføre luftkvalitetskontroll for Yerevan, Armenia

KEYWORDS		
Air quality monitoring	Air quality management	Yerevan

ABSTRACT (in Norwegian)
Rapporten inneholder informasjon om luftkvaliteten i Jerevan, Armenia. Tilstanden for nettverkssituasjonen for luftkvalitetsovervåking i Armenia, inkludert instrumenter i bruk og parametre som måles. Kapasiteten til å overvåke luftkvalitet og anbefaling om luftkvalitet styring i Jerevan.

** Classification*
A Unclassified (can be ordered from NILU)
B Restricted distribution
C Classified (not to be distributed)

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NILU
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