National University of Mongolia
and University of Bath

INTERNATIONAL RESEARCH COLLABORATION INITIATIVE

Initial report: March 2017

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Executive Summary

The International Research Collaboration Initiative (IRCI) was established by the University of Bath (UoB) and the National University of Mongolia (NUM) in 2016 with the aim of establishing long-term research collaborations between academics, industrialists, and policy-makers. Initial interactions have focused on data science, mathematics, and policy research, but the list of disciplines is expected to expand over time.

The first major IRCI activity took place from 21st to 25th November 2016 when a delegation from UoB, with expertise in mathematics, statistics, data science, and health psychology, was hosted by the Institute of Mathematics at NUM. The UoB delegation consisted of staff and PhD students from the Departments of Mathematical Sciences and Psychology[1], the Institute for Policy Research (IPR), and the EPSRC Centre for Doctoral Training in Statistical Applied Mathematics (SAMBa).

Activities during the visit included the following:

- A training course (Data Science and Statistics in Research: unlocking the power of your data) delivered by members of the UoB delegation. The course was part funded by the Higher Education Reform Project of Mongolia and was delivered to 130 participants (selected from 300 who expressed interest).
- Four research workshops on the themes of Air Pollution, Mining, Public Health, and Ecology.
- Bilateral meetings with policy makers and governmental institutions.

During the visit, the topic that dominated research and collaboration discussions with Mongolian academics, public institutions and government officials was air quality in Ulaanbaatar. Air pollution in Ulaanbaatar is 7.5 times the safe level determined by the World Health Organisation. The importance of this problem, and the associated health effects, has led to the IRCI formulating a substantial integrated research and training package on this subject.

The planned programme of research combines data science, social science, policy research, mathematics, and statistics to describe the complex inter-dependencies between local and long-range causes of air pollution, and its health effects. State-of-the-art methodology will allow data from a variety of sources to be integrated within a coherent framework providing a realistic model. Behavioural change will be enabled through psychological and social studies of the population and development of appropriate policy decisions and should lead to a reduction in deaths from air pollution related disease in Mongolia. Once research is underway, the methodology can be applied to other cities and regions suffering from severe air pollution.

The following report is intended for readers both in Mongolia and the UK and describes a research agenda devised collaboratively between academics and institutes in the two countries. It also details a funding strategy that will support academics, both in the UK and Mongolia, to participate in joint research, and to support the development of a sustainable base of expertise in Mongolia.

[1] Delegates were Professor Andreas Kyprianou, Professor Paul Milewski, Professor Gavin Shaddick, Dr Daniel Simpson (all Mathematical Sciences), Professor Julie Barnett (Psychology and Institute of Policy Research), Dr Susie Douglas (EPSRC Centre for Doctoral Training in Statistical Applied Mathematics (SAMBa)), Robbie Peck, Adwaye Rambojun, Aoibheann Brady, Matthew Thomas (SAMBa PhD students)

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Introduction

In early 2016 the International Research Collaboration Initiative was formed consisting of academics from the University of Bath (UoB) in the UK and the National University of Mongolia (NUM). The principle objective of this initiative is to explore possible science-based collaborative research between the UK and Mongolia. As far as we are aware, this is the first UK-Mongolia collaboration of this kind. In November 2016, there was an exploratory visit from UoB to Ulaanbaatar hosted by Dr Otgonbayar Uuye from the Institute of Mathematics at NUM.

During the visit, there were a number of activities involving academics, students, government employees, and industry from both the UK and Mongolia. Interactions between the groups of participants took the form of three interrelated sets of activities: (i) a short course on Data Science; (ii) four workshops on the topics of: Air Pollution, Ecology, Mining, Public Health; and (iii) meetings with governmental organisations.

Figure 1: Representatives from the IRCI during the November 2016 visit

Data Science short course

The course was led by Professor Gavin Shaddick, a world-expert in Data Science and the effects of air pollution on health, co-taught by Dr Daniel Simpson, and supported by four PhD students. Participants on the course were trained in the application of modern methods in Data Science and statistical analysis, gaining experience through a 'hands-on' approach, working with open source computing packages to analyse data in a series of practical sessions. The course was delivered to 130 people over 4 days.

Workshops

Four workshops were held on the themes of Air Pollution, Mining, Public health, and Ecology. Participants at the workshops included researchers from the Economic Research Institute, the Institute of Mathematics, and the School of Medical Sciences at the National University of Mongolia, the Mongolian University of Science and Technology (MUST), the National Centre for Public Health, the Institute of Meteorology and Hydrology, and the German Institute for Resources and Technology. Although each workshop had different themes and participants, the prominent discussion points from all of them related to air pollution in Mongolia.

Meetings with policy makers and governmental institutions

During the visit, academic participants from Bath met with representatives from the Department for Health, the National Centre for Communicable Disease, the Institute of Mathematics, the Minister of Health, the British Embassy, the Ministry of Education, the Economic Research Institute, and the Institute for National Strategy. As with the other activities, the overriding focus of these discussions was air pollution and its impact on health and there was a strong desire to fully understand and quantify the problem and subsequently to instigate strategies that would result in improvements in air quality and public health.

Air pollution in Ulaanbaatar

Throughout the IRCI visit, the topic that dominated discussions was air quality in Ulaanbaatar. The importance of this multi-faceted problem, and in particular the health effects associated with air pollution, underpins the interactions between Mongolian researchers and the UoB delegation and sets the future research strategy.

Air quality is the result of a combination of factors including pollution, the surrounding environment and meteorology. Air pollution arises from emissions from various sources, both natural and man-made and levels will depend on volume of emissions, temperature, wind conditions and local topography. Ambient (outdoor) air pollution poses a significant threat to global health and has been associated with a range of adverse health effects, including respiratory and cardiovascular diseases, and some cancers.

Mongolia has rapidly transformed demographically, economically, and socially over the last 20 years which has brought significant changes and pressures on the infrastructure of Ulaanbaatar. The Mongolian population has increased from around 2.18 million in 1990 to its present total of 3 million. Rural to urban migration has increasingly concentrated this population in Ulaanbaatar and its suburbs. Migrants to the city and lower income city dwellers often settle in permanent ger (or yurt) camps on the Northern outskirts of Ulaanbaatar and account for over 60% of the capital's population. Within these areas, open fires are used for heating and cooking. A wide variety of sources are used for fuel including unrefined coal, wood, and rubbish. The result is a thick smog that hangs over the valley in which Ulaanbaatar is located.

Figure 2: Air pollution in Ulaanbaatar

Particulate matter air pollution is a mixture of solid particles and liquid droplets in the air. Ultra-fine particles, known as $PM_{2.5,}$ are particularly hazardous to human health and come from both naturally occurring and man-made sources, the latter including power generation, domestic heating, and vehicle engines. The World Health Organisation's air quality standards state that annual average levels of $PM_{2.5}$ should not exceed 10 μgm^{-3}. Annual averages in Ulaanbaatar are 7.5 times this level and the situation has become so bad in recent years that (hourly) measurements of $PM_{2.5}$ have exceeded 1000 μgm^{-3} in some districts.

Proposed collaborations in Data Science and Policy Research

Modern techniques in data science can have significant impact both in determining the magnitude of the effects of air pollution, and in formulating future mitigation strategies. From these analyses, health psychologists, sociologists, and policy experts, can make recommendations about how to deliver solutions to reducing exposure to air pollution through raising awareness and changing behaviour.

Whilst there is an abundance of data, measured both locally and by global institutions (such as the WHO), Mongolia does not currently have the expertise and experience required to perform such analyses and it is essential that local people are trained to enable them to use modern data-intensive techniques. We believe that collaboration between Mongolian academics and policy makers, and UK experts in data science and policy research can deliver rapid and lasting impact to the health and quality of life for those living in Ulaanbaatar.

Following the first IRCI delegation, it became clear that a collaboration between data scientists, health psychologists, data analysts and public health researchers was essential to understand the causes and effects of air pollution in Mongolia, and Ulaanbaatar in particular, and to deliver effective policy and investment decisions to tackle the problem.

Several interrelated themes for future work based on air pollution were identified including: (i) quantification of population level exposures to particulate matter in Mongolia; (ii) the development of a full chain analysis of the causes of air pollution, its health effects, and methods for improvement; (iii) the development of a Mongolia specific risk function for the effects of air pollution on health; (iv) methods for communication between stakeholders and the public.

(i) Quantification of population level exposures to particulate matter in Mongolia

It is vital that the risks, trends, and consequences of air pollution are monitored and modelled to develop an effective environmental and public health policy. Accurate measurements of population level exposures are required but this may be a demanding task: the processes involved are extremely complex and ground monitoring may not be sufficient to fully characterise the pollution that is experienced by the populations at risk. Based on Prof. Shaddick's work with the WHO on producing global estimates of air quality, we will investigate the spatial distribution of concentrations of ultra-fine particulate matter within Mongolia and match this to high-resolution population estimates. This will allow the quantification of population exposures to air pollution and assessment of the subsequent risks to health.

(ii) A full chain analysis to identify the effects of air pollution and inform potential future mitigation strategies.

In a full chain analysis, stages on the pathway from emissions to health impacts and economic cost are considered in a holistic manner. In addition to understanding the links between the different stages it is essential to assess the level of confidence associated with the understanding of each of the stages. A formal assessment of uncertainties, including the understanding of the processes and the quality of available data will provide essential guidance in targeting areas in which further expertise and data collection may be required. The stages in the process that will be considered include, but are not limited to, those shown below.

policy → emissions → concentrations → exposures → health impacts → monetary valuation → communication → future policy decisions

Our goal is to generate usable and useful insights to support public health policies by engaging policy makers, practitioners, and citizens in mitigating health risks from exposure to air pollution. The primary route to this will be to seek research funding to implement a full chain analysis approach to assessing the effects of policy options on the prevention and management of air pollution related disease.

Information about the current state of air pollution can be obtained from routine monitoring. However, an individual's actual exposure is a complex interaction between their behaviour and the environment. Personal exposure to air pollution will affect the risk of certain health outcomes, e.g. respiratory diseases, heart disease, and stroke. Managing these health issues places a care and financial burden on society. Policy decisions, for example relating to permissible levels of emissions, or the provision of guidance about the way in which people might best interact with their environment, can reduce mortality and morbidity,

and will have associated financial costs. However, this pathway is complex and subject to uncertainties at every stage.

A full chain analysis for Ulaanbaatar will encompass initial analysis of the available data and policy options, an exploration of different mechanisms to reduce air pollution, the implementation of organisational and behavioural interventions, and analysis of the impact (monetary, environmental, health) of those interventions. For example, in terms of human health, this involves tracking the fate of pollutant emissions through a set of stages, as depicted in Figure 3. The diagram shows, among other things, that a policy or measure may change environmental exposures not only by affecting emissions but also by affecting (i) the state of the environment, and/or (ii) how people interact with that environment.

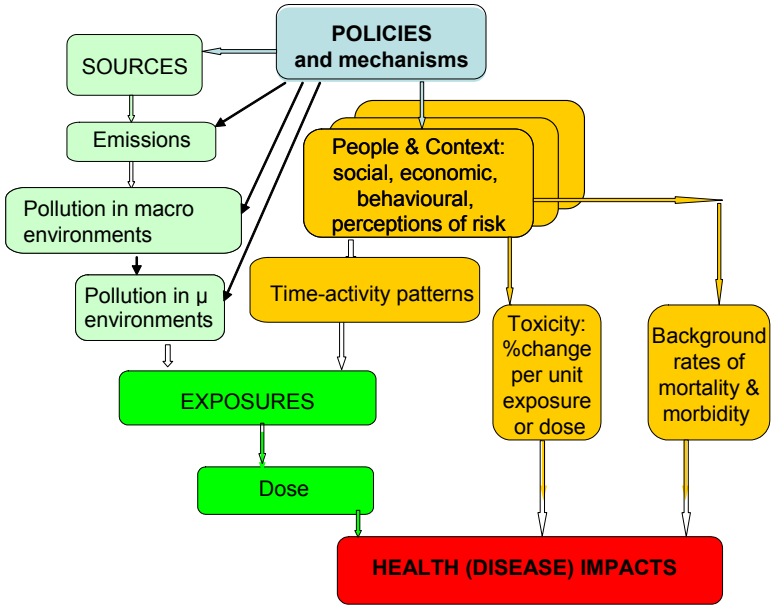

Figure 3: Tracking of the progress of pollutant emissions to their impact on human health

This interdisciplinary full chain approach to the analysis of the effects and management of air pollution will allow the effects of potential policy initiatives, and environmental and behavioural interventions to be assessed. The full chain analysis model will allow us to identify the magnitude of the impacts of different sources of air pollution (e.g. slow burning fuels, traffic), and test and quantify the effects of possible policy scenarios. Building on the full chain analysis, information on pollution emissions, monitoring and weather data, meteorological models, and local geography will be combined to develop a model to forecast real time pollution levels.

It is likely that social media and wireless technology will have a role both in facilitating monitoring as well as in delivering communication. As with many developing countries, globalisation has meant that Mongolia has jumped to the latest technology in one step with excellent Wi-Fi coverage and a large number of people owning smartphones. Integrating and exploiting sources of data can provide information and insights at greater levels of specificity to give personalised and geo-localised in (close to) real time information which can support robust healthcare policy and practice as well as personal action.

(iii) The development of a specific concentration-response function (CRF) for Mongolia.

The specific composition of air pollution in Ulaanbaatar will be unique to the city and it is imperative that the CRF used in estimating the health impacts of air pollution in the city reflects this. At present the estimate of the health impact of air pollution in Mongolia is estimated based on CRF analyses that have been developed in other countries. Time-series epidemiological studies will need to be performed using local measurements of air pollution and health outcomes. This will be based on data that was shared following the IRCI meeting in November and builds on Prof. Shaddick's collaborative research with the

WHO. The result of this work will provide a step change in the information available and help produce highly accurate estimates of the health effects of air pollution in the country which can then better inform policy.

(iv) Communication.

With such a wide range of people interested in understanding and contributing to the solution (e.g. health providers, weather and pollution forecasters, energy utilities, urban planners, schools, universities, and many more), it is essential that effective communication and collaboration is enabled across all groups. The creation of a stakeholder map and communication plan will be an integral part of this contribution.

A key aspect of appropriate strategies to mitigate the effects of pollution is to communicate the dangers appropriately to the target audience, for example reducing traffic and commuting in Ulaanbaatar when the levels of air pollution are hazardous. This will form an integral part of the full chain analysis and will require collaboration between Mongolian policy makers, and experts in health psychology, public policy, and sociology.

Current ICRI work

Work since the delegation in November 2016 has focussed on the first of the objectives described above: the quantification of population level exposures to particulate matter in Mongolia. We used the recently developed Data Integration Model for Air Quality (DIMAQ) that was developed by the WHO and the University of Bath. DIMAQ produces estimates of annual exposures of $PM_{2.5}$ levels at high spatial resolution (0.1° × 0.1°, which equates to approximately 11x11km at the equator). The sources of data used in the model include: ground measurements, satellite remote sensing, population estimates, topography, information on local monitoring networks, and measures of specific contributors of air pollution from chemical transport models.

Estimates of levels of $PM_{2.5}$ were produced on a high-resolution grid covering Mongolia, as can be seen in Figure 4. By matching these estimates to the corresponding population (in each cell of the grid), the distribution of population exposures can be constructed. These population level exposures can be seen in Figure 5 from which it can be seen that:

- 91.5% of the population reside in areas where air pollution exceeds the WHO air quality guideline (AQG) limit of 10 μgm^{-3}
- 37.6% experience levels of $PM_{2.5}$ that are greater than 25 μgm^{-3}
- 9.1% are exposed to levels of air pollution which exceed the WHO's interim target of 35 μgm^{-3}, a level which is associated with about 15% higher long-term mortality risk relative to the AQG level.

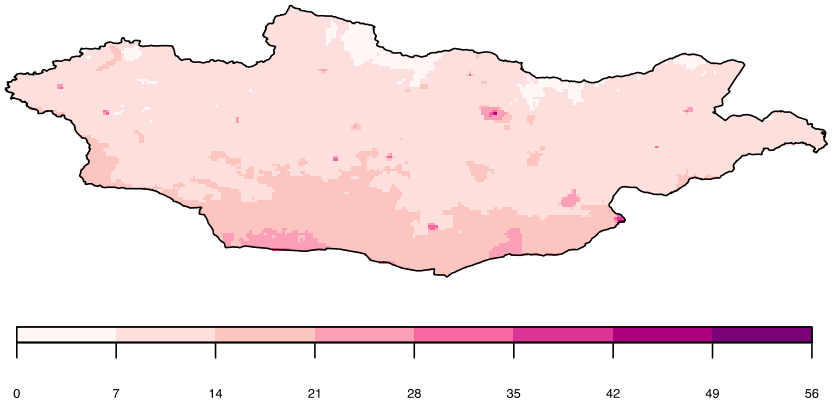

Figure 4: Estimated levels of $PM_{2.5}$ across Mongolia produced using the Data Integration Model for Air Quality

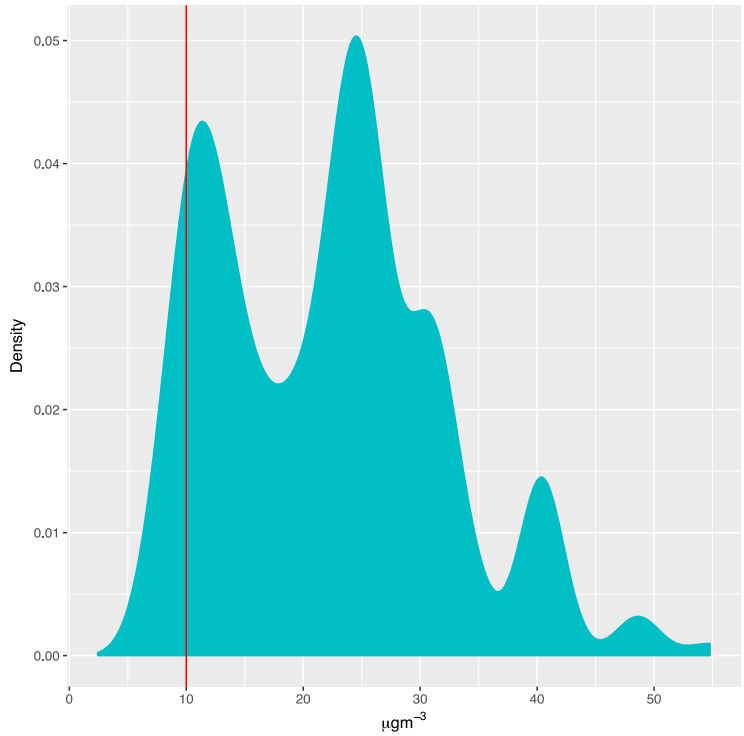

Figure 5: Population level exposures of PM2.5 in Mongolia. The vertical red line indicates the WHO limit for annual average PM2.5 (10 μgm^{-3}).

Future activities

It is essential that the momentum of this fruitful collaboration is maintained. In order to pursue these high impact, collaborative research projects, substantial financial investment is essential. The scoping of the proposed projects ideally needs to be done through face to face intensive discussion between researchers and policy makers from different disciplines, an expansion of those who met in November 2016, to ensure concerted and effective effort towards common goals.

Funding for both the scoping workshop and research proposals will be sought immediately. Although ideally the workshop will take place prior to the start of a research proposal, opportunities will be taken to begin research wherever they become available.

Scoping workshop

A facilitated workshop to take place in Ulaanbaatar (ideally during 2017) in order to build further collaboration between academics, public bodies, government officials, and other stakeholders. The design and facilitation of the workshop will be based on the Integrative Think Tank (ITT) model that has been developed at the University of Bath as part of its Centre for Doctoral Training in Statistical Applied Mathematics (SAMBa). ITTs focus on problem formulation leading to well-defined starting points for future research. Participants in the workshop will be by invitation only and will include, but not be limited to, the following:

Dr Enkhjargal Altangerel (Public Health Institute, Mongolia)
Prof. Julie Barnett (Department of Psychology, Institute of Policy Research, UoB)
Dr Tuvshintugs Batdelger (Economic Research Institute, NUM)
Dr Tsogtbaatar Byambaa (Public Health Institute, Mongolia)
Dr Fiona Gillison (Department for Health, UoB)
Dr Alistair Hunt (Department of Economics, UoB)
Dr Barbara Kasprzyk-Horden (Department of Chemistry, UoB)

Prof. Andreas Kyprianou (Department of Mathematical Sciences, UoB)
Prof. Gavin Shaddick (Department of Mathematical Sciences, UoB)
Dr Bazarragchaa Tsogt (National Centre of Communicable Diseases, Mongolia)
Dr Otgonbayar Uuye (Institute of Mathematics, National University of Mongolia)

Funding for the workshop will be sought through the home institutions of UoB and NUM, UK funding agencies (e.g. Royal Society, Research Councils, Leverhulme Trust), international funding bodies (e.g. Asian World Bank, The World Academy of Sciences), and more. Depending on the amount and scope of the funding received, this workshop could include relevant researchers from other countries where air pollution poses a significant threat to health (Mexico, China, India, and Chile are examples where the IRCI already has strong links).

Research proposals

A major objective of the IRCI is to obtain funding for research to enable a step change in the effect of air pollution on the health of citizens of Ulaanbaatar. Funding will support researchers time, travel expenses, high performance computer resources, venue hire, and any associated application or development costs. As alluded to above, this research could have wider implications as the findings will be applicable to other urban areas affected by severe air pollution.

Research will initially focus on the delivery of the full chain analysis for Ulaanbaatar that will result in significant impact on the health and economic stability of the city. Applications for funding will be made from both the UK and Mongolia to national and international agencies. In the UK, there is an excellent opportunity to explore the recently established UK Government Global Challenges Research Fund (GCRF) (£1.5bn) which supports cutting-edge research that addresses the challenges faced by developing countries. Our proposed research is naturally multidisciplinary, requiring expertise in mathematical sciences, applied sciences, psychology, policy, social sciences, and engineering. All projects will incorporate a strong focus on capacity building; providing training for local researchers and policy makers in Mongolia to ensure that the research agenda outlives any start-up base of funding.

Initial work has sought to investigate spatial patterns in levels of fine particulate matter ambient air pollution ($PM_{2.5}$) within Mongolia and to quantify population-level exposures to this key driver of adverse health. Using the Data Integration Model for Air Quality, developed by the World Health Organisation and the University of Bath, it is estimated that 91.5% of the Mongolian population reside in areas in which levels of $PM_{2.5}$ are greater than WHO limits.

It is essential that change is implemented to reduce the health effects of air pollution and to improve the quality of life for citizens of Ulaanbaatar. To implement change effectively, the factors contributing to air pollution and the subsequent effects on public health must be understood and formulated in a manner that allows the inter-dependence between causing factors and outcomes to be quantified. Collaborative research between experts in the UK and Mongolia will deliver this understanding and the strong relationship with policy makers will ensure that the findings from the research are acted upon to deliver change within a meaningful time frame.

Air pollution, and the resulting health effects, is a global issue and the research performed through the IRCI in Mongolia will form a platform for further collaboration and research with other cities and countries ensuring lasting and wide-ranging impact. The IRCI is committed to securing funding to pursue this ambitious of programme of work.

Wider application

Air pollution poses a significant threat to public health globally. The WHO recently estimated that 3 million premature deaths can be attributed to air pollution. The development of the full chain analysis

methodology in Mongolia as proposed in this report will lead to a data-to-policy approach that will be applicable in all areas that are experiencing problems with poor air quality. Although the nature of air pollution, population dynamics, population health and possible mitigation strategies will differ from country-to-country, the experience that will be gained in its development and implementation in Mongolia will be invaluable.

Conclusion

Ambient air pollution poses a significant threat to public health in Mongolia. This was the major theme that arose from the ICRI visit to Ulaanbaatar in November 2016, which included a variety of activities designed to promote collaboration between the University of Bath and Mongolian academics, industrialists, government officials and policy-makers, and has become the initial focus of the ICRI. Funding and support needs to be obtained to implement this ambitious programme of work and deliver tangible, near-term benefits to residents of Ulaanbaatar and Mongolia.