Institution: Nottingham Trent University (NTU)

Unit of Assessment: C14 - Geography and Environmental Studies

Title of case study: Controlling eutrophication and algal blooms to safeguard human and ecosystem health and prevent economic loss.

Period when the underpinning research was undertaken: 2016-2020

Details of staff conducting the underpinning research from the submitting unit:

Name:	Role:	Period employed by submitting HEI:
Gang Pan	Professor	2016-present

Period when the claimed impact occurred: 2017-July 31, 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Eutrophication and harmful algal blooms threaten human health and aquatic ecosystems and cause economic loss around the world. Geo-engineering research at NTU has led to the commercial development of a patented technology that removes algal blooms from water sources, controls eutrophication and restores water quality. This Modified Local Soil (MLS) method has been successfully applied to freshwater lakes in China, leading to improved water quality, biodiversity, recreational environment and benefits to local economies. Through licensing agreements, the technology has generated revenue for two Chinese companies, created new employment, production capacity and societal impact.

2. Underpinning research

Harmful algal blooms (HABs) are increasing across the world as temperatures rise, according to recent research published in *Nature* by the Carnegie Institution for Science. HABs are overgrowths of algae in water due to excess nutrient supply. Toxic blooms affect drinking water supplies, agriculture, fishing, recreation and tourism; in the United States alone, they result in economic loss of ~$4 billion per annum (£3 billion). While valuable progress has been made in monitoring and understanding these environmental phenomena, significant challenges remain in cleaning up HABs, controlling associated nutrient release from sediment, and mitigating eutrophication at large scale. Previous technologies targeted at HAB removal have proven to be ineffective, expensive and slow-acting, and in some cases have caused adverse effects.

Research at NTU led by Professor Gang Pan, in collaboration with the Chinese Academy of Sciences, has applied geo-engineering methods to develop a breakthrough technology capable of mitigating eutrophication and accelerating ecological restoration. The Modified Local Soil (MLS) technology uses natural soil and clay particles, modified by natural polymers, to remove HABs and remediate polluted sediment over large areas. Field trials in five freshwater sources in south and north China showed that MLS treatment removed HABs within hours and resulted in sustained improvements to water quality and biodiversity over a period of up to three years **(R1)**.

The approach involves addition of MLS to flocculate the HABs from the water, so they settle onto the bed sediment. An additional layer of MLS material is then used to cap the algal cells, embedding them in the sediment so that diffusion of nutrients back into the overlying water is chemically blocked. The research demonstrated that nutrient limitation and biodiversity of treated waterbodies can be manipulated using the MLS approach, which is important for preventing recurrence of algae blooms following treatment **(R2)**. The MLS method can be used to switch

the environment from an algae-dominated state to one where macrophytes dominate, which is essential for restoring the aquatic ecosystem **(R3)**.

Pan further enhanced the method with three modifications. The first was development of a new geo-engineering material that can lock in nutrient phosphate during capping, which is five to eight times as effective at phosphate removal than commercial products currently on the market **(R4)**.

The second modification uses the addition of nanobubbles to the MLS to deliver oxygen to achieve remediation of anoxia **(R5)** and mitigation of associated greenhouse gas emissions **(R6)**. The materials used are cheap and natural and can be delivered to large and deep waterbodies using natural hydraulic forces such as river flow to avoid the huge energy costs of mixing that made previous methods unviable. This modification deals with the oxygen depletion or anoxia, which is often responsible for eutrophication as it creates the conditions for the release of excess nutrients, greenhouse gases and other toxic substances from the sediment.

Finally, Pan, as the sole inventor, filed an international patent (WO2018234791) in 2018 for an 'Aquatic Vegetation Restoration Device and Method' based on further development of the MLS technology using dissolvable clay frames. These frames are added as part of the capping layer and can selectively restore indigenous macrophytes in shallow waters, through actively inducing target seedlings and preventing invasive macrophyte growth. Grants **(G1, G2)** from two Chinese companies have funded further refinement of the patented technology.

In summary, Pan has developed MLS technology that removes harmful algal blooms from waterbodies via flocculation and capping in the bed sediment, and incorporates three optional modifications: (1) addition of a highly efficient phosphate sorbent to further enhance nutrient removal; (2) addition of oxygen nanobubbles to combat anoxia; (3) addition of dissolvable clay frames to deliver enhanced indigenous macrophyte growth.

3. References to the research

The high quality of the underpinning research is indicated by the wide range of funding organisations continuing to invest in the research and its dissemination (see also additional contextual data).

R1 Pan, G., Miao, X., Bi, L., Zhang, H., Wang, L., Wang, L., Wang, Z., Chen, J., Ali J., Pan, M., Zhang, J., Yue, B., Lyu, T. Modified local soil (MLS) technology for harmful algal bloom control, sediment remediation, and ecological restoration, *Water*, 2019, 11(6): 1123. DOI: 10.3390/w11061123

R2 Wang, L., Pan, G., Shi, W., Wang, Z., Zhang, H. Manipulating nutrient limitation using modified local soils: A case study at Lake Taihu (China). *Water Research*, 2016, 101, 25-35. DOI: 10.1016/j.watres.2016.05.055.

R3 Zhang, H., Shang, Y., Lyu, T., Chen, J., Pan, G. Switching Harmful Algal Blooms to Submerged Macrophytes in Shallow Waters using Geo-Engineering Methods: Evidence from a ^{15}N tracing study. *Environmental Science & Technology*. 2018. 52(20), 11778-11785. DOI: 10.1021/acs.est.8b04153.

R4 Xu, R., Zhang, M., Mortimer R., Pan, G., Enhanced Phosphorus Locking by Novel Lanthanum/Aluminum–Hydroxide Composite: Implications for Eutrophication Control, *Environ. Sci. Technol.* 2017, 51, 3418-3425, https://doi.org/10.1021/acs.est.6b05623

R5 Zhang, H., Lyu, T., Bi, L., Tempero, G., Hamilton, D., Pan, G. Combating hypoxia/anoxia at sediment-water interfaces: A preliminary study of oxygen nanobubble modified clay materials. *Science of the Total Environment*. 2018, 637, 550-560. DOI: 10.1016/j.scitotenv.2018.04.284.

R6 Shi, W., Pan, G., Chen, Q., Song, L., Zhu, L., Ji, X. Hypoxia Remediation and Methane Emission Manipulation Using Surface Oxygen Nanobubbles. *Environmental Science & Technology*. 2018. 52(15), 8712-8717. DOI: 10.1021/acs.est.8b02320.

Selected grants:

G1 The development of MLS material towards preventing sediment resuspension and stimulating indigenous macrophyte restoration; Yantai HABs Control and Ecological Restoration Technology Co., Ltd; £116,000; 2019-2021; PI: Gang Pan.

G2 MLS technology for control of harmful algal blooms, sediment remediation and ecological restoration; Hunan Zhongke Water Environment Management Co., Ltd; £21,000; 2019-2022. PI: Gang Pan.

4. Details of the impact

Context

The ecological, economic and health impacts of harmful algae blooms captured public attention in 2007 when the world's media reported an outbreak in China's third largest freshwater lake, polluting drinking water for more than two million residents in the neighbouring city of Wuxi. In recent years, a key tenet of Chinese government policy has been the concept of 'ecological civilisation': the recognition that the environment cannot be sacrificed in the pursuit of economic growth. This has resulted in a tightening of regulations, an increase in financial penalties for the contravention of environmental laws and rising pressure on local governments to take swift action. This wider context underpins the demand in China, as well as in other countries, for a solution like the MLS technology and highlights the commercial opportunities arising from this technological intervention being brought to market.

Delivering environmental benefits through removal of HABs in Chinese water sources

A collaboration with Chinese company Hunan Zhongke Water Environment Management Co. Ltd (Hunan Zhongke Ltd), a joint venture co-owned by the Hunan Provincial Water Resources Development & Investment Co., Ltd and Beijing Advanced Sciences and Innovation Center of Chinese Academy of Sciences, led to the delivery of three commercial projects that used the MLS technology between 2017and 2019 **(S1)**:

1. Longguang Lake (Huizhou City, Guangdong Province) has a water surface of 4,000 m^2 and is in a new residential district with a population of around 2,000. Hunan Zhongke Ltd was commissioned by Huizhou Dayawan Dongzhen Real Estate Co. Ltd in 2017 to remove an algal bloom from the lake and improve the water quality. The outbreak had led to complaints from residents and was affecting sales of new-build properties. One day after the MLS technology was applied, the algal bloom in the entire lake was removed. Five months later, the water quality had improved from grade 'bad V' to grade 'good III' **(S2)**. The treatment "*significantly improved the quality of the living environment for the residences and allowed apartment sales to increase again*", according to Hunan Zhongke. The company asked an independent expert panel to review the project. The panel chair, a former director at the National Development and Reform Committee (China's economic development agency), was quoted as saying: "*MLS technology combines water quality improvement, sediment remediation and ecological restoration into one cost-effective and eco-friendly in-lake operation, which needs to be promoted for aquatic ecological restoration in south China inland waters.*" **(S3)**.

2. Ximo Lake (Changde City, Hunan Province) has a water surface of 16,300 m^2 and is on the campus of No.1 Middle School, Lixian County. The lake is a historical landmark and a visitor attraction. Every year it hosts around 10 events, such as calligraphy competitions and photographic exhibitions. Hunan Zhongke Ltd was commissioned to remove the algal blooms. In the summer of 2018, the heavy algal blooms in Ximo Lake were cleared up using MLS

technology. Three months later, the water quality achieved grade "good III" from grade "bad V" with over 70% of the submerged vegetation restored. The restoration project not only improved the ecological environment, but also allowed the school to attract more visitors to their events **(S2, S4)**. Hunan Zhongke reported the expert panel chair from Changde City Water Conservancy Bureau (local government agency) as saying: "*The MLS technology is cost-effective and safe for HABs removal, internal nutrient loading control and ecology restoration for inland urban waters*." The school confirmed that the project outcomes were "*highly recognized by the County government and environment protection department*" and had been "*well complimented by teachers, students and tourists*".

3. Hefei Botanical Garden (Hefei City, Anhui Province) has a surface area of 6,000 m^2 and is a popular attraction with both domestic and international tourists; it is rated number six out of 94 'things to do in Hefei' (population: 4.2m) on Tripadvisor. However, annual harmful algal blooms in the watershed had been causing economic losses due to falls in visitor numbers as a result of the environmental damage, which had killed fish and created a strong odour. From September 2019, as part of a local government initiative to increase tourism, the Garden was closed for water ecological restoration. Hunan Zhongke Ltd was commissioned to remove the algal bloom. MLS technology improved the water quality from grade "bad V" to grade "good III", associated with the successful recovery of fish stocks and vegetation. The Garden Management Committee said the number of tourists was expected to increase by 300% following the reopening of the garden in April 2020 **(S2)**, although this has subsequently been impacted by Covid-19.

Providing economic benefits through full commercialisation of technology in China

The three projects over 2017-2019 were worth RMB 3.5M (£390,000) to Hunan Zhongke Ltd. This created four full-time jobs. In 2019, Hunan Zhongke Ltd sponsored NTU with £21k to support Pan to investigate universal MLS materials for lake restoration with different water conditions, with the aim of expanding the company's engineering capacity **(S2)**.

After the NTU patent for MLS was filed in 2018, another Chinese company, Yantai HABs Control and Ecological Restoration Technology Co. Ltd, signed an exclusive five-year licence to fully commercialise and roll out the technology to other places in China suffering from harmful algae blooms. Yantai HABs Ltd is a subsidiary of a listed Chinese company Yantai Great Mind Ecological Environment Technology Co. Ltd, which specialises in lake restoration. To support its commercialisation plans, Yantai sponsored Pan's group with RMB 1M (£116,000) to further refine the technological approach to sediment remediation and macrophyte restoration. The clay frame product based on the patent has been manufactured and successfully tested. The company has established a production capacity of 350 units per day. In 2020 the company conducted a successful pilot test to improve the water quality of a waterbody at Xiabeitan, near the Yellow River in Lanzhou, which has since resulted in the award of an RMB 200M (£22M) ecological restoration project for the whole catchment, which will include the use of MLS and the new patented vegetation restoration device **(S5)**. Eight jobs have been produced due to the project. This is one of the largest projects in the Lanzhou area in response to the Chinese central government's Eco-civilization strategy. It has high societal impact as it involves and benefits many stakeholders from farmers to local industries and residents in a city with a population of 3 million.

Summary

MLS technology directly based on Pan's research has been successfully implemented in three projects to clean up HABs in lakes in China undertaken by Hunan Zhongke Ltd, leading to environmental, social and economic benefits. Another company, Yantai HABs Ltd, has established a manufacturing line producing the associated clay frames that help restore native macrophytes, and has deployed MLS in a pilot project to secure a £22M catchment wide clean-up project in Lanzhou, resulting in environmental benefits, new jobs and economic impact.

5. Sources to corroborate the impact

S1 News updates on the Longuang Lake and Ximo Lake projects respectively, via the Beijing Advanced Sciences and Innovation Center of Chinese Academy of Sciences.
http://www.basic.cas.cn/xwdt/zhxw/201801/t20180110_4931487.html
http://www.basic.cas.cn/cyfh/gzjz2/201812/t20181224_5220003.html
S2 Corroborating statement from the General Manager of Hunan Zhongke Ltd.
S3 Corroborating statement including quote form former director at the National Development and Reform Committee (China's economic development agency) (In Chinese).
S4 Corroborating statement from No.1 Middle School, Lixian County regarding Ximo Lake.
S5 Corroborating statement from the General Manager of Yantai HABs Ltd.