Atmospheric pollution and human health: the significance of a datable sedimentary archive from a small urban lake in Merseyside, UK

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Abstract

Preliminary results from sediment cores taken at Speke Hall Lake, Merseyside (UK) are presented. They demonstrate the use of sediments from a small, man-made, urban lake to reconstruct the local environmental history from the last 250 years. The lake is set within the heart of the Merseyside region, which saw the instigation, and subsequent burgeoning of major industries, notably petro-chemicals during the nineteenth century and by the expansion of the use and manufacture of automobiles in the last century. Given the widely reported concerns over public health, the use of such datable environmental archives is promoted in order to examine the relationship between environment and human health.
Keywords: environmental pollution, palaeolimnology, mineral magnetism.

1 Introduction

There are considerable concerns about relationships between atmospheric quality and human health, particularly the links between lung disease and air quality, which are widely discussed [1, 2]. Many studies have investigated the possibility that atmospheric pollution is a direct cause of high mortality rates, increased hospital admission rates and many types of cancer [3]. Areas with the highest concentrations of atmospheric pollution are normally those with the highest density of industrial sites and major route ways [4]. Historically, the major sources of pollutants to the atmosphere were derived from the burning of fossil fuels, which released particulates and heavy metals [5]. Following legislation, in the 1950s, emissions have been controlled to some extent and the delivery of atmospheric particulates and heavy metals has been reduced [6]. However, the rapid rise of the automobile, over the last 50 years, has meant vehicle emissions are now a major component of atmospheric pollution [7].

Particulate materials, particularly <10 μm (known as PM10s), are acknowledged to contribute to serious human health problems [8, 9]. Indeed, it is now widely reported that particulates <2.5μm diameter (known as PM2.5) may be instrumental in contributing to a wide variety of diseases, most notably cancers [10, 11]. Similarly, high-density urbanisation and industrialisation goes hand-in-hand with serious concerns about human health, where high mortality rates, hospital admission and referrals are concentrated [12, 13].

2 Records of air pollution in urban sites

The majority of work reporting historical atmospheric pollution records come from relatively remote locations, either in peat deposits or lake sediments, well removed from the major sources of industrial output [14, 15]. A few studies [16, 17] have examined urban sites but the majority of work conducted within the urban setting has concentrated on contemporary monitoring of atmospheric pollution using road dusts, surface soils and filtration/capture equipment, and stations recording daily air quality [18]. While this contemporary monitoring yields significant spatial information about diurnal and seasonal changes, plus the relationship of air quality to weather patterns, there is a distinct need to generate information about the temporal patterns of atmospheric pollution. Lake sites within an urban setting, which will yield historical records, are rare and therefore hugely important, as they will allow the construction of datable, detailed historical archives of changes in atmospheric pollution, which may then be examined alongside the historical community health archives for the area in question.

3 The need for datable urban archives

To fully understand and appreciate the relationship between human health and atmospheric pollution, researchers must not only examine the contemporary situation but also the historic one, because both the nature of atmospheric pollution and the style of life in communities have changed considerably over time. This means that the physiological effects of changing types of atmospheric particulates upon humans may have altered. So there is a clear need to examine whether air quality has had an impact on local communities in the past. To do this, datable and detailed temporal records must be obtained. Until recently, the majority of historical environmental records have come from remote and rural locations and while this work clearly demonstrates that atmospheric pollution is widespread and ubiquitous [19], it does not allow for a very detailed examination of datable environmental archives (with records of disease) for *urban* communities. Public health archives become less reliable and lose clarity further back in time as they rely more on the recording of oral histories and increasingly scant documentation [20]. It is vital therefore, that sites from within the urban landscape are identified, tested for their suitability and then used for detailed investigation to produce a datable, accurate, temporal and high-resolution pollution history. Where that is possible, and when such records are generated, environmental and public health workers may test the relationship between them, in the hope that they will deepen our understanding of how community health has been affected by the changing nature of atmospheric pollution over time. It is from the sedimentary archives, rather than the local community histories, that reliable, accurate information about the nature and extent of atmospheric pollution may be obtained. Where that is achieved, medical health specialists may be able to determine the relative importance of local environment and lifestyle to the problems of community disease patterns, in particular, problems associated with lung disease and specific cancers.

The need then, is to identify and select urban sites that may be able to generate suitable sediment histories, and to submit them to a series of scientific techniques, to produce an environmental history for the site. Using historical maps, documents and archaeological records, lake sites found within modern conurbations and industrial centres can be subjected to rigorous investigations to determine their suitability. Sadly many such sites have either been in-filled, desilted or have totally disappeared under spreading urban developments. However, in South Merseyside, northwest England, a viable, small, anthropogenic lake site has been identified within an urban, industrial area, which has witnessed the birth and development of chemical industries. The lake has yielded a well-dated, high-resolution record of atmospheric pollution and land use change.

4 Lake sediments

Lake sediments have long been used as archives of environmental information since they act as natural repositories for atmospheric and catchment-based materials [21]. Many studies report their use in reconstructing environmental histories and lake sites of varying size, shape and situation around the world have been investigated documenting land-use change, lake acidification and erosion studies [22,23]. It is recognised that, if a lake has not been disturbed by drainage or desilting over the course of its history then as sediments accumulate they will capture a record of ecological change and anthropogenic impact at a range of resolutions. Both atmospheric deposition directly to the surface of the lake together with catchment input through inflowing streams or groundwater flow provides material, which becomes entrained within the deepening sediment column [24]. The lake and its catchment can then be seen as a ‘trap’ for local and regional environmental change. The sediments themselves may be subjected to a wide range of analytical techniques that allow the generation of information about atmospheric pollution and catchment (land-use) change.

5 Case study at the Speke Hall site

Surrounded by the urban areas of Speke, Halewood and Garston, in south Liverpool, the lake at Speke Hall is located in an area that includes the heavy industries of Widnes and Runcorn, East Wirral, the Stanlow oil refinery and the city centre and docklands of Liverpool (Figure 1). Major industries include coal and oil fired power stations, shipbuilding, chemical and petro-chemicals, pharmaceuticals and the burgeoning John Lennon International Airport immediately adjacent to the site. Urban communities and landscapes situated in and around these major sites receive the atmospheric pollution output generated by their industrial activity.

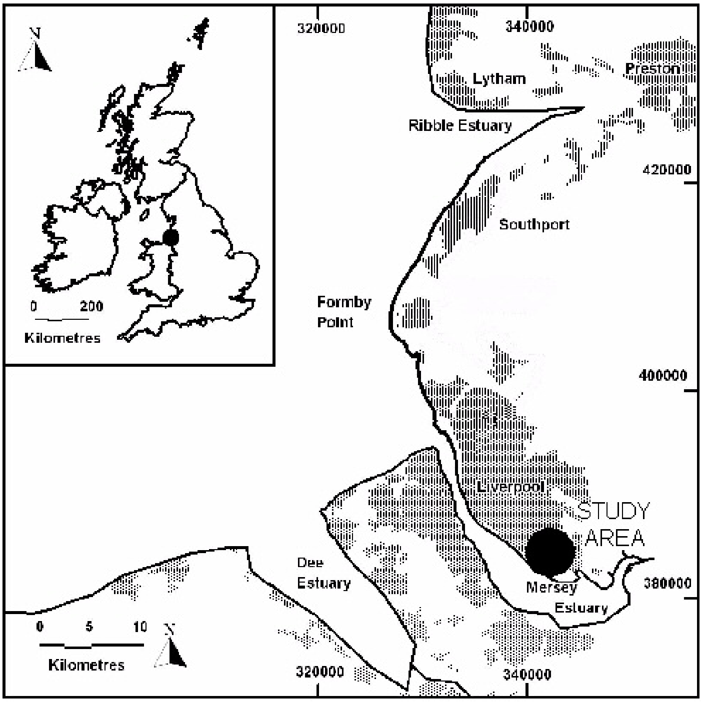

Figure 1: Location map of the study area.

The small lake at Speke Hall satisfies the requirements for the research programme, in that historical maps and documents attest to its anthropogenic origins, its maintenance, lack of disturbance and its longevity: in order to generate a suitable archive covering the rise of industrial development from the late seventeenth century onwards (the Industrial Revolution) the lake needed to be at least 300 years old. The site is approximately 11 km south of Liverpool

City Centre and lies close to the River Mersey (~20 m a.s.l.). At its deepest, the lake is 3-4m deep and it has a surface area of 30 m^2 derived from a modern–day catchment of approximately 620 m^2. There is no fluvial drainage either into or out from the lake at the present time.

5.1 Methodology

The lake was cored using a Gilsen hand operated piston corer and four cores were obtained from the deepest part of the lake. These were sampled at 0.5 cm intervals and the sediment dried at 35°C, packed into 10ml plastic pots [25] and subsequently subjected to mineral magnetic analyses (magnetic susceptibility measurements using a Bartington MS2 Magnetic Susceptibility Meter). Sediment chemistry was determined using an energy dispersive isotope source x-ray fluorescence (XRF) analyser [26]. Total concentrations of Aluminium (Al), Bromine (Br), Calcium (Ca), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Potassium K), Silicon, Si), Sulphur (S), Titanium, (Ti), Zinc (Zn) and Zirconium (Zr) were obtained for Core 2. Of these Br, Cu, Ni, Pb and Zn are chiefly derived from atmospheric deposition [27] and Pb is used (Graph 1) for the purposes of this paper. Spheroidal carbonaceous particles (SCPs) were counted for the top 8 cm following procedures described by Rose [28]. Further SCP characterisation was conducted using a Scanning Electron Microscope (SEM), namely A Zeiss EVO-50 SEM, using an Oxford Instruments INCx-sight analyser, software V05.00.09 (21 Feb 2005), supplied by Carl Zeiss SMT Ltd. (Cambridge, U.K.), was employed. Work continues on the remaining samples.

Table 1: ^{210}Pb chronology for sediment core 2.

Depth		Chronology	
cm	G cm^{-2}	Date AD	Age (y)
0.5	0.03	1999	2
1.5	0.10	1994	7
3.5	0.28	1979	22
5.5	0.46	1963	38
7.5	0.65	1949	52
9.5	0.88	1932	69
11.5	1.15	1912	89
14.5	1.63	1881	120

5.2 ^{210}Pb dating

Dried sediment from core 2 was analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs, ^{241}Am at Liverpool University's Environmental Radioactivity Laboratory. ^{210}Pb dates were calculated using the CRS dating model [29] and the 1963 depth was determined from the ^{137}Cs record, which places 1963 at a depth of 6.3 cm. The dating therefore suggests that sedimentation rates have been fairly uniform during the past century (0.013 g cm^{-2} y^{-1}). Table 1 shows the ^{210}Pb chronology of core 2; the dating results are discussed further in Worsley et al., [30]. But it is clear from Table 1 that 14.5 cm gives a date of 1881 and if the mean sedimentation rate is assumed for the lower core then at 24.5 cm it equates to a date of 1800. However, below this depth the sediment column is comprised of a thick clay layer (itself 24 cm deep), which represents the basal clay lining. Given that the lake (named the Higher Damme) was already in existence by the time that Addison's 1781 map was published and that detailed records from the Speke Hall Estate (1710-1719) clearly account for the "Higher Damme" [31], then the sedimentation rate for the core between 14.5 cm and 24.5 cm is notably lower, between 0.45 and 0.6 cm y^{-1}. This then includes the period of the Industrial Revolution and the start of the major industrialisation of the Mersey region.

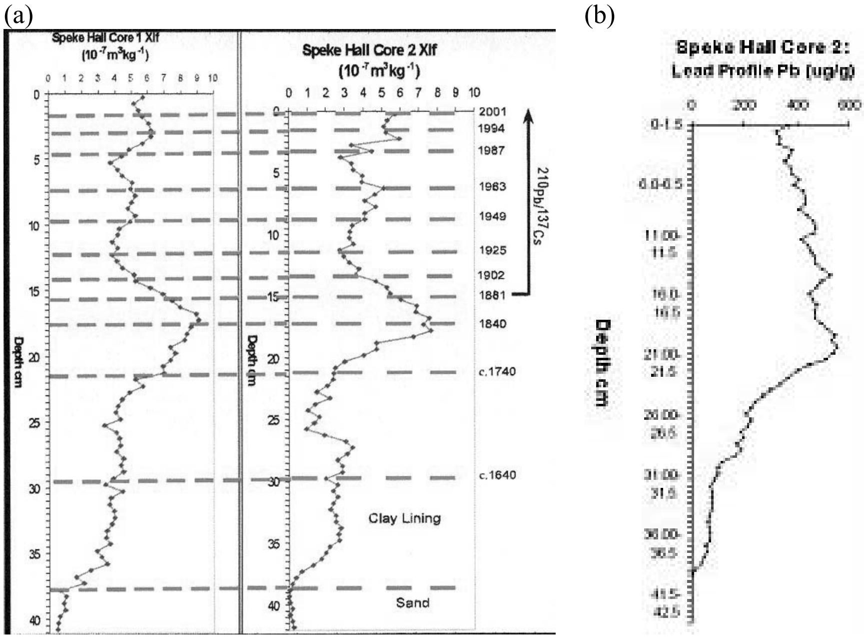

Figure 2: Sediment profile data (a) χ_{LF} for cores 1 & 2, with radiometric datable horizons labelled and (b) Pb concentration profile for core 2.

5.3 Results and discussion

Low frequency magnetic susceptibility (χ_{LF}) for cores 1 and 2 and demonstrates the efficacy of χ_{LF} for correlation and any concerns of sediment disturbance in the past are dismissed (Figure 2). For reference, χ_{LF} (measured within a small magnetic field and is reversible, i.e. no remanence is induced) is roughly proportional to the concentration of ferrimagnetic minerals within the sample, although in materials with little or no ferrimagnetic component and a relatively large antiferromagnetic component, the latter may dominate the signal.

The profiles suggest three major phases:

Phase 3:	1970–2000 (4.5–0 cm)	Replacement of old industries, expansion of road and air traffic
Phase 2:	1881–1970 (14.5–4.5 cm)	Regional expansion of industrial Merseyside
Phase 1:	1700–1881 (24.5–14.5 cm)	Early industrialisation in the Speke area

The Pb profile (Figure 2b) is noteworthy because lead is important to the regional and local history, Lead was used extensively on the Speke Hall estate [31] and it was produced widely at Widnes as part of the manufacture of Sulphuric Acid [32, 33]. High values in the lower part of the core support the conclusion that the lower χLF values result from intensive local industrial activity. The values decline but still reflect the regional signal along with the magnetic measurements and the various peaks can be attributed to changes in the chemical industries along with the arrival of car and air transport [30].

SCP counts demonstrate that a major contribution of atmospheric pollution comes from combustion processes. The χLF peak at 3.5 cm (Figure 3) is therefore largely accounted for by these particulates. Implications for discussions about human health are paramount. Further results and discussion will be disseminated in future publications.

(a) (b)

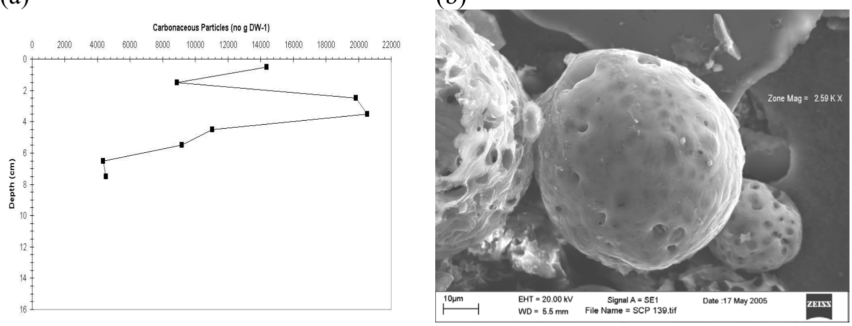

Figure 3: (a) Spheroidal Carbonaceous Particle (SCP) counts for Core 1 and (b) SEM image of SCP grains.

6 Conclusions

A combination of sedimentary analytical techniques on sediment cores taken from Speke Hall Lake (Merseyside) demonstrate it is possible to reconstruct a datable archive of atmospheric pollution from within an urban area. Rather than relying on remote sites to produce such records, with care and detailed investigations into their history, small urban lakes and ponds can be used effectively. Records produced at Speke show the development of local and regional industry and its contribution to the atmosphere and they can therefore be used as a detailed record of atmospheric pollution. Public health and medical workers in turn can now use this information, as they strive to understand the contribution of the region's industrial legacy to community health problems.

Acknowledgements

This research forms part of the research development programme funded by Edge Hill University College. All authors would like to thank Mrs Barbara Hodson of the School of Applied Sciences at the University of Wolverhampton for her SEM technical support.

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