Review of Ambient Air Pollution and Its Measurement along the River Basin

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Abstract : The elevated air pollutants in the regional atmospheric environment is a major problem that affects human health across the world particularly in the river basin. The river basin is important for social and economic development. This area is a good location for settlement and industrial estates as well as agriculture due to the availability of resources. This paper presents a review on ambient air pollutants in the river basin. This paper not only presents the mobile platforms, but also introduces the factors that affect air pollution measurements along the river and discusses the future research on fusing the mobile campaigns. The first part of this review presents several forms of ambient air pollution such as particulate matter, gaseous pollutants. The second part emphasises on the methodology of measurement by mobile platform.

Keywords: Air pollution, River Basin, Mobile platform measurement

1. Introduction

Worldwide, extended urbanization and increased industrial estates have led to air pollution problems reaching a critical crisis point. This is particularly evident in megacities that have a higher population density. There are many air pollutants from natural and anthropogenic activities, as well as a diverse range of natural original pollutant concentrations. The majority of megacities in many countries are located along the artery of rivers where a substantial number of people live and work. To date, growing evidence from research on air pollution in capital cities in Asia has shown more harmful elevated pollutant concentrations in air-sheds. This is a topic worthy of research as a WHO global study affirmed that pollution is one of the principal causes of premature deaths in the world. Indeed, pollution levels were higher than WHO guideline values [1,2] and urban residents in Asia are more at risk of air pollution than western urban dwellers as they spend more time in the ambient environment [3,4]. Toxicological studies have proved that ultrafine particles are detrimental to human health [5-7]. Few studies have considered the effects of aerosol pollutants along river basin. Of these, experimental studies, they only used a fixed monitoring site which does not adequately measure air pollutants in the real environment [8].

In contrast, the use of mobile pollutant laboratories offers the benefit of increased access and flexibility. In recent years, an increasing number of mobile pollutant measurement laboratories have been situated on freeways in cities, both in developed and developing countries. However, limited research has been carried out on their use in river basin. Due to this paucity of the investigation, it is clear that more appropriate methods are required. The mobile pollutant laboratories platform is crucial in collecting practice information about ambient particle matter pollution in the river basin. Ultimately this could lead to the novel scientific discovery of information to support policy and strategy development and ultimately assist in managing the air quality in these regions.

2. Ambient air pollution along rivers around the world

The river and riverbank are important for societies and economic development. There are around 25 major rivers located around the world, as illustrated in Figure 1. Currently, the age of rapid industrialisation worldwide has caused some major river basin to become highly populated regions, especially in Asian countries.

Figure 1 The Major River of the World [9]

Transverse diverse geographical features along the river contribute to an elevated level of pollutants. In addition to factories, several urban cities and proximate pollution generating sources were investigated in diverse river basin environments. Many studies have determined that the regional air quality in river basin mainly originates from anthropogenic activities [10]. In the last decade, a few air pollution studies based on measurement in major river basin have been reported around the world as discussed below.

In the United States, air quality was investigated in the Mississippi River and Columbia River regions. In 1999, to characterise source distributions of air quality over the Mississippi River region, principal components analysis was applied to classify the black carbon (BC) finding that 27% of BC was produced from incomplete combustion processes. Furthermore, BC was a principal source of riverine carbon that discharged into the ocean [11]. Severe weather in this region has also been linked to climate change affecting the air quality in the Columbia River basin. The significant aerosol pollutant Carbon dioxide (CO_2) is emitted from escalating anthropogenic activities during all seasons [12]. Furthermore, the Amazon, the most important river in Brazil, offers a myriad of natural resources. To qualify the contribution of aerosol pollutant sources in the Amazon River basin, air modelling (WRF- Chem model) has been applied to air quality monitoring station data. Abou Rafee et al. (2017) [13] found that the dominant source of pollution emitted from Manus, Brazil was fuel combustion, and it can travel many hundreds of kilometres in the atmosphere. A further source of air pollution in Amazon River basin is biogenic, volatile organic compounds (VOCs) from the world’s largest forest. Additionally, particulate matter from bushfires has been shown to have adverse acute effects on children in the Amazon River basin [14].

In Europe, river basins are a substantial area for settlement, industrial estates and economic activities. They also face air pollution problems due to anthropogenic activities caused by transport and industrial pollution [15]. There is limited literature on the investigation of air pollutants along riversides in Europe, however, several studies have investigated air quality on a regional scale [16, 17]. Additionally, a range of studies has focused on measuring air quality with monitoring stations and air modelling. Therefore, to develop and apply a mobile monitoring platform to characterise the air pollutants and their sources will use practical methods in the real world without relying on stationary monitoring.

The next section presents a detailed review of research literature on the spatial and temporal qualities of outdoor air pollution along the major river basin in Asia.

Considering the air pollution along the Yangtze River Basin (YRB), elevated anthropogenic activities caused a continuous increase air pollutants level in mega cities, in particular, Shanghai. For example, the worst haze weather ever occurred on 17 January 2007. At this time, the highest concentration of inhaled particle ($PM_{2.5}$), with a reading of 512 μg.m^{-3}, was observed compared with the annual average PM2.5 concentration of approximately 115 μg.m^{-3} [18].This is due to unusual metrological conditions such as high humidity and cold weather [19]. In Wuhan, a study further investigated the distribution of fine particles. The highest concentration of inhaled particles was observed in 2012. In order to reduce the emission of $PM_{2.5}$, the local government set a policy to control it with National Ambient Air Quality Standards of China(NAAQS) [20]. More broad research on atmospheric pollution in the Yangtze River Delta (YRD) was done by the end of 2013. In this study, Xu et al.(2016) [21] found that the large range of air pollutants from biomass burning was playing a crucial role in haze episodes. A number of studies applied air modelling (MM5/CMAQ) to predict the distribution of air pollution in YRD. Those studies have commonly noted that the concentration of NO_2 in Shanghai exceed NAAQS. The concentration levels of NO_2 and SO_2 also exceed NAAQS in Nanjing, particularly in the summer [22,23]. Advanced investigation of the spatial-temporal pattern of outdoor pollutants in the YRD by stationary monitoring found that it varies with the geographic area and can be considered a moderate health risk for residents [24].

A review of air pollution problems in the provinces where the Chao Phraya River flows through, includes Pathum Thani, Nonthaburi, and Samut- Prakan, has also been conducted [25-27]. Vichit-Vadakan et al. (2010) [28] examined the PM_{10} concentrations in Bangkok and found that they were higher than Western cities and also correlated with the mortality rate. Stieb et al. (2002) [29] further examined the effects of air pollution on the daily mortality rates in many capital cities around the world. In Bangkok, their study found that the readings for PM_{10}, CO, NO_2, O_2 and SO_2 were harmful to human health. Further, Boonyatumanond, et al. (2007) [30] reported that PolycyclicAromatic Hydrocarbons (PAHs) concentrations in diesel aerosol and road dust in many parts of Bangkok exceed the Thai ambient air quality concentrations standard. Ambient pollution has played a significant role in bringing the adverse effects on human health in Bangkok caused by a long-term exposure. Overall, these results indicate that air pollutants in Bangkok and BMR had a lethal effect on the population's health [31-33].

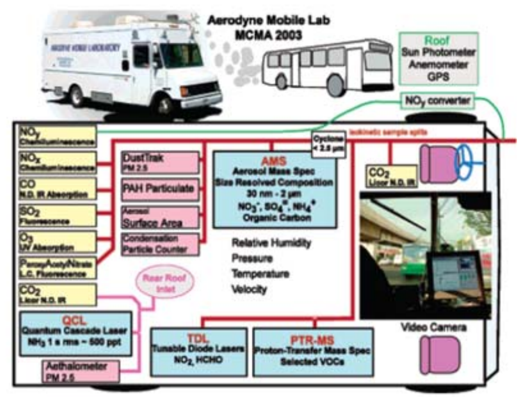
3. Mobile measurement

3.1 Overview of mobile measurement for air pollution

The following section will provide a review of instruments used to obtain mobile laboratory measurements. According to Larson, et al.(2017) [34], several mobile platforms can be used to obtain ambient air quality measurements at a high spatial and temporal resolution. Each platform is suitable for using in different geographic conditions. These encompass a wide diversity of platforms dependent upon the source of air pollution. For example, air toxic pollutants from on-road combustion would be measured with moving platforms such as a car, bicycle and Unmanned Aerial Vehicles (UAV), which are shown in Figures 2.

The mobile monitoring platform is deployed to measure and characterise the sources of air pollutants depending on a special system configuration. Monitoring systems need to analyse the sampling mechanism with extractive configuration. In-situ, this needs to analyse the sensing element capable with their different sensors. Stagnation pressure is a classic problem in the measurement in some mobile sensors, especially at high speed. For particle matter measurement, there is the possibility that particles may exit from their streamlines, and this may cause an error [38]. In addition to these technical considerations, the other important factor is the operational cost. For a detailed study, the air quality monitoring requires many stationary stations working continuously, causing a high capital and operational cost. In contrast to a pilot study which is not practical the laboratory mobile platform is better tool [39].

(a)



(b)

(c)

Figure 2 Example of different moving platform including (a) Bicycle (b) Car (c) UAV for monitoring air quality along the road [35-37].

Nowadays, the mobile platforms are commonly used to measure air pollution around the world. One advantage is that they can also present a more practical option in locations where it may not be easy or possible to place fixed monitors. Furthermore, real-time continuously moving monitoring has emerged as a powerful platform for advancement in aerosol monitoring instruments and can also be used in a variety of applications [40]. Researchers have measured different air pollutants with a variety of platforms, as can be seen from Table 1.

Table 1 Mobile measurement platforms used in previous studies.

Author	Findings	Methods
Maciejczyk et al. (2004) [41]	Other pollutants measured by methods PAHs and BC where the results show high levels of these pollutants.	Car
Westerdahl et al. (2005) [42]	High correlation with concentration of UFP with NOx , BC, PAH in Los Angeles, US	Car
Wang et al. (2009) [43]	The concentration of SO_2 and NO_2 in Guangzhou, China. During The Asian Games, 2010 levels were high.	Car
Wangchuk et al. (2015) [44]	The air pollution along the East-West Highway, Bhutan, which varied widely with different source emissions.	Car

Table 1 (cont.) Mobile measurement platforms used in previous studies.

Author	Findings	Methods
Elen et al. (2012) [36]	UFP, $PM_{2.5}$ and BC were measured with a high-resolution air quality instrument.	bicycle
Crosman et al. (2017) [45]	Inhaled particles and Ozone measured by an effective sensor, varied with elevation in an urban area	Helicopter
Geng et al. (2009) [46]	NO_2, SO_2, CO, O_3, concentration in urban areas was higher than rural areas, in the Yangtze River delta region, China.	Aircraft

From Table 1 it can be noted that several studies have produced estimates of mobile assessments by car, but there is still insufficient data for monitoring air quality by ship. Therefore, the next part will review the articles about the mobile laboratory monitoring by ship.

3.2 Mobile measurements using global ships

Table 2 Review the measurements of air pollution by global ships

Author	Study location	Parameters	Type of Air pollution measurement
Price et al. (2017) [47]	North Atlantic	Chemical component in particle phase -PM_1, CO_2 -UFP count	- Ship emission
Betha et al. (2017) [48]	North Atlantic	- Sub-micrometre particles (0.01- 1mm) - CO_2, PM_1 - BC - UFP count	- Ship emission
Williams et al. (2010) [49]	Southern oceans	Isoprene -Methanol, acetone and DMS -CO, O_3, NO_x	- Air quality
Warneke et al. (2004) [50]	The Gulf of Maine, USA	-CO -Acetonitrile -Chloroform	- Air quality

Table 2 (cont.) Review the measurements of air pollution by global ships

Author	Study location	Parameters	Type of Air pollution measurement
Brown et al. (2004) [51]	- East coast, USA	-NO_2 and N_2, O_5	-Air quality
Warneke et al. (2007) [52]	- New York city and Boston, USA	-VOC -CO	-Air quality
Chu Van et al. (2016) [53]	- East coast of Australia	Gaseous emission -UFP	-Ship emission
Jayaratne et al. (2016) [54]	- Southern Ocenan	- Charged and neutral particles	-Air quality
Morawska et al. (2016) [55]	-Yangtze River, China	- UFP - $PM_{2.5}$	-Air quality

Measurement on the riverway air pollution is challenging since the stationary monitoring has a limitation on assessing the air pollution in a real environment. Therefore, a complementary monitoring platform (ship) was used to fill this void. There have been several recent studies measuring air quality on oceans using Research Vessels (RV), as shown in Table 2.

It can be observed that almost all mobile laboratory monitoring platforms are addressed in this review of RV. Until recently, there has been little interest in air quality monitoring along rivers. Recently, atmospheric observations in the Yangtze River campaign were first, carried out by a mobile real-time monitoring platform. This was done for charactering on-river aerosol particles in the Yangtze River Basin and its sources [56]. The ship carried a container (9000m x 2352m x 2391m) up to ten high-resolution air quality monitoring instrument as shown in Figure 3.

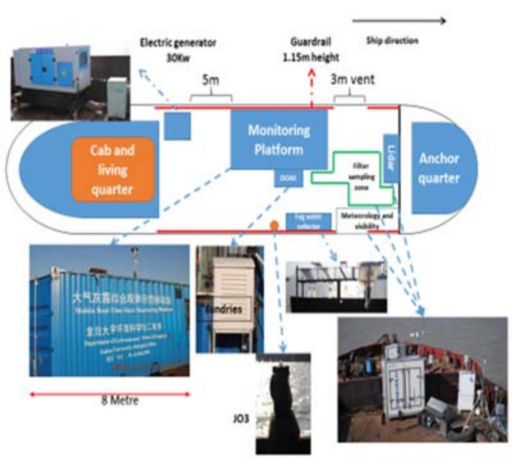


Figure 3 Ship and Instrumentation on board ship

With such a system, the spatiotemporal study of air pollution in the real environment by mobile platforms can gain more accurate air quality data to for studying the concrete problem and improving environmental policy in river basin.

4. Factors that affect air pollution measurement along the river

4.1 Seasonal variation

Seasonal variation plays a vital role in the dispersion patterns of air pollution. It is a consideration regarding measurement of air quality. For example, Li et al. (2017) [57] investigated the correlation of the $PM_{2.5}$ measured by mobile platform and stationary monitoring. They found that the correlation of $PM_{2.5}$ was very strong in the winter but was weakly correlated in the summer. Similarly, as noted by Fontes et al. (2017) [58], in Beijing, China, the concentration of $PM_{2.5}$ levels was highest in the morning and night time, and also showed higher levels in the winter (as shown in Figure 4).

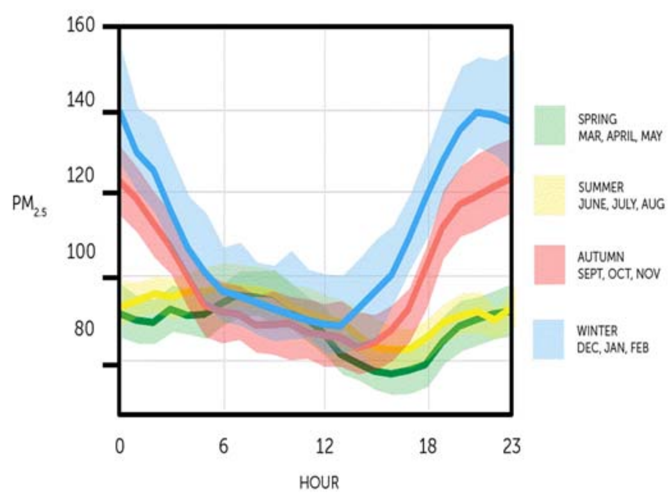


Figure 4 Average daily $PM_{2.5}$ cycle by season in Beijing during 2009-2015

A broader perspective has been adopted by Pochanart et al. (2004) [59] who investigated persistent aerosol pollutants such as CO and Ozone. This is clearly noticeable in the diurnal annual record of CO in the area of Baikal Lake, Russia (Figure 5a). The concentration of CO in the winter is higher than that in the summer because of the air pollution transported by the air mass from Europe to this region (as shown in Figure 5b).

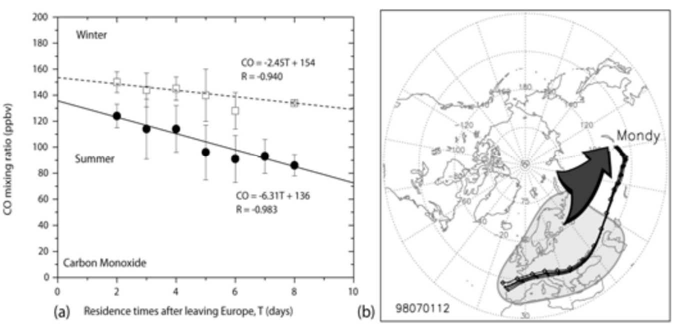


Figure 5 (a) The correlation between CO concentration and the residence times of inflow of air pollution and **(b)** The distribution of air pollution as show by a 5-day backward trajectory

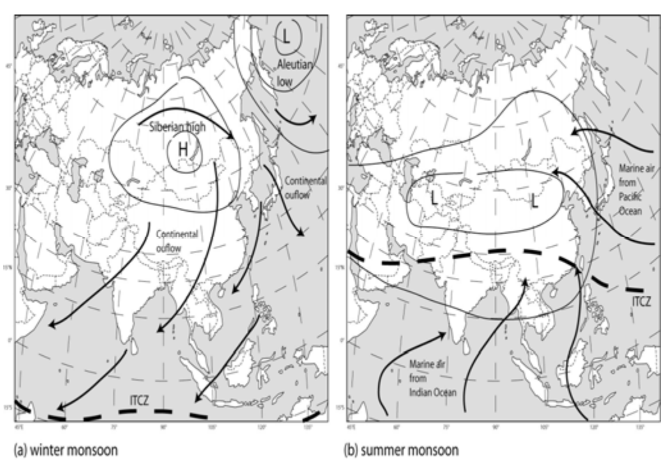


Figure 6 The air mass flow rate in Asia [60]

It is also worth noting that the monsoon regime has an effect on the seasonal variation. The example of this is in Southeast Asia, where the winter monsoon takes the cold air mass from the high continental regions to Southeast Asia, affecting the regional air pollution (as shown in Figure 6). Further, the elevated air pollution was found in the dry season as a consequence the long-range transport of air pollutants from other regions and anthropogenic sources within these regions [60].

4.2 Ship emissions

Ship emissions can play an important role in addressing the issue of the measurements of air quality along the river. Most studies in the field of ship emission have only focused on marine vessels. This allows them to adhere to the agreement of the International Organization (IMO) convention for the control of air pollution from ships [61,62]. However, the ship emissions may have played a vital role in bringing about principle sources of aerosol pollution. The evidence presented Until now, supports the idea that river ships distribute ship emission that affects regional air pollution [63]. Therefore, the current study needs to investigate these issues in order to overcome the gaps surrounding the restriction of IMO law and reduce the risks to human health.

In order to control the ship emission, IMO sets the Annex VI regulation to control the air pollution emitted from marine ships such as Nitrogen oxide and Sulphur oxide [64]. Corbett et al. (2007) [65] applied the air modelling model when they studied the correlation between mortality and marine ship emissions. They found that $PM_{2.5}$ released from ships has a detrimental effect on the cardiopulmonary system. These results were reported in settlements near major ports such as the Singapore, Shanghai and Tokyo as shown in Figure 7

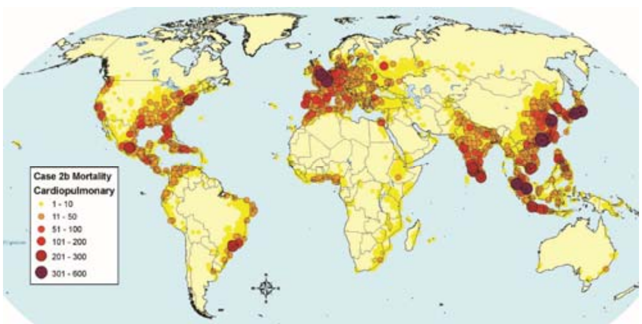


Figure 7 The ship inhale particle matter ($PM_{2.5}$) emission that affects cardiopulmonary mortality [65]

The fuel oil used by the marine ships contains high concentrations of Sulphur. Therefore, a large amount of aerosol pollution that is emitted from ships is sulphur dioxide. This has been shown to have a negative effect on the regional air quality along coastal areas and water ways [66]. Further studies by Yang et al. (2007) [67] show the variety of air pollutants emitted from ship exhausts; this is dependent on the type of engine and vessel, and the nature of shipping. These level of emissions from the ships are visualised in Figure 8.

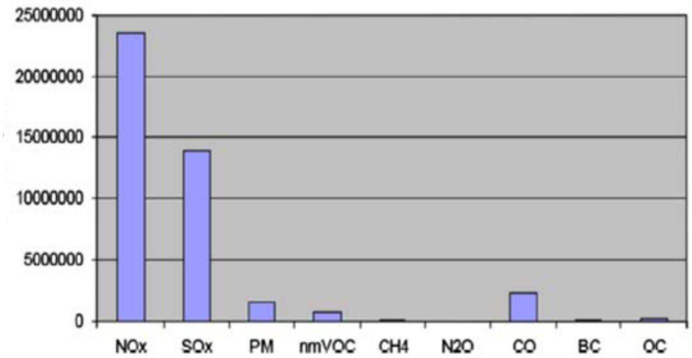


Figure 8 The approximation of other aerosol pollutants from ships in 2008 [68]

In terms of measuring ship emissions, the researcher investigated the gas emissions in two parts: the main stack and plume. The aerosol and particle emissions were measured to a distance of about 20 metres in a downwind direction. This was also done using a probe to sample air pollutants inside the stack. Ultimately, they calculated the emission factors (EFs) with a variation of gaseous emission and different of the equation.

It is also important also to consider the literature about the evidence of emissions of inland ships. With the rapid growth of the shipping and tourist industries in China, a number of ships and river cruises in the major river in China have been increasing. As a result, this has a direct impact on air pollution in China [63]. Along these lines, Fu et al. (2013) [69], investigated the emissions from local ships on the Grand Canal, China. They found that the gaseous emission was higher than the emission standard and can affect regional air quality in Jiangsu Province, China. There is some evidence that ships have had an effect on the distribution of air pollutants along rivers.

However, the study of air pollution by mobile platforms be greatly beneficial for monitoring air pollution in the river basin.

5. Conclusion

This review has provided an overview of the air pollution along the river which includes particulate matter and gaseous pollutants. The meteorological parameters and air-pollution data can be collected by stationary and mobile platforms. However, the latter is beneficial in terms of a better ability to collect data continuously and to access a greater variety of areas. For collecting air-pollution data in the river basin, using ships as a mobile platform is preferable than other moving platforms since it can carry high-resolution instruments for the measurements and has already successfully shown in collecting data above the ocean. Nevertheless, its implementation is still limited due to high cost in an installation of the instruments and a difficulty in maintenance. If these limitations can be overcome, the researchers would gain more understanding about the cause of the air pollution along the river basin, which can help them to prevent it in the future.

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