

International Research Workshop on
Solar technologies for water disinfection
for developing communities

Chair: Dr Pilar Fernández-Ibáñez

Ulster University, School of Engineering, NIBEC, Jordanstown, Shore Road, BT37 0QB

Venue: NIBEC Building, Room 25B01, **21 June 2018**

09:00 – 09:30	Registration
09:30 – 09:35	Welcome
09:35 – 10:20	Innovation in rainwater treatment and monitoring – Wesaal Khan (Stellenbosch University, South Africa)
10:20 – 10:50	Giardia cysts and Cryptosporidium oocysts in water samples: detection challenges in developing countries – Lyda Sabogal (University Sao Paulo, Brazil)
10:50 – 11:20	Photocatalytic disinfection of water; materials and mechanisms – J. A. Byrne (Ulster University, UK)
11:00 – 11:30	Coffee
11:30 – 12:00	Solar disinfection of harvested rainwater for rural communities – Pilar Fernandez (Ulster University, UK)
12:00 – 12:20	Identifying the primary microbial source tracking markers in harvested rainwater for the detection of faecal contamination – Monique Waso (Stellenbosch University, South Africa)
12:20 – 12:40	Solar PEC reactors for disinfection of water – Stuart McMichael (Ulster University, UK)
12:40 – 13:00	2D nanomaterials for solar disinfection of water – Anukriti Sight (Ulster University, UK)
13:00 – 14:00	Lunch
14:00 – 14:20	Water quality methods: from lab to the field – William Snelling (Ulster University, UK)
14:20 – 14:40	Disinfection technologies for rural communities - Analysis and proposed solutions – Helen Lubarski (Ulster University, UK)
14:40 – 15:00	Improvement of existing water quality monitoring tests with electronics – Jeremy Hamilton (Ulster University, UK)
15:00 – 15:20	Antimicrobial Resistant Microorganisms in water – Patrick Dunlop (Ulster University, UK)
15:20 – 15:50	Coffee
15:50 – 16:10	Photodisinfection of water using organic photosensitisers – Thayse Marques Passos, (Dublin City University, Ireland)
16:10 – 16:30	Visible light photocatalytic degradation of organic pollutants in water using $\text{Ca}_x\text{MnO}_y\text{-TiO}_2$ – Preetam Sharma (Ulster University, UK)
16:30	Closure



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STREAM-MENA programme
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Acknowledgements

Project - Low cost technologies and microbial assessment for safe drinking water in South Africa.

In 2015, the WHO estimated that 663 million people worldwide still lacked access to improved drinking water sources, with 156 million people located in Africa utilizing sub-standard water supplies. This is a matter of concern as it is estimated that contaminated drinking water causes 502 000 diarrheal deaths each year. Diseases such as cholera, dysentery, typhoid and polio may also be contracted through the consumption or exposure to a contaminated water source. To compound the problem, countries located in sub-Saharan Africa, such as South Africa, are currently facing severe water shortages and drought conditions. A need arises for the utilization and treatment of alternative water sources to alleviate the pressure being placed on existing resources. This proposal aims to reinforce the benefits of collaborative research by utilizing the skills and knowledge at NIBEC, Ulster University (UU, UK) to implement low cost technologies to provide safe drinking water and harness the knowledge and skills at the Dept. of Microbiology of Stellenbosch University (SUN, SA) to evaluate the microbial impact of these technologies to control waterborne diseases in developing regions.

The main goal of the research is to develop new low-cost reactors for solar disinfection based on compound parabolic collector (CPC) reflectors, photocatalytic materials and novel engineered design for the optimization of solar drinking water disinfection. The aim is to deliver a significant output of treated water (rainwater, river water, etc.) for daily utilization at the household level that is free of water pathogens and safe for consumption. The systems should be maintained without the need of technical skills, chemical additives or expensive quality assessment. Two CPC systems will be designed; one will be based on solar disinfection without added photocatalytic materials, but with improved engineering key parameters, i.e. optical path length of reactor, dissolved oxygen and static batch concept-design. The second system is a photocatalytic [Titanium dioxide (TiO₂)] reactor with low-cost, reusable and easy to separate photocatalytic materials for enhancing the solar water disinfection performance. TiO₂ will be immobilized on glass beads for easy separation in one of the prototypes; its disinfecting efficiency and reusability will be evaluated. The microbial quality of the water samples before and after treatment will be determined utilizing general indicator analysis (fecal coliforms, *Escherichia coli*, etc.). Molecular-based viability assays will be utilized in combination with 16S Ion Torrent to assess the microbial community shifts during the treatment process and to identify the persisting genera. The chemical quality of the water samples will be determined by monitoring cations and anions, and turbidity.

Research aims:

1. Utilize low-cost materials to develop engineering systems for improved solar disinfection efficiency for the production of drinking water from harvested rainwater, surface water, etc.
2. Develop and construct compound parabolic collector prototypes for drinking water disinfection.
3. Undertake field trials of the optimized low-cost drinking water disinfection reactor systems at household level in South Africa to assess the efficacy of the technologies.
4. Assessment of the microbial and chemical quality of the water sources before and after treatment.
5. Utilize viability 16S Ion Torrent to identify the primary bacteria persisting after disinfection treatment of the water sources.
6. Determine whether isolate(s) have increased virulence following disinfection treatment.

Participants: Dept. Microbiology, Stellenbosch University (South Africa) and Nanotechnology and Integrated BioEngineering Centre, School of Engineering, University of Ulster (UK).

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Acknowledgements

Project - Low cost technologies for safe drinking water in developing regions (SAFEWATER)

Waterborne diseases from drinking unsafe water contribute to high incidence of illness in developing regions. At least 1.8 billion people globally use a source of drinking water that is fecally contaminated and thus likely to lead to diarrheal illness: nearly 1,000 children die each day due to preventable water and sanitation-related diarrheal diseases. In 2010, the UN General Assembly explicitly recognized the human right to water and sanitation. Everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use. Low cost technologies for safe drinking water have significant potential to improve the health of communities who rely on unsafe water, and thus improve their quality of life through reduced illnesses, reduced absence from employment, improved school attendance, improved family life, and less stress on females (normally responsible for water in household). Low cost water treatment systems may be produced and maintained in these communities thereby potentially creating benefit with social economy enterprise (pro-poor development). Safe drinking water is required for drinking, food preparation and personal hygiene. Diseases related to the consumption of contaminated drinking-water place a major burden on human health. Therefore, interventions to improve the quality of drinking water will provide significant benefits to health. Furthermore, there is a severe lack of access to improved sanitation with up to 2.5 billion people who do not have access to improved sanitation facilities, with open defecation being widely practiced in many regions.

The main objective is to develop low cost technologies to disinfect drinking water in rural areas of Brazil, Colombia and Mexico, and develop devices that can evaluate the quality of drinking water in remote regions with no hi-tech laboratory access. These water technologies will be tested in real conditions working along with rural communities to evaluate health benefits after implementing the technologies.

The main benefit of this research will be a reduced incidence of water borne diseases in developing regions. This will result in less illness and fewer deaths for children. This will also lead to improved quality of life for families. Females are normally responsible for water in the home and user-friendly, safe water systems will result in less pressure on females. Reduced illness means that children are more able to attend school and there will be less absence from employment for adults. If local communities can get involved in the manufacture, deployment and/or maintenance of water treatment systems, then this may lead to economic development in the communities.

The project will generate significant new knowledge benefiting the large community of researchers and academics with interests in drinking water treatment and water quality assessment devices. Our research into the understanding of social interactions with technology, and the use of behavioural analysis for end user engagement and adoption, will lead to the development of a range of protocols and recommendations which could be translated into hygiene, nutrition and medical training. Co-operative research in the creation of pro-poor technology development and business strategy can again be translated into other areas of overseas development work - providing additional opportunities for economic benefit. The use of non-laboratory based pathogen indicators will have application in many areas of healthcare. We shall also assess any health benefits in the communities following the use of the technologies to give safe water.

Participants: School of Engineering, School of Biomedical Sciences, Department of Marketing, Entrepreneurship and Strategy, School of Psychology, School of Law, Ulster University (UK); University Sao Paulo (Brazil); University of Medellin (Colombia); Fundacion Cantaro Azul (NGO, Mexico); Centro de Ciencia y Tecnología de Antioquia –CTA (NGO, Colombia).

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Innovation in rainwater treatment and monitoring

Prof. Wesaal Khan

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Our research links directly to the Sustainable Development Goal 6, which primarily aims to achieve universal and equitable access to safe and affordable drinking water for all by 2030. Two primary research themes are focused on in our laboratory: rainwater treatment and innovation in water quality monitoring, and; bioprospecting for novel biosurfactant producing bacteria and biosurfactants.

In South Africa, a large percentage of the population live in informal settlements on the banks of natural watercourses with inadequate sewage and drinking water facilities. The fundamental aim of our current research is thus to provide communities in urban informal settlements and rural areas with a sustainable solution to water shortage by using the natural resource, rainwater. Numerous rainwater harvesting (RWH) tanks have also been implemented by the Department of Water and Sanitation in South Africa, as the local government has earmarked RWH as a sustainable solution to water shortage. However, possible health risks associated with the consumption of harvested rainwater remains one of the major obstacles hampering the large-scale implementation of this water source, as microbial and chemical contaminants have previously been detected in rainwater tanks. One of our first major research projects thus focused on “Point of use disinfection systems designed for domestic rainwater harvesting (DRWH) tanks for improved water quality in rural communities.” Overall, results of the study indicated that rainwater samples pasteurized at 72°C and above could be utilised for potable purposes as total coliforms, *E. coli* and heterotrophic bacteria were reduced to below the detection limit. Our subsequent research focused on providing communities in urban informal settlements with a sustainable solution to water availability, through the design, construction and monitoring of small- and large-scale domestic rainwater harvesting (DRWH) solar pasteurization (SOPAS) treatment systems in Enkanini informal settlement, Stellenbosch. Results indicated that a minimum SOPAS temperature of 66°C (small-scale systems) and 71°C (large-scale system) was required to reduce the levels of indicator organisms to within drinking water standards. However, quantitative PCR analysis indicated that *Legionella* spp. and *Pseudomonas* spp. were still being detected following SOPAS treatment. Currently we form part of the WATERSPOUTT European Union Horizon 2020 project, where one aim is to install solar disinfection prototypes in South Africa and Uganda.

To ensure that our research remains current, we implement novel, innovative water quality monitoring strategies. We were subsequently one of the first research laboratories to implement the viability-quantitative PCR (qPCR) technique for the monitoring of rainwater quality. Illumina next generation sequencing was also coupled with the viability dye ethidium monoazide bromide (EMA) to characterise the bacterial community present in roof-harvested rainwater pre- and post-treatment.

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Giardia cysts and Cryptosporidium oocysts in water samples: detection challenges in developing countries

Prof Lyda Patricia Sabogal-Paz

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Water-borne diseases associated with *Giardia* spp. and *Cryptosporidium* spp. protozoa have been recorded around the world and these protozoa are identified as etiologic agents in waterborne disease outbreaks in developing communities. In Latin America countries, methods to detect protozoa in water samples have not been well-defined, leaving the population vulnerable to waterborne infections.

Difficulties in removing cysts and oocysts at water treatment are associated, among other factors, their reduced size and the ability that oocysts have of compressibility can facilitate their passage through the filtering medium, reaching, therefore, the treated water. In addition to the reduced size, the encysted forms are considerably resistant to inactivation by chlorine, a commonly used disinfectant.

The complexity of the threat of the *Giardia* and *Cryptosporidium* species also involves difficulties in detection. Researchers worldwide have developed protocols for the evaluation of protozoa in environmental samples; nevertheless, a standard procedure is required to provide credibility to results. The reagents, consumption material and equipment used in Method 1623.1 represent high costs and technical analytical complexity. Furthermore, this protocol shows a variable recovery efficiency which depends on, e.g., type of matrix, sample volume and turbidity.

The application of a simplified protocol, which complies with the restrictions of Method 1623.1 in Latin America, will make it possible to estimate the dynamics of these parasites in water, and therefore, measures can be taken to improve the efficiency of the treatment phases aiming to provide good quality water to the population.

Some developing countries have implemented laws in their surveillance systems to detect protozoa, however it is important to establish effective and suitable microbiological risk diagnosis according to the technical and economic capacity of each nation.

In this context, this presentation shows the main techniques of protozoa detection studied by University of São Paulo, explaining their advantages and disadvantages. Concentration methods by calcium carbonate flocculation, filtration using mixed cellulose esters membrane and direct centrifugation are presented. Purification method with immunomagnetic separation and its technical and economic difficulties are presented and discussed. Detection stages with immunofluorescence microscopy, 4,6-diamidino-2-phenylindole dihydrochloride (DAPI) and differential interference contrast (DIC) are also shown. The new label-free darkfield based technique to assist in the detection of *Giardia* cysts is discussed with its characteristics. The main purpose of the presentation is to provide the basic notions of the above mentioned detection methods and their applicability in developing countries.

Acknowledgements: The Global Challenges Research Fund Research Councils UK Collective Fund for funding the SAFEWATER Project (EP/P032427/1).

Photocatalytic disinfection of water; materials and mechanisms

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Since Matsunaga et al. first reported the inactivation of bacteria using TiO₂ photocatalysis in 1985 [1] there have been more than 1000 research papers published in the area. Heterogeneous photocatalysis has been shown to be effective for the inactivation of a wide range of microorganisms, including bacteria (cells, spores and biofilms), viruses, protozoa, fungi and algae [2]. In general, photocatalytic disinfection in water requires at least tens of minutes of direct UVA exposure (using TiO₂ as the photocatalyst) and it is considered to be quite a slow microbial inactivation process, as compared to e.g., UVC disinfection (seconds of direct exposure); however, the mechanism of photocatalytic inactivation is much different from that of UVC disinfection.

Whilst the majority of papers published in on photocatalysis focus on the assessment of novel materials, new reactor systems or the effect of experimental parameters on the rate of inactivation, a significant number of studies have specifically investigated ROS interaction with the biological structures within microorganisms in an attempt to elucidate the mechanism resulting in the loss of organism viability; however, the exact sequence of events leading to loss of viability is not completely understood.

This paper will explore some recent investigations into photocatalytic and electrochemically assisted photocatalysis (photoelectrolytic) disinfection of water including; novel materials, the mechanisms involved, and some of the challenges to be addressed.

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Solar disinfection of harvested rainwater for rural communities

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Harvesting rainwater can be a sustainable means for reducing water demand, increasing the regional water security and providing economic benefits to the community, especially in rural areas of developing countries with no access to centralized water supply systems, providing a number of significant economic, social and environmental benefits and reducing the water scarcity crisis. A number of studies reveal that harvested and storage water can be contaminated by a variety of pathogenic organisms and heavy metals and trace organic compounds, especially in runoff from rooftops which material could leach additional chemical pollutants. The main sources of contamination of collected rainwater are dust, organic matter, faecal droppings of birds, rodents and other wild and domestic animals and also pollutants from human activities present in rooftops. Therefore, appropriate treatment of collected rainwater is necessary to make that harvested rainwater fits the quality values for domestic uses of water.

The EU H2020-WATERSPOUTT project aims at the development of technologies based on Solar Disinfection (SODIS) to make safe drinking water using solar radiation and solar-engineered reactors for Sub-Saharan African communities. The GCRF - Low cost technologies for safe drinking water in developing regions (SAFEWATER) aims to develop new low-cost systems for drinking water treatment at domestic scale for rural communities in Colombia (Antioquia) and Mexico (Chiapas).

Based on our previous models of solar reactors (Castro-Alferez et al., 2016, 2018), we are developing new solar reactors based on SODIS for disinfection of harvested rainwater in the field in remote locations of Africa. These will provide up to 100 litres/day of treated harvested rainwater of suitable microbiological and chemical standards. The prototype rainwater solar reactor pilot systems has been designed using principles of maximising efficiency of disinfection using new solar mirrors with a balance in the cost of manufacturing and resilience of the materials, and minimising the technological components to ease their use in the field and reduce the end user dependency. The constructed prototypes have been tested against a number of water pathogens (*Escherichia coli*, *Enterococcus faecalis*, Total Coliforms, *Salmonella*, phage-MS2, and *Cryptosporidium parvum*). Field trials with these reactors will be carried out also.

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Identifying the primary microbial source tracking markers in harvested rainwater for the detection of faecal contamination

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As it is impractical to monitor for the presence of all pathogens in a water source, indicator organisms are routinely utilised to monitor water quality and predict the presence of pathogens in contaminated environmental waters. Various research groups have, however, indicated that the analysis of indicator organisms may not be sufficient to accurately identify the source of contamination. Supplementary indicators are therefore required to accurately identify contamination sources, with microbial source tracking (MST) markers currently being investigated and applied to various water sources. The primary focus of the research conducted during my MSc was thus to identify a toolbox of MST markers that could be utilised to supplement indicator organism analysis of domestic rainwater harvesting (DRWH) systems.

To achieve this aim, harvested rainwater was screened for a panel of MST markers [using PCR and quantitative PCR assays] and traditional indicator organisms (using culture-based and qPCR assays). Correlation and concurrence statistical analyses were then performed for the MST markers versus the indicator organisms in order to identify which MST markers could supplement indicator analysis for the monitoring of harvested rainwater quality. Significant positive correlations were recorded for Lachnospiraceae versus heterotrophic bacteria, adenovirus versus *E. coli* (culturing) and the HF183 marker versus *E. coli* (qPCR) ($p = 0.024$). In addition, 100% concurrence was observed for the HF183 marker, adenovirus and Lachnospiraceae versus *E. coli* (qPCR) and enterococci (qPCR), amongst others. Based on the correlations and the concurrence analysis, it was concluded that the HF183 marker, Lachnospiraceae and adenovirus may be utilized to supplement indicator organism analysis for the monitoring of harvested rainwater quality.

A secondary aim was focused on designing and validating a novel pigeon-associated MST marker in order to screen DRWH tanks for pigeon faecal contamination. The design of this marker was warranted as pigeons have been hypothesised to be significant sources of faecal contamination of DRWH systems and it is known that pigeon faecal matter harbours pathogens such as *Listeria monocytogenes*. The marker was designed to target the mitochondrial DNA (mtDNA) Cytochrome b gene by employing mismatch amplification mutation assay kinetics and was subsequently validated by screening 69 non-pigeon and 9 pigeon faecal samples. After the validation tests, harvested rainwater samples were screened for the pigeon MST marker, whereafter Bayes' theorem was applied to determine the conditional probability of detecting true pigeon faecal contamination using this marker in harvested rainwater. The host-sensitivity of the pigeon MST assay was determined to be equal to 1.00, while the host-specificity of the assay was 0.96. Subsequently, 78% of the harvested rainwater samples tested positive for the pigeon MST marker and it was found that there was a 99% probability that the marker detected true pigeon faecal contamination. These results indicated that targeting mtDNA for the design of source tracking markers may be a valuable tool to detect avian faecal contamination in environmental waters. The research conducted in our laboratory in South Africa focuses predominantly on the treatment and monitoring of harvested rainwater. The work conducted at the Nanotechnology and Integrated BioEngineering Centre (NIBEC) at Ulster University thus focuses on the use of biocontrol agents, specifically the use of predatory bacteria, in combination with solar disinfection technologies and photocatalysis for the treatment of rainwater.

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Solar photoelectrocatalytic reactors for disinfection of water

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A photoelectrocatalytic reactor has been designed, fabricated and tested for the inactivation of *E. coli* K12. The reactor (figure 1) had a reservoir and recirculating pump to treat 200 ml with a concentration of 10^6 CFU/ml. A TiO_2 photoanode was made by anodising commercial grade titanium sheet, followed by annealing at 500°C . The counter electrode was a carbon cloth gas diffused electrode with a hydrophobic polymer on one side to prevent water diffusion while allowing oxygen diffusion. To increase the geometric surface area of the photoelectrodes the electrodes have been angled. The photocurrent response for different applied biases was examined for $0.1\text{ M Na}_2\text{SO}_4$ solution and distilled water. To access the reactor performance, the reactor was tested photocatalytically and photoelectrocatalytically under different biases.

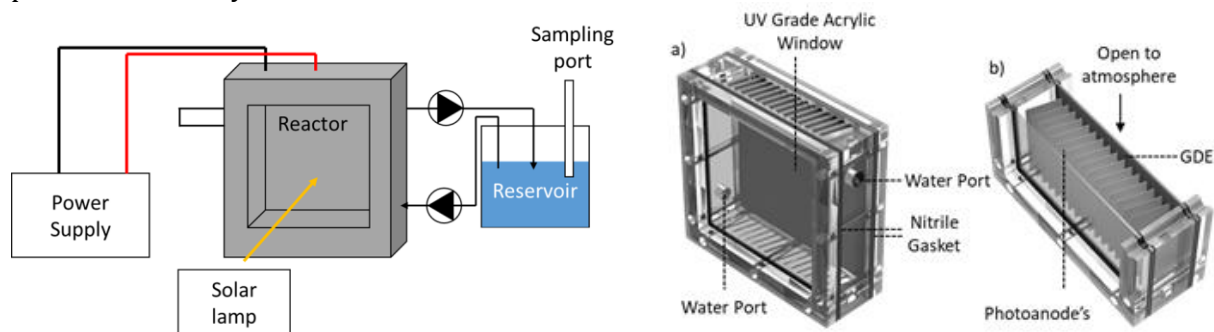


Figure 1 – Solar reactor scheme and diagram of PEC electrodes.

2D materials for solar disinfection of water

Anukriti Singh, Jeremy W.J Hamilton, Pilar Fernandez, Patrick S.M Dunlop, John A Byrne

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Semiconductor photocatalysis has been reported to be effective for treating water contaminated with pathogens and a wide range of toxic organic pollutants. To increase the photocatalytic efficiency of the photocatalyst under solar irradiation, novel materials have to be explored to utilise both UV and visible photons. Two-dimensional nanomaterials are potential candidates for novel photocatalyst materials due to high surface area and possible size quantization effects leading to increased absorption coefficients for desired wavelengths. This work primarily focuses on development of 2D nanomaterials (WO_3 & $\text{g-C}_3\text{N}_4$) as visible light photocatalysts to enhance the efficiency of photocatalytic disinfection of water by targeting *E. coli* K12 as the model micro-organism for inactivation. Herein, an approach to construct 2D composites of WO_3 nanosheets in layered $\text{g-C}_3\text{N}_4$ was followed using two step facile hydrothermal-calcination method. Different approaches were followed in constructing these hybrid materials, i.e. *in situ* growth of WO_3 nanosheets on surface of $\text{g-C}_3\text{N}_4$, combination of different ratios of physical mixture by post annealing method and ultrasonic exfoliation and annealing of the composites. These 2D materials were characterized using a range of techniques to study their structure morphology, crystalline properties and optical bandgap using TEM, XRD and DRS respectively. This work aims to provide an effective method to increase the photocatalytic efficiency of solar water disinfection using Z-scheme heterojunction construction of 2D/2D WO_3 - $\text{g-C}_3\text{N}_4$.

Microbial water quality methods: from lab to the field

William J. Snelling, N. Ternan, J. Dooley

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Water quality is influenced by interacting microbial populations and introduced microbial and chemical contaminants. Clean and safe drinking water is vital for human health. Globally, at least 2 billion people use a drinking water source contaminated with faeces. More than 800,000 people die annually from drinking unsafe water, and from having poor sanitation and hand hygiene practices. Consumption of microbial-contaminated water can result in diarrheal illnesses and enteropathy, with the heaviest impact upon children below the age of five. Contaminated water can contain a wide variety of pathogens, including bacteria, viruses, protozoa and helminths. Powerful, sensitive and reproducible methods for effectively monitoring water quality are essential. Currently there is no unified protocol to encompass the collection and analysis of a water sample for all important pathogens. Detection method challenges include the physical differences between the major pathogen groups, low concentration of pathogens in large volumes of water, sample inhibitors, establishing protocols for sample collection, culture-independent detection methods, and the accurate detection of the host origin of pathogens. Faecal indicator organisms, normally coliforms, are used to indicate faecal contamination and as a measure of microbial quality in drinking water, wastewater and recreational water. The difficulty in finding associations between indicator organisms and health outcomes highlights the challenges in water quality research. Important requirements for reliable analysis include specificity, sensitivity, reproducibility of results, speed, and low cost. Where culture dependent methods are applied, these are limited by their relatively low sensitivity and turn-around-time.

Current and future global challenges include;

- detecting viable, but non-culturable microorganisms,
- improved pathogen survival in biofilms,
- climate change,
- increasing water scarcity, antibiotic resistance, and a growing global population.

Next-generation sequencing (NGS) technologies are providing new insights into the ecology of microbially mediated processes that influence fresh water quality such as algal blooms, contaminant biodegradation, pathogen dissemination and diversity.

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Disinfection technologies for rural communities - Analysis and solutions

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In many developing countries, sanitary risks associated with surface water becomes greater due to poor protection of water sources and inadequate wastewater and solid waste management (PAHO, 1997). An estimated one billion of the world's population does not have access to safe and clean water, and approximately 2.6 billion people lack improved sanitation (WHO/UNICEF, 2010). More than two million people die each year from waterborne diseases, 499 000 are under the age of 5. Ninety percent of diarrheal cases are related to unsafe water and poor sanitation and hygiene. Illness and diseases that don't lead to death also have an impact on society such as the inability to work, go to school and medical cost.

The disinfection technology available on the market is a low cost technology include boiling, filtration, chemical disinfection using chlorine or solar disinfection and novel technology e.g. UVC, electrolytic, photoelectrolytic, photocatalysis, ozonation or enhanced solar disinfection is widely used techniques. Determination of disinfection performance need to include assessment of effectiveness e.g. quantity and quality produced, appropriateness for targeted region such as local availability, time to produce water, operation and maintenance and acceptability and simplicity-willingness of people to use and continue to use this device. All these systems have advantages and drawbacks. We propose a combination of technologies for a better performance.

We target to treat 250L of water per family per day. The system will consist of modules that could be exchanged depending on targeted region. The first module includes multi-stage filtration (MSF) system built from two parallel units packed with 3 layers of materials of different sizes ranging from coarse at the top to fine at the bottom. The first layer of this system is a gravel and targeted to reduce turbidity and improve the water colour. The second layer is rapid sand filtration and targeted to retain large microorganisms (bacteria, protozoa). The third layer is granular activated carbon to adsorb viruses and chemical pollution. Since without presence of biolayer the MSF would only remove 30-70% of pathogens this module will be used for water pre-treatment only.

After pre-treatment stage we propose to treat water separately - 200L for the domestic use (personal hygiene, house and clothes washing etc.) and 50L for drinking water. For the domestic use we proposed to use chlorination. Then second module is a vessel with 200L of pre-treated water will be further treated with chlorine. The third module is solar reactor targeted to treat 50L. This module could be exchanged to a vessel with UVC lamp. To reduce power consumption, the solar battery could be attached to the lead of this vessel.

Proposed temperature, sand and sun (TSS) system employs physical and chemical processes as its combination of thermal inactivation, granular filters and UV radiation technologies and targeted to disinfect turbid water with high total solids under different weather conditions with maximum efficiency. The final decision of implementation of this system will be based on capital and running costs.

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Improvement of existing water quality monitoring tests with electronics

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As part of the SAFEWATER device design process a number of methodologies for detection of e.coli were assessed including the use of chromogenic media, tryptophan like fluorescence (TLF) and molecular techniques. Assessment considered the sensitivity, selectivity, diagnostic time, cost, skill of end user and acceptance by regulatory bodies as a suitable methodology. Of the technologies assessed the less mature molecular technologies, although the most sensitive and selective, were shelved due to high levels of skill and regulator acceptance issues. There is an aim to integrate these technologies in a later prototype should issues with regulatory acceptance and useability be overcome.

Chromogenic media by contrast is well recognised as a method of water assessment and only showed disadvantages in terms of diagnostic time. Improvement of diagnostic time in this selected technology can be achieved in the hardware reader through the use of continuous monitoring and improved sensitivity of machine over reading by eye. The design of the safewater water assessment devices is performed in a modular fashion so that systems developed for non diagnostic functions (power communications etc) can be moved seamlessly for prototype to prototype as the underlying chemistry of the diagnostic changes.

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Antimicrobial Resistant Microorganisms in water

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The excessive use of antibiotics in human and animal medicine has led to the development of antibiotic resistant bacteria (ARB) which have been isolated from both clinical and non-clinical facilities and in almost everywhere you can imagine in the environment (Berendonk et al., 2015). ARB, and corresponding antibiotic resistance genes (ARGs), are not completely removed from water treated in traditional biological based wastewater treatment plants (WWTP), indeed, the high bacterial load, sub-therapeutic concentration of antibiotics and the physical and mechanical processes used in WWTP can encourage the proliferation of ARB, with these selective pressures potentially promoting the evolution of antibiotic resistance and ARG transfer (Rizzo et al., 2013).

Given the potential for ARB and ARGs to persist and spread, the subsequent release of WWTP effluent and sludge could therefore increase the reservoir of ARB and ARGs in the environment contributing to the mobility of genetic elements and the development of antibiotic resistance in human pathogens. As such, new methods of water treatment/disinfection are required to target these emerging biological contaminants (Dunlop et al., 2015). This presentation will focus on the use of advanced oxidation processes to remediate ARB and consider the complications of sub lethal stress and incomplete disinfection.

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Photodisinfection of water using organic photosensitisers

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The photodynamic inactivation of bacteria in water has been gaining interest in recent years. The process involves using a light source, which can be sunlight, to activate a photosensitiser. The reactive oxygen species generated can kill bacterial cells. It is an interesting alternative approach to traditional disinfection techniques such as chlorination, ozonation and irradiation with UV light because it is low cost, low environmental impact and low maintenance. The process is also a promising ecologically-friendly option for water disinfection because it does not induce bacterial resistance, is not mutagenic or genotoxic (Alves *et al.*, 2008; Spagnul *et al.*, 2015). Photosensitisers are frequently based on heterocyclic ring structures such as porphyrins (Figure 1) (Stojiljkovic *et al.*, 2001).

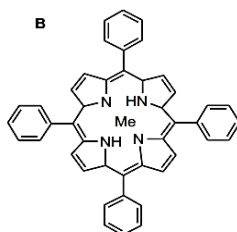


Figure 1 – Chemical structure of a porphyrin.

In this project an efficient laboratory scale system was designed to investigate the photodynamic inactivation of Gram-positive and Gram-negative bacteria in water using as photosensitiser the porphyrin 5,10,15,20-tetrakis(N-methyl-4-pyridyl)-21H, 23H-porphine (TMPyP). The investigations were performed in 60x15 mm glass Petri dishes. The light source used was a light-emitting diode (LED) dichromatic lamp with emission at the wavelengths 430 and 660nm. *E. coli* T37-1 showed a total deactivation after being exposed to a light dose of 39.47 J/cm². *S. enterica*, *S. sonnei* and *S. aureus* were slightly more resistant to PDI than *E. coli*. The three strains were completely inactivated after 45 minutes of light exposure (59.21 J/cm²) at 3.65 µM.

Escherichia coli is widely used in PDI studies. The organism is a well-known Gram-negative bacterium and member of the coliforms group. It is generally chosen as a representative biological model for Gram-negative bacteria and its presence in food or water is used as an indicator for monitoring the presence of other harmful microorganisms (Masters *et al.*, 2011).

While *E. coli* is widely studied as a representative of the family *Enterobacteriaceae*, other members of the family, like *Shigella* and *Salmonella*, are a particular challenge when considering water quality and in particular water for drinking. They are transmitted mainly through the faecal-oral route, being considered one of the most important waterborne and foodborne pathogens worldwide. (Yang *et al.* 2005; Holt *et al.*, 2012; Jun *et al.*, 2016). The bacterium *Staphylococcus aureus* is normally used as a model of Gram-positive bacteria. Studies of the organism are important because of its presence in water bodies and its resistance to traditional antibacterial treatments (i.e. methicillin resistant *Staphylococcus aureus* – MRSA) (Tolba *et al.*, 2008; Barker-Reid *et al.* 2010; Rossi *et al.* 2012; Batalha *et al.*, 2015).

Visible light photocatalytic degradation of organic pollutants in water using $\text{Ca}_x\text{MnO}_y\text{-TiO}_2$

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Semiconductor photocatalysis is an advanced oxidation process which is effective for disinfection and the degradation of environmental pollutants. Titanium dioxide (TiO_2) is one of the most promising photocatalytic materials because it is photoactive, photostable, chemical inert, abundant and inexpensive. However, the band gap of TiO_2 (anatase) is 3.2 eV and it can only utilise UV photons limiting the solar efficiency.

In the current investigation, TiO_2 (Hombikat UV100) was modified with Ca_xMnO_y . Calcium birnessite (Ca_xMnO_y) was synthesized by a precipitation method (Luo et al., 1999). The Ca_xMnO_y powder was mixed with TiO_2 by mechanical grinding followed by annealing at 500°C for 24 h to obtain $\text{Ca}_x\text{MnO}_y\text{-TiO}_2$. The materials were characterised by UV-Vis spectroscopy, transmission electron microscopy and X-ray photoelectron spectroscopy to determine the optical band-gap and the composition of the material. The powder samples were utilised as an aqueous suspension in a stirred tank photocatalytic reactor for the degradation of imazapyr. Imazapyr is a herbicide from imidazolinones family which is toxic for most of the plants even at very low concentration. The photocatalytic degradation rate towards the degradation of imazapyr for TiO_2 under UV-Vis irradiation enhanced by 50% upon Ca_xMnO_y modification. $\text{Ca}_x\text{MnO}_y\text{-TiO}_2$ also demonstrated some visible light activity towards imazapyr degradation. The possible degradation pathways were determined by mass spectrometry.

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Notes: