Chapter 1
Background

1.1 The Malé Declaration

The Malé Declaration process was initiated in March 1998 during a policy dialogue organize by UNEP in collaboration with SEI (the Stockholm Environment Institute) with financial support from the Swedish International Development Cooperation Agency (Sida) Senior government officials of the South Asian region and experts on air pollution attended the policy dialogue. The meeting agreed on a draft declaration on air pollution to be presented to the Environment Ministers during the Governing Council of SACEP.

The Seventh meeting of the Governing Council of South Asia Cooperative Environment Programme (SACEP) held in April 1998 in Malé, the Republic of Maldives, adopted the declaration naming it the "Malé Declaration on Control and Prevention of Air Pollution and its likely Transboundary Effects for South Asia". The Malé Declaration stated the need for countries to carry forward, or initiate, studies and programmes on air pollution in each country of South Asia. The first stage in this process is to document current knowledge and information/institutional capacity in each nation relevant to air pollution issues. To this end it was agreed that baseline studies to be developed. Gaps in the current status of knowledge and capacity would become apparent and national action plans to fill these gaps could then be implemented, creating a solid scientific basis for the policy process. Implementation of the action plan will put in place expertise, equipment and information for quantitative monitoring, analysis and policy recommendations for eventual prevention of air pollution.

1.2 Implementation of the Malé Declaration

The implementation of the Malé Declaration was envisaged to be in separate phases. Phase I started with the establishment of a network of organisations to implement the Declaration. The air quality baseline studies were based on data collected from different agencies in the countries relating to the structure, modalities, regulations, institutions and capacities available, to address the problems of local air pollution. The baseline studies led to the formulation of National Action Plans by NFPs and NIAs, indicating requirements in terms of monitoring equipment and capacity building for the measurement and analysis of air quality data.

The implementation plan for Phase II was to put in place expertise, equipment and information for quantitative measurement and monitoring, analysis and policy recommendations for eventual prevention/control of air pollution.

The sixth session of the inter-governmental network meeting, which was held in Teheran, Iran in October 2004, adopted the plan of implementation for Phase III. The general objective of Phase III was to continue to promote the scientific base for prevention and control of transboundary air pollution in South Asia, and to encourage and facilitate coordinated interventions of all the stakeholders on transboundary air pollution at the national and regional level. One of the focuses of Phase III is to enhance the analytical and impact assessment capabilities at the national level through integration of findings from the monitoring stations, local pollution prevention studies and conducted impact assessment studies.

1.3 The Corrosion Impact Assessment

Impacts of air pollution on materials is little known in the participating countries of the Malé Declaration. Phase III implementation of the Malé Declaration has included exposure of materials, training in stock at risk and economic assessment. Tow training workshop were organized (Bangkok, October 2006 and Zambia, February 2008) on the evaluation of corrosion on materials. These workshops were jointly organized with APINA to enhance the South-South cooperation. The exposure experiments were under taken in 5 countries (Kathmandu, Nepal; Agra, India; Battaramulla, Sri Lanka; Teheran, Iran; and Hanimaddoo, Maldives). Materials exposed include: carbon steel, painted steel, Portland limestone, zinc, and copper. Results for monthly mean pollutant concentrations measured at these sites, and the amount of corrosion damage measured in year one and two. This report present the preliminary findings of the study.

Chapter 2
Assessment Methodology

There is and has been a concern that the high pollution levels combined with the elevated temperature levels and high amount of precipitation observed in many developing sub-tropical and tropical countries will result in higher corrosion rates than previously observed in Europe, Canada and the United States. A review of available data and exposure programs in sub-tropical and tropical regions[1] showed that either the environmental characterization is limited to SO_2 or the exposure time is relatively short. In order to fill this gap a network of test sites was developed in Asia and Africa under the framework of the Swedish International Development Cooperation Agency (Sida) funded progamme on RAPIDC. Five Malé corrosion sites are part of the network. Please see map of test site. (Figure 1)

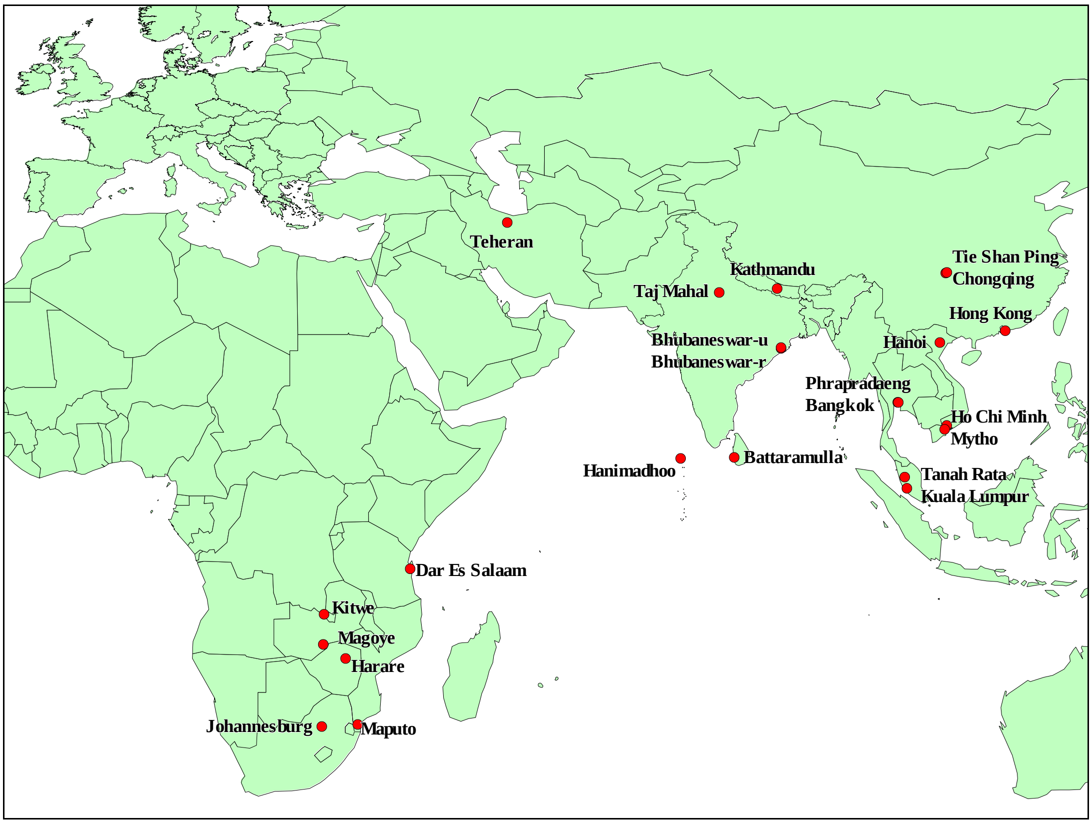


FIGURE 1 – Map of test sites

Exposure Racks and Test Sites: The exposure racks were fabricated in Sweden and shipped to the different test sites and personnel from Swerea KIMAB AB were present at the start of each exposure. Figure 2 shows a photograph of the rack in Nepal with samples of carbon steel, zinc, copper, painted steel and limestone on a carousel. In the background, a glimpse of another rack type can be seen attached to the white wall. This is a so-called kit for rapid assessment of corrosion originally developed in the EU 5FP project MULTI-ASSESS[2]. Ten kits of this type have been exposed in the Kathmandu valley.

FIGURE 2 – Rack installed at the roof of the International Centre for Integrated Mountain Development (ICIMOD), Nepal, Kathmandu

Characterization of the Environment: Passive sampling was performed on all sites for the gaseous pollutants SO_2, NO_2, O_3 and HNO_3 and for particulate matter. Sampling was performed on a bi-monthly basis i.e., samplers were exchanged each second month. Complementary data on temperature, relative humidity, amount of rain and its pH were collected by the partners at a nearby meteorological station. These data should be reported to Swerea KIMAB AB on a monthly basis.

TABLE 1 – List of test sites including country, name, responsible organization and start of first exposure (2002 – original network; 2006-2007 – enlargement of network)

Country	Test site name	Responsible organisation	Start
India	Taj Mahal	Central Pollution Control Board	25 November 2006
Iran	Teheran	Environmental Research Center	20 November 2006
Sri Lanka	Battaramulla	Central Environmental Authority	27 November 2006
Nepal	Kathmandu	International Centre for Integrated Mountain Development	14 November 2006
Maldives	Hanimadhoo	Department of Meteorology	23 January 2007

Sample Preparation and Evaluation of Corrosion Attack: Each site was maintained by a dedicated partner who was responsible for the safety of the rack, the exposure/withdrawal of passive samplers, the collection of environmental data and the withdrawal of corrosion specimens (see below). After exposure, the samples were returned to Swerea KIMAB AB for evaluation of corrosion attack.

The total sampling of passive sampler period was one year making in total six bi-monthly sampling periods. The starting date of the first sampling period varied from site to site and coincided with the starting date of the exposure of specimens. All exposure periods for passive samplers were consecutive so that the end of a sampling period marked the start of a new sampling period.

All flat samples, carbon steel (Dc 04, SS – EN 10 130), zinc (Z1 – DIN EN 1179), copper (Cu DHP, SS 5015) and painted steel were cut to dimensions 100 x 150 mm2 as suggested by ISO 9226. The thickness of all flat samples was 1 mm except for steel, which had a thickness of 2 mm. Carbon steel, zinc and copper were degreased and weighed prior to exposure. Steel was painted with two layers of alkyd (90 µm): i) Conseal Primer 50 µm, fast drying alkyd based primer; ii) Ultra Topcoat 40 µm, quick drying and glossy acrylic modified alkyd topcoat and then edge protected using Vinyguard Silvergrey 88 from Jotun, Norway.

The corrosion attack of the metal samples was evaluated with 10 min. consecutive pickling using Clarkes solution; 20 g Sb_2O_3 and 60 g $SnCl_2 \times 2H_2O$ and 1000 ml concentrated HCl (□□= 1.19 g ml^{-1}) for steel, 250 g glycine (NH_2CH_2COOH) and distilled water to make 1000 ml, saturated solution for zinc and 50 g amidosulfonic acid (sulfamic acid) and distilled water to make 1000 ml for copper. Painted steel was evaluated by visual examination of the spread of corrosion attack in both directions from the 1 mm cut but expressed as the average spread in one direction following ASTM D 1654-79a.

Portland limestone specimens of dimensions 50 x 50 x 8 mm^3 were obtained from the Building Research Establishment Ltd, United Kingdom, where also the corrosion attack was evaluated as mass change during exposure. The mass change was then recalculated to surface recession.

Chapter 3
Results of Corrosion Sites

3.1 India

Description of Corrosion Site Location at Agra (India) (RAPIDC Station No. 21)
Date of Installation: 2006-11-25
Geographic Location : N 270 10' 18.12"; E 780 02' 26.52"
RAPIDC Station No. 21

Figure 3: Corrosion Site - Agra

The site is north centrally located in India, about 200 km south of Delhi and its Geographic Location is N 270 10' 18.12"; E 780 02' 26.52".Two-thirds of its peripherals (SE, W, NW) are bounded by the Thar Desert. The area is semi-arid with extreme climatic condition. Highly Industrial in the recent past, however due to restriction in the operation of coal based industries, most of the air polluting industries have stopped their operation, while a few of them are switched over to CNG. The soil is alkaline and the prevalent ions in the soil are Na^{+}, Ca^{2+}, NH_4^{+} , SO_4^{2-} and Cl^{-}.

Under this activity Copper, Zinc, Painted Steel, Carbon Steel and Stone samples (total three sets of nine each) are being exposed. One set (total 12 samples) of each sample (of three each) shall be studied for corrosion on completion of First year (completed and submitted in December 07 for analyses), Second year (due in Nov. 08) and Fourth year (due in Nov. 10).

The passive samples are also were exposed regularly during Nov 2006 to December 2007 for monitoring of HNO_3, SO_2, NO_2, O_3 and particulates at the site. All exposed samples (total six sets) have forwarded on regular intervals (every two months with temperature & Humidity data) to Corrosion & Metal Research Institute, Sweden for analyses.

3.2 Iran

The site is located on the roof of the Environmental Research Center building (E :51° 21' 44.7"; N :35° 46' 25.8") in the Pardisan ECO Park, northwest of Tehran between Hemmat and Hakim highways. The first exposure started in November 2006.

Exposed Materials: Metals including Zinc, Copper, Carbon Steel, Painted Steel Passive samplers:HNO_3, O_3, SO_2, NO_2 , Cylindric Teflon Stones.

Figure 4: Corrosion Site – Tehran

3.3 Maldives

The corrosion rack is placed on 23rd of January 2008 at the Hanimaadhoo Island in the northern most atoll of Maldives located about 400 km to the north of the country's capital, Malé. Its Geographic Location is 6.780 N and 73. 180 E and altitude is ~2 m.

Figure 5: Corrosion Site - Hanimaadhoo

Metals exposing are iron, Zinc, Cupper, Painted steel and Limestone. First portion will be sent after one year, and the next after 2 years and the last after 4 years. Exposing diffusive samplers are NO_2, SO_2, O_3, HNO_3, and Particulate each of those are exposed for 2 months, and sent to IVL for analysis.

3.4 Nepal

Two types of racks with standard materials were exposed for this study. The main rack which contains materials like carbon steel, zinc, copper, painted steel and limestone (figure 6.1) are exposed at ICIMOD head Quarter for four years period. The materials will be taken out from the racks at year one, year two and finally in the fourth year to access the rate of corrosion due to air pollution. The mini racks which contains only carbon steel, zinc and limestone (figure 6.2), are exposed for one year at nine different locations including cultural heritage sites. Passive samples like SO_2, NO_2, O_3, HNO_3 and PM (particulate matter) is also exposed in all the sites. Table 1 shows the location of the sites along with the coordinates.

Figure 6.1: Main rack - ICIMOD

Technical support to this study is provided by Corrosion and Metal Research Institution (KIMAB), Stockholm, Sweden.

Location: The racks along with the passive samplers were exposed in 2006 at ten different locations. In nine out of ten sites, the mini racks were exposed for a year whereas the main racks were exposed at one site. Table 1 shows the details of the exposed sites. Apart from that in 2008 one mini rack was exposed at Bhaktapur durbar square.

Figure 6.2: Mini rack- ICIMOD

Table 1. Location of exposed sample

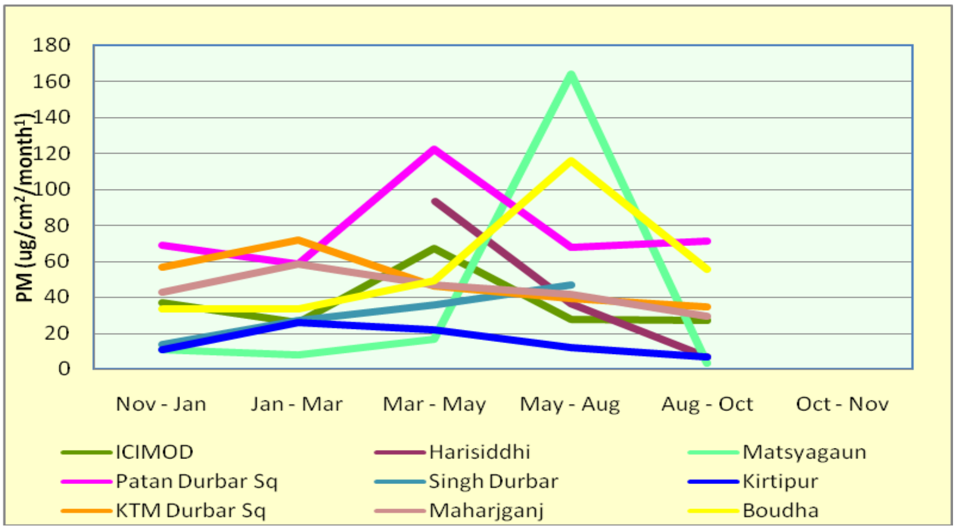
Station ID	Location	Latitude	Longitude	
17829-24/25	ICIMOD Headquarter (City background)	27°38'47.20"N	85°19'24.31"E	Main & mini rack
17830-26	Harisiddhi (Brick kiln area)	27°38'23.45"N	85°20'22.51"E	Mini rack
17831-27	Matsyagaun (Rural Site)	27°40'7.84"N	85°15'5.84"E	Mini rack
17832-28	Patan Durbar Square (Cultural Heritage)	27°40'23.53"N	85°19'31.21"E	Mini rack
17833-29	Singh Durbar (Ministry office)	27°41'53.80"N	85°19'22.37"E	Mini rack
17834-30	Tribhuvan University (City Background)	27°40'51.02"N	85°17'1.11"E	Mini rack
17835-31	Kathmandu Durbar Square (Cultural Heritage)	27°42'15.24"N	85°18'27.64"E	Mini rack
17836-32	Tribhuvan University Teaching Hospital	27°44'7.76"N	85°19'50.31"E	Mini rack
17837-33	Boudha Stupa (Cultural Heritage)	27°43'17.60"N	85°21'43.54"E	Mini rack
17838-34	Bhaktapur Durbar sq. (Cultural Heritage)	27°40'16.82"N	85°25'44.50"E	Mini rack

Results: The standard material from 9 mini racks and main rack which were exposed for a year has been shipped to Sweden for analysis. The result from these standard materials is yet to be sent from Sweden. However, the results from the passive samplers are shown in the below figures 15-20. Particular matter is seen high is traffic congestion areas which is quite common from other measurements too. However, the high concentration in the rural site during the month of May-August is quite uncommon as the result from the active sampling is 36 $\mu g/m^3$; this means either we need to validate the passive sampler for PM or the ID of samples had mixed up while sending for analyses.

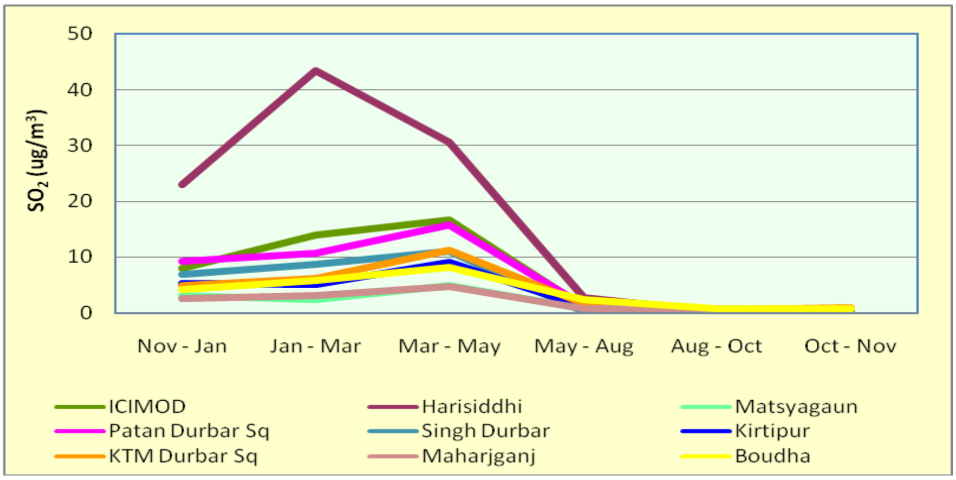
ICIMOD is on the way to Harisiddhi, where most of the brick kilns are located. SO_2 is relatively higher in these areas. In March 2002, the government decided to ban the Moving Bull Trench Kiln (BTK) technology in Kathmandu. The kilns have now adopted new and less polluting technologies mainly; Fixed Chimney and Vertical Shaft Brick Kilns (VSBK).

In almost all graphs the trend shows the reduction of pollution from May to October. This is mainly because monsoon starts from May till September where the pollutants are washed down by the rain.

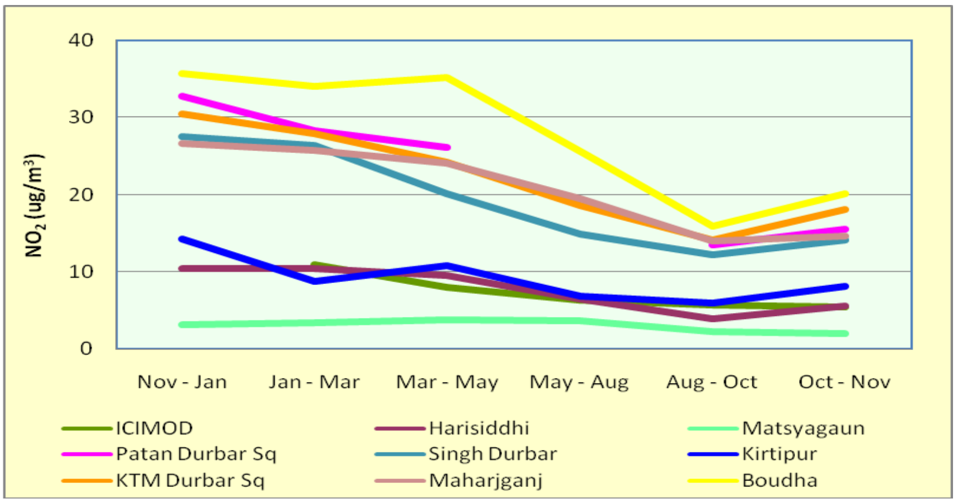
Boudha, Patan, Singha Durbar, Kathmandu Durbar Square were the areas with high traffic flow. In measurement too, high NO_2 concentration was shown in these areas. Similar was the case with HNO_3. However, ozone was found higher in the rural sites where agriculture field was dominant.



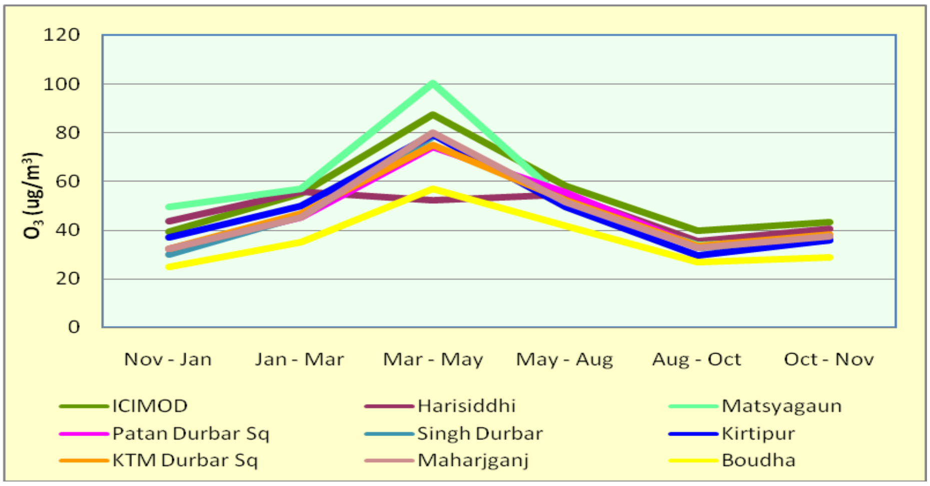
Graph 1: Concentration of PM



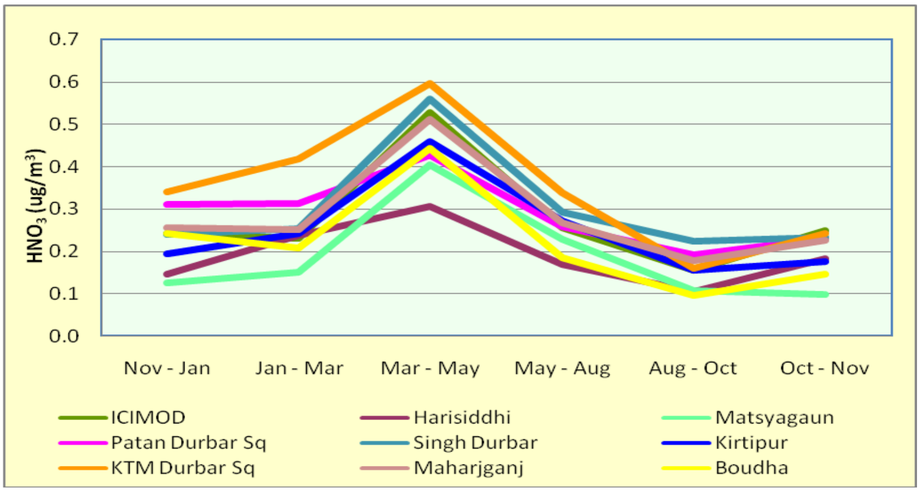
Graph 2: Concentration of SO_2



Graph 3: Concentration of NO_2



Graph 4: Concentration of O_3



Graph 5: Concentration of HNO_3

Conclusion: As the result from the analysed materials is yet to come final conclusion could be made after incorporating the result from it. Further, the stock at risk is yet to be conducted in the city, which is planned for Phase IV.

3.5 Sri Lanka

Description of test site: Site no 23 Battaramulla (E-079° 55’ 35.2” : N- 6°54’ 02.4”)(premises of Central Environmental Authority) – Sub urban area with low level of air pollutants lies 10km(Arial distance) east of Colombo, Fort, Ambient air quality monitoring station. The surrounding consists mainly of Wet lands residents and government offices with moderate traffic intensity. The rack is placed on the roof garden of 3rd floor (16 meters above from the ground) of Central Environmental Authority building. The first exposure started in 27th

Figure: Corrosion Rack at the beginning (2006 Nov.)

November 2006. The national contact persons are Mrs. Warnika Ranawaka Arachchi and Mr. Champika Aiyawansa, Central Environmental Authority, No 104, "Parisara Piyasa" Denzil Kobbakaduwa Road, Battaramulla.

Exposed Materials are Carbon steel, Painted steel, Copper, Zinc and Limestone.

Figure: Corrosion Rack – 2008 June

3.6 Preliminary Results

The first exposure of the enlarged network of CORNET which included five Malé sites and two APINA sites from Africa (Maputo, Mozambique and Dar Es Salaam, Tanzania) was concluded in November 2007 but at writing moment all samples has not arrived at Swerea KIMAB AB. Therefore, it is only possible to show results from passive sampling of pollution, Figure 7. The highest SO_2 value was measured in Teheran but combining with data from other CORNET network sites, this site is only ranked fifth from the top. Regarding HNO_3, the relative situation is similar. In all, the sites complement the existing CORNET sites and provide a valuable contribution to the network taking into account geographical distribution, climate and pollution.

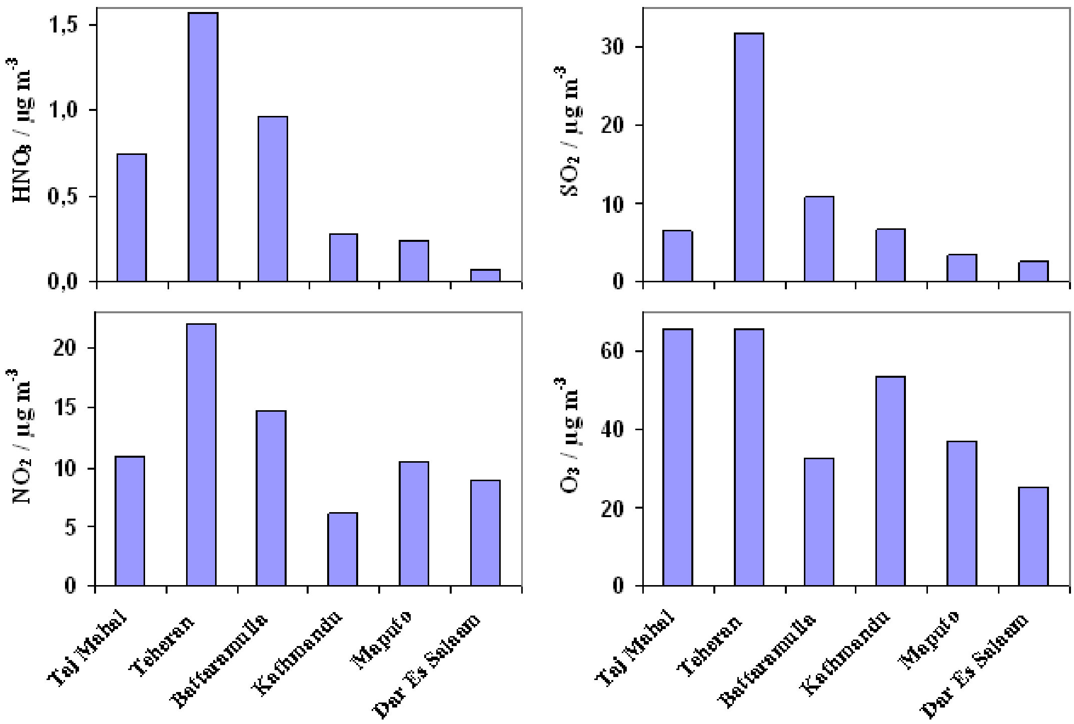


FIGURE 7 – Average concentrations (2006-2007) of HNO_3, SO_2, NO_2 and O_3.

Chapter 4
Summary and Recommendation

A network for monitoring corrosion has been successfully established under the framework of the Malé Declaration. The network includes 5 test sites: Kathmandu, Nepal; Agra, India; Battaramulla, Sri Lanka; Teheran, Iran and Hanimaadhoo, Maldives. This network has also established link with the CORNET network, which currently includes in total 23 test sites in Asia and Africa. Results are still preliminary and to use the full potential of these test sites it is important to continue exposures in phase IV to establish trends in corrosion and pollution and to continue capacity building.

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