**Stepping into Water Crisis: analysing the driving forces of China’s water resources exhaustion**

*Dabo Guan1,2\*, Klaus Hubacek3*

1. School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

2. St. Edmund’s College, University of Cambridge, Cambridge, CB3 0BN, UK

3. Department of Geography, University of Maryland, College Park MD 20742, USA

\*To whom correspondence should be addressed. E-mail: [dg346@cam.ac.uk](mailto:dg346@cam.ac.uk)

**Abstracts**

China is a country with abundant water resources, but these are unevenly distributed. The statement that all rivers run dry in the North, and all water is polluted in the South sketches a realistic picture about China’s current water challenges. . Alongside the South-to-North Water Transfer Project, China sees technology as a rescue from the water crisis without harming its economic development. China announced its ambitious plan to cut “water consumption per unit of GDP to 125 m3 by 2020, down by 60% from today” with special focus on more efficient irrigation, in order to cope with the projected economic growth of 60% by 2020 (Ministry of Water Resources, 2007). In this paper, we employ three indicators to assess water issues in China: freshwater consumption discharged COD in wastewater, and unavailable water (amount of freshwater bodies contaminated and thus unavailable for any purpose of usage). For this we use the latest available datasets and adopt structural decomposition analysis to investigate the driving forces of China’s water crisis from 1992 to 2007. We find that 1) agriculture is not the major contributor to China’s water crisis, although it remains the largest freshwater consumer in China. 2) technology improvements can effectively offset some freshwater consumption and COD discharge but it fails to eliminate cumulative pollution which can be seen as a key contributor to the water crisis. Finally, China’s water-intensive export production pattern is responsible for 1/4 of total consumed freshwater to be used (virtual or embodied water) for export production and about 1/3 of freshwater resources is too polluted to serve for any other production purposes.

KEYWORDS: China, water crisis, water scarcity, water pollution, input-output analysis, structural decomposition analysis

# Introduction

The continuously large-scale economic development in past decades and recent double-digits growth largely driven by constructions and export production has pulled China to be the second largest economy and the world largest manufacturer for export. These remarkable achievements have come at a tremendous cost to the country’s environment, particular around water. China has abundant freshwater resources in terms of total availability, ranked as the 6th world largest, however the per capita volume is only 2,300 m3 which accounts for one-third of world average. China’s water resources are unevenly distributed: northern China has only about 20% of the total water resources in China, but is supporting more than half of total population ([Guan and Hubacek 2007a](#_ENREF_10)), which has resulted in less than 300 m3 of per capita water availability in north China ([Guan and Hubacek 2007b](#_ENREF_11)). Furthermore the water resources have been inefficiently used and grossly polluted by human and industrial wastes ([Gleick 2009](#_ENREF_9)).

After “*all rivers run dry in the North, and all water is polluted in the South*”, China announced its ambitious plan to cut “*water consumption per unit of GDP to 125 m3 by 2020, down 60% from now*” ([Xinhua 2007](#_ENREF_26)) with special focus on irrigations, in order to cope with the projected economic growth by 60% by that time ([NewScientist 2009](#_ENREF_20)). Furthermore in 2011, China announced that it will invest four trillion Yuan (US$600 billion) over the next ten years to protect and improve access to water ([Yu 2011](#_ENREF_28)). The messages from Chinese authority indicates that (a) agriculture is a key to combat water scarcity; (b) China is confident with and will rely on constructing more water related infrastructures with latest technologies to offset future mounting demand and pollution; (c) the economic production may largely follow the same pattern as previously; (d) the authority gives priority to economic growth when water shortages for social and environmental needs meets economic recession. Those four points sketch some influencing factors to China’s water crisis: e.g. technology, production and consumption patterns and water policy and management. However, there are many common misperceptions with regards to the drivers behind consumption and pollution led water scarcity in China.

The aim of the paper is to employ structural decomposition analysis (SDA) to investigate the key driving forces of water consumption and pollution and further quantify the magnitude those factors in contributing China’s water crisis.

# Method and Data

This paper extends the *Impact = Population × Affluence × Technology (IPAT)* model ([Ehrlich and Holdren 1971](#_ENREF_7); [Commoner et al. 1971](#_ENREF_4)) by using structural decomposition analysis (SDA) ([Leontief and Ford 1972](#_ENREF_18); [Rose and Casler 1996](#_ENREF_22)) to assess the key drivers of China’s recent water crisis led by consumption, pollution and associated emission dispersion in water bodies. Further we apply the *IPAT-SDA* to a hydro-economic accounting framework developed by Guan and Hubacek 2007 ([Guan and Hubacek 2007a](#_ENREF_10)) to capture the drivers of changes of water consumption during production and consumption processes; wastewater discharges after production and consumption activities; and water being contaminated in hydro-ecosystem that is unavailable for any purpose of economic activity.

The *IPAT* equation was developed in the 1970s ([Ehrlich and Holdren 1971](#_ENREF_7)) to explain the environmental effects of population, affluence (usually measured in GDP per capita), and technology (usually measured in emissions per unit GDP), and to project future environmental change based on changes in these main driving forces ([Dietz and Rosa 1997](#_ENREF_5); [York et al. 2002](#_ENREF_27); [Commoner 1972](#_ENREF_3)). One of the key limitations of *IPAT* and its variants is that the model can only assess the direct impacts on the environment caused by these driving forces. Furthermore, it is too aggregated to clearly allocate the sources of emissions to particular industries or consumers ([Chertow 2001](#_ENREF_2)). The limitations of the *IPAT* model can be overcome using input-output (IO) analysis ([Hertwich 2005](#_ENREF_14)). Input-output analysis is a suitable tool to evaluate both direct and indirect environmental impacts by examining the flow of goods and services among the producing and purchasing sectors of a country or region ([Leontief 1986](#_ENREF_17)). By adopting this approach, the *IPAT* variable *affluence* can be represented by a disaggregated final demand which accounts for household consumption in sectoral detail; the variable *technology* is better described by the Leontief inverse matrix which captures the inter-linkages between all economic sectors.

Just as the standard *IPAT* analysis decomposes changes over time into components for population, affluence, and technology, using input-output analysis the main driving forces can be divided into more detailed subcomponents by employing a technique called structural decomposition analysis (SDA) ([Hoekstra 2005](#_ENREF_15)). Rose and Casler ([1996, p34](#_ENREF_22)) define SDA as an “*analysis of economic change by means of a set of comparative static changes in key parameters in an input-output table.*” The first application of SDA to environmental issues can be traced back to the early 1970s ([Leontief and Ford 1972](#_ENREF_18)). Most SDA studies focused on energy consumption and its related emissions in developed countries or regions ([see Hoekstra and van der Bergh 2002](#_ENREF_16)). SDA studies focussing on energy and related emissions have been performed for China ([Lin and Polenske 1995](#_ENREF_19); [Garbaccio et al. 1999](#_ENREF_8); [Andresosso-O'Callaghan and Yue 2002](#_ENREF_1); [Guan et al. 2008](#_ENREF_13); [Peters et al. 2007](#_ENREF_21); [Guan et al. 2009](#_ENREF_12)). The applications of SDA to other fields are rare, except for physical material flows ([Hoekstra and van der Bergh 2002](#_ENREF_16)) and nitrogen accounting ([Wier and Hasler 1999](#_ENREF_25)). There is no study that employs such method to assess driving forces in the change of water consumption and associated emissions.

The principal formula for *IO-IPAT SDA* can be illustrated as **Freshwater Consumption** . Water consumption can be decomposed into five driving forces: population (*p*), water consumption intensity (**F**) – amount of freshwater consumed to produce a unit of industrial output, economic production structure (**L**), final consumption pattern (**ys**) and per capita consumption volume (*yv*). Bold notation denotes matrices (capitals) and vectors. The change in freshwater consumption from time *t-1* to time *t* can be decomposed into changes in the component driving forces, but there is no unique solution for the decomposition; the five factors utilized in this paper have *5!=120* first-order decompositions ([Dietzenbacher and Los 1998](#_ENREF_6)). One of the 120 possible decompositions is shown in Equation 1.

|  |  |
| --- | --- |
|  | (1) |

Each of the four terms in Equation (1) represents the contribution to change in CO2 emissionstriggered by one driving force with keeping the rest of variables constant. For example, the first term ―  represents the change in CO2 emissions due to changes in population, with all other variables (**F**, **L**, **ys** and *yv*) remaining constant. This also serves to highlight a methodological issue with SDA – non-uniqueness. For instance, in the fourth term **F**, **L**, **ys** and *yv* can be evaluated at the start or the end-point of the time-period investigated. There are several methods for dealing with this issue. We average all possible first-order decompositions; for a detailed discussion see Hoekstra & van der Bergh 2002 ([2002](#_ENREF_16)).

# Results

## Freshwater consumption

In the 13 years from 1992 to 2005, China’s annual production-related freshwater consumption decreased about 10% from 285 million tons to 259 million tons. Our structural decomposition analysis for the time period shows that the decrease are the effort from the combination of water consumption efficiency gains and the improvements of consumption pattern toward less water intensity products consumption. For example, if China’s population, economic structure and people’s consumption level had remained constant, the technology improvement would have saved 339 million tons (-119%) water consumption between 1992 and 2005, and improved consumption pattern would have reduced 165 million tons (-59%) freshwater consumption. In contrast, if without China’s technology and consumption pattern improvements, the increased per capita GDP (consumption volume) would have led to the increase of 418 million tons (147%) freshwater consumption, and population growth and structure change in production led to 37 million tons (13%) and 23 million tons (8%) increase respectively.

We only analyse the freshwater consumption from the production of products and services which represents 85-90% of China’s total freshwater consumption. There are also direct household consumption such as drinking, cooking and washing. We estimated the direct domestic freshwater consumption has been increasing from 26,603 million tons in 1992 to 36,704 million tons in 2005 and further to 37,473 million tons by 2007. In fact, the per capita domestic freshwater consumption in both urban and rural households has declined from 230 and 92 litres per day in 1992 to 211 and 71 litres per day in 2007, respectively. The significant increase of the total domestic freshwater consumption is due to China’s rapid urbanisation process. For example, 18% of rural populations (e.g. 12 million) have been urbanised and adopted urban lifestyle.

If we allocate the decrease of production-related freshwater consumption – 26 million tons (10%) to the separate final demand category, the declined rural population and lifestyle change in rural households’ consumption have led to 66 million tons or 254% of reduction in freshwater consumption, while the change in urban households and governmental consumption has reduced 1 and 7 million tons or 2% or 27% of freshwater consumption, respectively. The majority of the freshwater reduction from households’ and governmental consumption has been vanished by the rapidly growth of capital investments and exports productions, which have caused 39 (154%) and 8 (32%) million tons freshwater consumption increase during 1992 to 2005.

Nevertheless, households have remained the largest consumer of freshwater, although their proportion has decreased from almost 70% in 1992 (e.g. 41% by rural and 28% by urban households) to 50% in 2005 (e.g. 19% by rural and 31% by urban households). Capital investment and exports production was responsible for 10% and 14% of freshwater consumption in 1992; but the share has been grown up to 26% and 19% in 2005, respectively.

## Wastewater discharge

China’s annual production-related wastewater discharge has remained in a constant range of 28 to 30 million tons in the 10 years period of 1992 to 2002. The figure broke through the 30 million mark in 2005 and further increased to xx in 2007. However, the pollutant level, for example the Chemical Oxygen Dioxide (COD), contained in the discharged wastewater has been increased to a peak of 11 million tons in 1997, then rapidly declined afterwards to 5 million tons in 2002 but climbed back slightly in recent years to 6 million tons in 2005. The similar trends can be found in the pollutants, such as heavy metals (i.e. Cadmium, Hexavalent Chrome, Lead, and Arsenic) and other pollutants (i.e. Volatile hydroxy-benzene, Cyanide, Petroleum and Ammonia Nitrogen).

If we adopt the change of COD level in discharged wastewater as an indicator, our structural decomposition analysis – that per capita GDP would have led to 11 million tons more discharge of COD (150%) during 1992 to 2005 if we keep all other variable constant. Technology improvements would have saved 13 tons of COD (-175%) being discharged into the hydro-ecosystem. Population growth and production structure change would have led to 1 (13%) and 0.6 (9%) million tons of increase of COD discharge while consumption structure change would offset 1.3 million tons (-18%) of COD during the same period. China’s technology improvements of wastewater treatment are strongly related to policy implementations. For example, the rapid decrease of COD discharge after 1997 was mainly benefited from the “Closure of the 15 Smalls”[[1]](#footnote-1) implemented in 1998 ([Tilt 2007](#_ENREF_23)).

**References**

Andresosso-O'Callaghan, B. and G. Yue. 2002. Sources of output change in China: 1987-1997: application of a structural decomposition analysis. *Applied Economics* 34: 2227-2237.

Chertow, M. R. 2001. The IPAT Equation and Its Variants. *Journal of Industrial Ecology* 4(4): 13-29.

Commoner, B. 1972. The environmental cost of economic growth. In *Population, Resources and the Environment*, edited by R. G. Ridker. Washington DC: Government Printing Office.

Commoner, B., M. Corr, and P. Stamler. 1971. *The closing circle: nature, man, and technology*. New York: Knopf.

Dietz, T. and E. Rosa. 1997. Effects of population and affluence on CO2 emissions. *PNAS* 94(1): 175-179.

Dietzenbacher, E. and B. Los. 1998. Structural decomposition techniques: Sense and sensitivity. *Economic Systems Research* 10: 307-323.

Ehrlich, P. and J. Holdren. 1971. Impact of population growth. *Science* 171: 1212-1217.

Garbaccio, R. F., M. S. Ho, and D. W. Jorgenson. 1999. Why has the energy-output ratio fallen in China? *The Energy Journal* 20(3): 63-91.

Gleick, P. H. 2009. The World's Water 2008-2009. Washington: Island Press.

Guan, D. and K. Hubacek. 2007a. A New Hydro-Economic Accounting and Analytical Framework for Water Resources: A case study for North China. *Journal of Environmental Management* forthcoming.

Guan, D. and K. Hubacek. 2007b. Assessment of regional trade and virtual water flows in China. *Ecological Economics* 61(1): 159-170.

Guan, D., G. P. Peters, C. L. Weber, and K. Hubacek. 2009. Journey to world top emitter – an analysis of the driving forces of China’s recent emissions surge. *Geophysical Research Letters* 36(L04709).

Guan, D., K. Hubacek, C. L. Weber, G. P. Peters, and D. Reiner. 2008. The drivers of Chinese CO2 emissions from 1980 to 2030. *Global Environmental Change: Human and Policy Dimensions* 18(4): 626-634.

Hertwich, E. G. 2005. Lifecycle Approaches to Sustainable Consumption: A Critical Review. *Environmental Science and Technology* 39: 4673-4684.

Hoekstra, R. 2005. *Economic Growth, Material Flows and the Environment: New Applications of Structural Decomposition Analysis and Physical Input-output Tables*. Cheltenham, UK: Edward Elgar.

Hoekstra, R. and J. C. J. M. van der Bergh. 2002. Structural decomposition analysis of physical flows in the economy. *Environmental and Resource Economics* 23: 357--378.

Leontief, W. 1986. *Technological Change, Prices, Wages, and Rates of Return on Capital in the USA Economy*. Second Edition ed, *Input-Output Economics*. Oxford: Oxford University Press.

Leontief, W. and D. Ford. 1972. Air pollution and the economic structure: empirical results of input-output computations. In *Input-Output Techniques*, edited by A. Brody and A. P. Carter. Amsterdam: North Holland.

Lin, X. and K. R. Polenske. 1995. Input-output anatomy of China's energy use changes in the 1980s. *Economic Systems Research* 7(1): 67--84.

NewScientist. 2009. China drought forces huge water cutbacks. *NewScientist*, section.

Peters, G., C. Webber, D. Guan, and K. Hubacek. 2007. China's growing CO2 emissions - A race between lifestyle changes and efficiency gains”. *Environmental Science and Technology* 41(17): 5939-5944.

Rose, A. and S. Casler. 1996. Input-Output Structural Decomposition Analysis: A Critical Appraisal. *Economic Systems Research* 8(1): 33-62.

Tilt, B. 2007. The Political Ecology of Pollution Enforcement in China: A Case from Sichuan's Rural Industrial Sector. *The China Quarterly* 192: 915-932.

van Rooij, B. 2002. Implementing Chinese Environmental Law through Enforcement: the Shiwu Xiao and Shuang Dabiao Campaigns. In *Implementing Chinese Environmental Law*, edited by J. Chen, et al. The Hague, The Netherlands: Kluwer Law International.

Wier, M. and B. Hasler. 1999. Accounting for nitrogen in Denmark—a structural decomposition analysis *Ecological Economics* 30(2): 317-331.

Xinhua. 2007. Official: Single-child parents in China can have second child *Xinhua Journal* July 10, 2007.

York, R., E. Rosa, and T. Dietz. 2002. Bridging environmental science with environmental policy: plasticity of population, affluence, and technology. *Social Science Quarterly* 83(1): 18-34.

Yu, C. 2011. China's water crisis needs more than words. *Nature* 470: 370.

1. The *State Council Decisions Concerning Certain Environmental Protection Issues*, which was released in 1996, establishes that fifteen categories of small enterprises must be closed and never reopened. Those fifteen categories (“*fifteen smalls*”) include: paper manufacturing factories with annual production capacities of less than 5,000 tons, tanneries with annual production of less than 30,000 equivalent cow hides, dye factories with annual production of less than 500 tons, and so on ([van Rooij 2002](#_ENREF_24)). [↑](#footnote-ref-1)