Emerging Water Treatment Technologies for decentralised systems:
An overview of selected systems suited for application in towns and settlements in remote and very remote regions of Australia and vulnerable and lagging rural regions in Sri Lanka

Jay Rajapakse\(^{1*}\), Peter Waterman\(^{1}\), Graeme Millar\(^{1}\), Sumitha Sumanaweera\(^{2}\)

1. Science and Engineering Faculty, Queensland University of Technology, Australia
2. National Water Supply and Drainage Board (NWSDB), Sri Lanka

*Corresponding Author: jay.rajapakse@qut.edu.au

ABSTRACT

The primary purpose of this paper is to overview a selection of advanced water treatment technology systems that are suited for application in towns and settlements in remote and very remote regions of Australia and vulnerable and lagging rural regions in Sri Lanka. This recognises that sanitation and water treatment are inextricably linked and both are needed to reduce risks to environment and population health from contaminated water sources.

For both Australia and Sri Lanka only a small fraction of the settlements in rural and remote regions are connected to water treatment facilities and town water supplies. In Australia’s remote/very remote regions raw water is drawn from underground sources and rainwater capture. Most settlements in rural Sri Lanka rely on rivers, reservoirs, wells, springs or carted water. Furthermore, Sri Lanka has more than 25,000 hand pumped tube wells which saved the communities during recent droughts.

Decentralised water supply systems offer the opportunity to provide safe drinking water to these remote/very remote and rural regions where centralised systems are not feasible due to socio-cultural, economic, political, technological reasons. These systems reduce health risks from contaminated water supplies. In remote areas centralized systems fail due to low population density and less affordability.

Globally, a new generation of advanced water treatment technologies are positioned to make a major impact on the provision of safe potable water in remote/very remote regions in Australia and rural regions in Sri Lanka. Some of these systems were developed for higher income countries. However, with careful selection and further research they can be tailored to match local socio-economic conditions and technical capacity. As such, they can equally be used to provide decentralised water supply in communities in developed and developing countries such as Australia and Sri Lanka.

*Key Words: Decentralised systems, sanitation, remote communities, drinking water, emerging technologies*
1. INTRODUCTION

Setting the Scene

Australia is the driest inhabited continent on planet Earth. Map 1 shows that some 86 percent of the geographical area is categorised as remote to very remote. ABS (2008) reported that in 2006, a total of 2.3 percent of the total Australian population lived in remote (1.5 percent) and very remote (0.8 percent) areas. Much of these areas are categorised as semi-arid and arid. However, there is a wide diversity of economic activity settlements in these regions, including pastoral, farming, mining and tourism activities. As well, there are Aboriginal and Torres Strait Islander (Indigenous) communities with limited formalised economic enterprises and high levels of under-employment and unemployment. Primary industry based economic activity in these regional areas can be severely imperilled by extreme weather and changing climatic conditions.

Map 1, Regional Spatial Characterisation of Australia
(Source: SEGRA 2014 Conference Handbook)
At the 2006 census, 2.5 percent of the total Australian population (517,000 people) was Indigenous. This is projected to increase to around 640,000 by 2016. ABS (2011) reported that over 15 percent (79,500 people) live in very remote areas while over 9 percent (47,900 people) lived in remote areas. As shown in Table 1, nearly 25 percent of all Indigenous people are living in some 1112 small communities in remote and very remote areas. In contrast, only 2.0 percent non-Aboriginal and Torres Strait Islander Australians live in remote or very remote areas (http://crc-rep.com/about-remote-australia). Overall, Indigenous communities comprise 48 percent of the total population in very remote areas, and 15 percent of the population in remote areas. And these are the people in greatest need of appropriate sewage and water treatment systems to reduce environmental health risks from surface and groundwater resources.

Although Sri Lanka is very different in demographic structure, rural regions are economically dependent on primary production. Specifically, the vulnerable and lagging rural Northern, Eastern, Uva and Sabaragamuwa provinces (shown on Map 2) are home to approximately 30 percent of the 21 million people of Sri Lanka (DFAT, 2011). In this context, these regions are at risk from vagaries in weather including more frequent droughts, longer dry seasons, more intensive rainfall events and changing climates. In turn, this reduces rural productivity and puts communities at risk. The most profound impacts of climate change in Sri Lanka will be in agriculture and food security, water and coastal resources, biodiversity changes, and human health (practicalaction.org, no date).

Purpose, Rationale and Structure of the Paper

The primary purpose of this paper is to overview a selection of advanced water treatment technology systems that could be suited for application in towns and settlements in rural and remote regions of Australia (Map 1) and vulnerable and lagging rural regions in Sri Lanka (Map 2). The focusing factors for preparing this overview are a combination of: the challenging biophysical and socio-economic conditions; inherent sanitation related environmental and population health issues; and the need to provide safe drinking water, especially for Indigenous or vulnerable communities living in these regional settings. The suite of systems overviewed in this paper need to be seen in the context of the broad demographic and climatic settings for the subject regions in each country (Maps 1 and 2).

The quantity and quality of water is of critical concern in maintaining human settlement in climatically challenged regions in remote and very remote Australia and rural Sri Lanka. Existing sanitation conditions and water purification are inextricably linked to the standard of faecal waste disposal and/or sewage treatment provided and the way contaminated effluent is entering the surface and subsurface drainage systems. Poor sanitation and inadequate sewage treatment coupled with un-managed release of discharges impacts seriously on the quality of raw water sourced for domestic use. This situation prevails in both remote Australia and rural Sri Lanka and seriously impairs public health.

The rationale for this paper is based on the acknowledgement that the first step towards reducing risks to environment and population health is to lessen threats from natural and human contaminated water sources.
Arguably, this needs to start with an in-depth understanding of: the quality of surface and ground water resources and any potential biological or chemical risks from these sources; and any potential threats to human health due to inadequate sanitation including inappropriate treatment of sewage and disposal of effluents and solid wastes from these systems. Water purification technology for specific applications needs to be tailored to this understanding because reducing the contamination of raw water sources is crucial to the effective design and of water treatment facilities and lowering operational costs.

Map 2. Lagging and Vulnerable Regions in Sri Lanka
(Source: From ALAF 12 (2013))

Summary descriptions of the selected water treatment systems centre on key criteria such as: ease of sourcing of the technology; capital and operating costs; opportunities to build and maintain the equipment in regional locations; and durability and flexibility of deployment to meet changing demand and supply situations. Conclusions drawn indicate benefits that can accrue from the take-up of advanced renewable energy driven technologies for sustainable regional development.

The paper has three further sections. The second section highlights the environment and population health imperative for having water treatment systems. Section three covers technologies for secure and safe water in rural and remote communities. The final section summarises an emerging approach towards better understanding the technological response to providing water in remote
Australia and the next steps in addressing the application of water treatment systems. Concluding remarks focus the overall findings of this review.

2. ENVIRONMENT AND POPULATION HEALTH IMPERATIVE

Sourcing Water for Indigenous Communities

Table 1 summarises the distribution of Indigenous communities by population categories and water sources. Data proved in ABS (2007) shows that water supplies in the majority of these areas are drawn from groundwater aquifers, as 694 communities (58 percent) used bore water as the most common source of drinking water, 209 (18 percent) used town water supply and the remaining 24 percent relied on rain water, rivers/reservoirs, wells, springs or carted water. Decentralised water supply systems offer the opportunity to provide safe drinking water to these rural and remote regions where centralised systems are not feasible due to socio-cultural, economic, political, technological and other reasons. Wright (2002) points out that in order to understand the sustainability of water in communities, one must first understand the cultural and social issues that induce how water is sourced, used and managed. A similar approach needs to be applied to sanitation where cultural attitudes towards human wastes, social mores and economic priorities influence the level of investment in waste water treatment. Arguably, water purification technologies cannot simply be taken from urban communities and be placed into remote or rural settlement; they must be socio-economically contextualised.

Table 1. Distribution of Indigenous Communities in 2006 by Regional Category and Sources of Drinking Water Sources (Source: ABS, 2007)

<table>
<thead>
<tr>
<th>Population</th>
<th>Non-Rural</th>
<th>Rural</th>
<th>Very Rural</th>
<th>All Communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Communities</td>
<td>75</td>
<td>104</td>
<td>1008</td>
<td>1187</td>
</tr>
<tr>
<td>&lt; 50</td>
<td>27</td>
<td>71</td>
<td>767</td>
<td>865</td>
</tr>
<tr>
<td>50 to &lt; 100</td>
<td>14</td>
<td>14</td>
<td>95</td>
<td>123</td>
</tr>
<tr>
<td>100 to &lt; 200</td>
<td>26</td>
<td>8</td>
<td>58</td>
<td>92</td>
</tr>
<tr>
<td>200 to &lt; 500</td>
<td>5</td>
<td>7</td>
<td>59</td>
<td>71</td>
</tr>
<tr>
<td>500 to &lt; 1000</td>
<td>-</td>
<td>2</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>3</td>
<td>2</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Main source of drinking water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bore water</td>
<td>10</td>
<td>21</td>
<td>663</td>
<td>694</td>
</tr>
<tr>
<td>Town supply</td>
<td>57</td>
<td>57</td>
<td>95</td>
<td>209</td>
</tr>
<tr>
<td>Rain water</td>
<td>2</td>
<td>7</td>
<td>32</td>
<td>41</td>
</tr>
<tr>
<td>River/Reservoir</td>
<td>6</td>
<td>3</td>
<td>48</td>
<td>57</td>
</tr>
<tr>
<td>Well/spring</td>
<td>-</td>
<td>2</td>
<td>37</td>
<td>39</td>
</tr>
<tr>
<td>Carted water</td>
<td>-</td>
<td>12</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

The share of population and unsafe drinking water usage for the lagging regions in Sri Lanka is summarised in Table 2. However, as shown, although the regional categories for settlement types and populations are not directly comparable with the Australian scene the data indicates the
dependence on unsafe sources of water. Again, this situation highlights the need for appropriate cost effective sewage disposal and waste water systems to reduce the load on water treatment systems.

Table 2. Use of unsafe drinking water in Lagging Regions, Sri Lanka
(Source: DFAT, 2011)

<table>
<thead>
<tr>
<th>Province</th>
<th>Share of population %</th>
<th>Use of unsafe drinking water %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>7</td>
<td>No data</td>
</tr>
<tr>
<td>Eastern</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Uva</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Sabaragamuwa</td>
<td>9</td>
<td>33</td>
</tr>
</tbody>
</table>

Sanitation and Water Use in Sri Lanka

ALAF 12 (2013) reported that Sri Lanka’s achievements in basic sanitation safe water facilities are not on track against the UN Millennium Development Goals in the four lagging and vulnerable regions delineated in Map 2. Specifically, this situation prevails in the Districts of Baticaloa (Eastern), Mullaithivu (Northern), Monaragala (Uva) and Kegalle and Ratnapura (Sabaragamuwa).

Currently, the sanitation and rural water issues in these areas are not being adequately covered by major donor-funded Programs. Donor effort is usually focused on the delivery of small water supply projects in selected rural communities. The major donor programs are currently being delivered with respect to piped urban water supplies and sewage treatment in Jaffna and related areas in the Northern Province (see Map 2). No funding is directed to systematically addressing the chronic sanitation problems by way of the treatment and disposal of human faecal wastes in towns and rural communities. This situation is adversely impacting on the quality of raw water from surface and groundwater sources. And in turn this is affecting the urgency of the need to reduce the health risks and for investment in water purification systems to meet the requirements of rural towns and villages.

ALAF 12 (2013) reported that all planning for and the provision of centralised domestic urban and rural water services in Sri Lanka (together with the operations, maintenance and fiscal administration of the sale of water from these services) is the responsibility of the National Water Supply and Drainage Board (the Water Board). As the central statutory domestic water supply authority for Sri Lanka, the primary function of the Water Board is the provision of piped water services to residences, commercial and industrial premises in urban and peri-urban areas and some small rural towns. This encompasses the capture and storage of surface and groundwater resources and their treatment (to national standards) to provide safe drinking water. As well, the Water Board provides safe drinking water using tank and ‘bowser’ facilities at ‘water points’ in rural villages and settlements. Responsibility for the on-ground provision and administration of the water supply services is devolved to ‘Water Board Offices’ operating at regional and district levels.

Additionally, the Water Board registers the operations of Community Based Organisations (CBO’s) as providers of drinking water in rural areas in the provincial regions. As well, the Water Board provides analytical services from a number of regional laboratories to determine and monitor the quality of
water provided by the CBO’s. The Water Board also provides central laboratory facilities in Colombo to cover chemical analytical determinations that cannot be provided by the regional laboratories.

Drainage is the term used to describe the provision of sanitation (sewage) services in Sri Lanka. Currently, no sanitation services are being provided by the Water Board in either urban or rural areas in regional Sri Lanka. The piped sewer coverage is 1.93%. As indicated previously, disposal of sewage is undertaken at individual homes and at commercial premises using a range of unsatisfactory methods. This situation contributes to bacterial contamination of rural and urban water supplies. And, because it is population and environmental health issue, it requires urgent intra-governmental policy and practical responses.

Water for irrigated agriculture and related primary production purposes is the responsibility of the Ministry of Irrigation and Water Resources Management. This institution exerts the greatest amount of control over Sri Lanka’s water resources. Hence, this situation needs to be seen in perspective with respect to the roles and responsibilities of the Water Board and the inherent policy conflicts over resource allocation and priority of use. In short, there are intra-governmental and societal tensions over the use of water for agricultural verses domestic purposes that require immediate resolution.

Current policy settings and institutional arrangements tend to favour agriculture over domestic usage. However, there are some institutional differences in estimates on the quantity of water used for irrigation and domestic purposes respectively. For example, in 1999 the Sri Lanka Water Resources Council and Secretariat stated that 90-95% of developed water is used for irrigation (Ariyabandu, 2008). On the other hand, in 2002 the Ministry of Environment and Natural Resources indicated that 85% of developed water is used for irrigation, 6% for domestic and 5% for industry (Ariyabandu, 2008). According to Bandaragoda and Babel (2010), in Sri Lanka, irrigation accounts for 97.5%, whereas domestic water supplies and industries sectors take only 1.25% each. This uncertainty in enumerating the quantum of water use, especially in rural regions, highlights the difficulties in ensuring that the water provided is safe.

**Key Population Health Indicators**

The health of a community is usually measured by three main indicators: the infant mortality rate, the childhood mortality rate and the life expectancy. Although globally Australia hails a very high healthy life expectancy of 74 years, it has been reported (Commonwealth of Australia, 2012) that the gap in life expectancy at birth between Aboriginal and Torres Strait Islander peoples and other Australians for 2005–07 was estimated at 11.5 years for males and 9.7 years for females. Commonwealth of Australia (2012) reported that in 2008, the Aboriginal and Torres Strait Islander child mortality rate was 213 per 100,000 people compared to 101 per 100,000 people for non-Indigenous children. In contrast, for the Sri Lankan situation, in 2012, life expectancy was 71 years for males and 78 years for females (WHO, 2012).

Factors such as lack of access to primary health care and treatment, poverty and overcrowded housing conditions, inadequate access to water and sanitation are considered responsible for infectious diseases in Aboriginal and Torres Strait Islander communities in Australia and at risk
communities in Sri Lanka. For example, Trachoma is an eye infection if untreated can lead to blindness, and Australia is the only developed country where trachoma is still endemic. It is found almost exclusively in remote Aboriginal and Torres Strait Islander populations (Commonwealth of Australia, 2012). Trachoma belongs to the category of ‘water-washed disease’ meaning it is spread due to lack of clean water for washing. In contrast, as outlined below, Chronic Kidney Disease of unknown causation (aetiology) or CKDu is a major environment and population issue in vulnerable and lagging regions in Sri Lanka.

**Chronic Kidney Disease of unknown causation (aetiology) or CKDu**

CKDu is not linked to traditional factors such as hypertension or diabetes, and patients are predominantly subsistence farmers and / or agricultural labourers. The disease is reasonably new in Sri Lanka (first death identified in 1993), but has been known to other Asian countries such as India, Thailand and China. In Europe, it was first recognized in the 1950s in the Balkans in geographically discrete areas along the Danube River and its tributaries in the Balkans (Pavlovoc, 2013; Batuman, 2006), stretching into Romania, Bulgaria, Croatia, Serbia, and Bosnia-Herzegovina, hence it was also known as Balkan Endemic Nephropathy (BEN). In Central America, beginning in the 1990s, chronic kidney disease cases were reported associated with non-traditional risk factors (CKDnt), primarily affecting farming communities and male agricultural workers (Ramirez, 2013). According to new data published by Kidney Health Australia (September 2014), there is an alarming prevalence of kidney disease amongst Indigenous people in Australia.

Although Aboriginal and Torres Strait Islander people only represent around 2.5 percent of the national population, they account for approximately 9 percent of people commencing kidney replacement therapy each year. Also, they are almost 4 times as likely to die with CKD as a cause of death than non-Indigenous Australians. Compared with those living in other areas, Indigenous Australians living in remote and very remote areas are more likely to have treated Early-Stage Kidney Disease (ESKD). This is also reflected in the higher hospitalization rates for CKD among Indigenous people in these areas.

In Australia, the greater prevalence of CKD in some Indigenous Australian communities has been attributed to the high incidence of traditional risk factors, including diabetes, high blood pressure and smoking (AIHW, 2011). Additionally, inadequate nutrition, higher levels of alcohol abuse, streptococcal throat and skin infection, poor living conditions and low birth weight (which are linked to reduced nephron development) are reported as other risk factors (www.kidney.org.au, 2014 and Hoy et.al., 2010). Arguably, these risk factors may explain much of the causation but not all. The role of poor quality groundwater resources needs serious consideration with respect to CKD in Indigenous communities. In this context, the implementation of the precautionary principal with the application of water purification systems in rural and remote regions is crucial.

The recent epidemics of Chronic Kidney failure Disease of unknown aetiology (CKDu) in the North Central, North Western, Eastern and Uva Provinces of Sri Lanka (Map 3) is a major concern for the nation. A range of reasons have been put forward as to why farmers are predisposed to the disease by Sri Lankan researchers such as IWMI (2014), Jayasumana et.al (2014), WHO (2013) and Jayatilake
Evidence from researchers also leads to a rejection of some of the suggested causes. These are summarised as follows.

Farmers undertake strenuous labour under hot climatic conditions that may lead to chronic dehydration and greater/lesser consumption of water. An inadequate intake of water places stress on the kidneys. Also, people in hot conditions drink greater amounts of water that may contain the causal agent(s) that could impact on kidneys. On this basis, it has been postulated that water and its chemical constituents may in part play a role in the etiology of the disease.

Pesticides have been raised as causal agents by researchers such as Jayasumana et al. (2014). Specifically, a range of agro-chemicals that are routinely used in rice production systems have been identified as a source of Arsenic (As) in areas with abnormal prevalence of CKDu. However, it is difficult to reconcile why the disease does not afflict all rice growing areas of Sri Lanka, where these chemicals are routinely used in the rice production systems (Noble et al., 2014). Moreover, according to Noble et al. (2014), Arsenic levels were found to be ‘normal’ in groundwater samples collected in areas identified as hotspots for CKDu as part of the study by the World Health Organization (WHO).
Elevated levels of Cadmium (Cd) were reported in waters from reservoirs, soils, and in a range of foods including rice, commonly consumed by rural communities Bandara et.al. (2008). However, they were not as high as those measured in Thailand, where known Cd-related kidney disease has been identified. The source of Cd contamination has been identified as triple super phosphate (TSP, Triphosphate). (Noble et.al., 2014) have questioned the veracity of these results as for example it is difficult to reconcile the role of Cd in the disease because TSP use is widespread throughout the agricultural sector in Sri Lanka and elsewhere in South and South East Asia.

The WHO study undertaken by Jayatilake et.al (2013) reported chronic exposure of people in the endemic area to low levels of cadmium through the food chain. Exposure to pesticides was also reported. Also, exposure to lead and arsenic through the food chain was suspected. In this case, Jayatilake et.al (2013) reported that urine concentrations of cadmium and arsenic in individuals with CKDu were at levels known to cause kidney damage.

Fluoride in the groundwater (Dissanayake, 1996) and, its interaction with other constituents that are present, namely, Calcium (Ca), Sodium (Na) and possibly Magnesium (Mg), has been suggested as a causal element for CKDu (Chandrajith et.al., 2011a). However, in their review of literature on CKDu in Sri Lanka, Noble et.al. (2014) concludes that there seems to be no obvious distinction between in F concentrations in drinking-water sources between endemic and non-endemic areas. Chandrajith et.al (2011b) hypothesised that the groundwater may have unique fluoride, sodium and calcium ion concentrations, and the possible complexation of fluoride with Na and in the presence of Ca could lead to fatal chronic kidney diseases. And that is not the concentration of fluoride per se, but rather the interaction of fluoride with constituent ions in the groundwater.

From the forgoing arguments it is apparent that there is no clear certainty as to the cause of CKDu. However, there is great certainty as to the impacts of the disease in vulnerable and lagging regions and the scale of the CKDu epidemic. Although the local media (The Sunday Leader, 2013) reported that in Anuradhapura, Polonnaruwa and Badulla districts around 15% of the total population (around 200,000) between the ages of 15 to 70 are suffering from CKD and the disease is spreading rapidly, Elledge et.al. (2014) reported that the number of CKDu patients in the endemic areas was likely to be over 25,000 by the end of 2013. Application of the precautionary principle dictates that the issue should be addressed with the best technology and environmental management techniques and this need can be met using advanced water treatment systems.

3. TECHNOLOGIES FOR SECURE AND SAFE WATER IN RURAL AND REMOTE COMMUNITIES

Decentralised Water Supply Systems

As stated in the introduction, the purpose of this paper is to overview a selection of small scale purification systems considered to be suited for application in towns and settlements in rural and remote regions of Australia and Sri Lanka. Arguably, they could equally be applied in other countries facing similar needs for cheap and ‘for-purpose’ safe domestic water from groundwater resources.
Decentralised water supply systems are broadly categorised into Household Water Treatment Systems (HWTS) and Small Scale Systems (SSS). The HWTS are further classified into Point of Use (POU) systems and Point of Entry (POE) systems. This categorisation is shown schematically in Figure 1.

A new generation of advanced water treatment technologies are positioned to make a major impact on the provision of safe potable water in rural and remote regions in Australia and Sri Lanka. The oldest type of engineered municipal water filtration system is the slow sand filtration. With recent developments, such as the introduction of new media such as expanded clay aggregates (Filtralite) or Granular Activated Carbon (GAC) sandwich beds (modified slow sand filters) are currently being successfully used by Thames Water for London water supply.

Practical experience shows that they remain a promising filtration method for small systems with low turbidity or algae containing source waters, providing virtually complete removal of *Giardia lamblia* cyst and *Cryptosporidium* oocyst. Other new developments include Advanced Oxidation Processes (AOP) and Electro Coagulation (EC). Some of these new technologies can be driven by renewable energy sources such as solar power and meet the domestic requirements for pure water from households through to communities.

![Figure 1. Classification of Decentralised Remote Community Water Supply Systems](image)

Going back as far as 1959, a range of decentralised treatment technologies from physical, chemical and disinfection methods have been extensively discussed by various authors, (Varbanets et.al, 2009; [www.sswm.info](http://www.sswm.info); Murcott, 2005; Mara, 2003; Mintz et.al 2001; Wagner and Lanoix, 1959). Examples of commonly used treatment processes are listed in Table 3 and a selection of technologies available for decentralised water treatment is listed in Table 4.

Some of the more recent developments that are applicable to surface water and groundwater treatment are discussed further as follows.
<table>
<thead>
<tr>
<th>Decentralised Treatment Technologies</th>
<th>Method</th>
<th>Technique</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical removal processes</strong></td>
<td>Aeration</td>
<td></td>
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<tr>
<td></td>
<td>Sedimentation</td>
<td></td>
<td></td>
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<tr>
<td>Roughing filtration</td>
<td>Aeration</td>
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<td></td>
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<tr>
<td></td>
<td>Sedimentation</td>
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<tr>
<td></td>
<td>Roughing filtration</td>
<td>Pebble Matrix Filtration (PMF)</td>
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<td></td>
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<td>Up-flow Roughing Filtration (UFRF)</td>
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<td>Horizontal Flow Roughing Filtration (HRF)</td>
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<tr>
<td>Granular media filtration</td>
<td>Slow Sand Filtration (SSF) – Physical and Biological process</td>
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<tr>
<td></td>
<td>Rapid Sand Filtration (RSF)</td>
<td>Also known as Biological Filtration</td>
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<tr>
<td>Membrane filtration</td>
<td>Micro Filtration (MF)</td>
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<td></td>
<td>Ultra Filtration (UF)</td>
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<td></td>
<td>Nano Filtration (NF)</td>
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<td></td>
<td>Reverse Osmosis (RO) – also Solar Powered systems</td>
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<td></td>
<td>Desalination</td>
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<tr>
<td>Ceramic filters</td>
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<tr>
<td>Kanchan filters for Arsenic removal</td>
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<tr>
<td><strong>Chemical processes</strong></td>
<td>Coagulation and flocculation</td>
<td>Alum, Ferric Chloride, Ferric Sulphate, Poly Ferric Sulphate, Poly Aluminium Chloride</td>
<td></td>
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<tr>
<td></td>
<td>Adsorption</td>
<td>Granular Activated Carbon (GAC)</td>
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<td></td>
<td>Ion Exchange</td>
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<td></td>
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<tr>
<td></td>
<td>Catalytic Advanced Oxidation (CAO)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Electro Coagulation (EC)</td>
<td>Also sometimes known as Electro Flocculation (EF)</td>
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<tr>
<td></td>
<td>Chemical disinfection</td>
<td>Chlorination</td>
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<tr>
<td><strong>Other disinfection methods</strong></td>
<td>Boiling with fuel</td>
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<tr>
<td></td>
<td>Solar disinfection</td>
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<td></td>
<td>UV lights</td>
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### Table 4. Selected Technologies Available for Decentralised Water Treatment

<table>
<thead>
<tr>
<th>Technology</th>
<th>Suitability</th>
<th>Pollutant</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>Roughing filtration</td>
<td>POE, SSS</td>
<td>Turbidity</td>
<td>Wagelin, 1996</td>
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<tr>
<td>PMF, UFRF, HRF</td>
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<td>Rajapakse &amp; Ives, 2003</td>
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<td>WHO (Water Sanitation Health)</td>
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<td>Rapid Sand Filters</td>
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<td>WHO (Water Sanitation Health)</td>
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<td>Membrane Filtration MF-0.1µm UF-0.01µm NF-0.001 µm RO-0.0001 µm</td>
<td>POE, SSS</td>
<td>Low turbidity Pathogens; NOM; Salts</td>
<td>Wessels (2000)-solar powered RO</td>
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<td>Li and Chu (2003) – membrane for surface water</td>
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<td>Hardness Nitrates, As</td>
<td>Yau and Thorne (2012)</td>
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<td>POE, SSS</td>
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**Membrane Technology for Groundwater Treatment**

Membrane processes separate pollutants by forcing the polluted water through a semi-permeable film (membrane). The driving force can be a difference in pressure, concentration, temperature, or electrical potential. In the water industry membranes are pressure-driven and referred to as membrane filtration. However, electrically driven (electrodialysis) and thermally driven (membrane distillation) systems are also available. The selection of the type of membrane based on the pore size of the membrane is dependent on the type of pollutant in question for separation. The pore size of microfiltration (MF - 0.1 µm) is capable of removing clay particles, bacteria and some viruses, while ultrafiltration (UF - 0.01 µm) has the ability to remove clay and all kinds of microbiological hazards such as *Cryptosporidium, Giardia* and substantial virus removal.

While both, nanofiltration (NF - 0.001 µm) and reverse osmosis (RO - 0.0001 µm) membranes are suitable for inorganic salts removal, NF are effective in removing bivalent ions (above 90 percent) and RO membranes are required for mono-valent ions such as the treatment of seawater or brackish water (desalination).

Some 60 percent of the nation’s mining companies operate in remote Australia, making a significant contribution to national wealth. Without groundwater extraction there would be no primary or mineral sector industries or towns and settlement in most rural and remote regions. However, with growing industry demands and population growth the demands on groundwater sources poses questions about sustainability of this resource in some remote regions. Also, with dependence on this resource come potential health risks from the natural chemical characteristics of the widely differing aquifers. Additionally, there are public health issues arising from contaminated ground water due to industrial discharges (including intensive agriculture and livestock stock production) and human settlements.

In this context, purification of raw groundwater to safe water (potable) standards is an essential requirement for sustaining economic and social development across much of regional Australia. Currently, treatment of groundwater is undertaken in larger towns as part of the centralised piped provision of water supply to commercial enterprises, industry and residences. These treatment systems provide relatively costly potable standard water for all purposes. The price of energy to operate the systems is a major cost item in water treatment. Further, there are a range of water purification systems are used in remote mining camps and Aboriginal settlements. Portable treatment systems are also used for emergency water supplies in disaster relief operations and for major exercises in military training areas.

**Reverse Osmosis (RO) Plants for CKDu affected areas**

From the available information around the world, there is some consensus that the CKDu may have some connection with heavy metals be it arsenic or cadmium, and until further research on the aetiology of CKDu is completed, the Government of Sri Lanka has embarked on a mission to provide safe water to CKDu affected areas by treating the available groundwater using small scale Reverse Osmosis plants for drinking and cooking only, under the supervision of the National Water Supply
and Drainage Board (NWSDB). Even though the treated surface water is a viable solution to the problem, the low population density of the affected areas is a problem to providing pipe born water to all of them. However the pipeline extensions from the existing water supply systems were considered one way of solving the problem. In addition to that bowser supplies to 1000 L storage tanks located roadside was practiced where feasible.

The ground water of the affected area contains high hardness in the range of 400 to 700 mg/L and Fluoride levels up to 2 mg/L combined with high iron and manganese up to 2 mg/L. This water for drinking and cooking assumes a daily consumption of 5 litres of water per capita. Hence a family of 4 needs 20 litres of water for drinking and cooking per day. It was identified that isolated affected villages could be provided with safe drinking water produced out of ground water using reverse osmosis (RO) technology with a guarantee of 99 percent removal of all the organic pollutants, divalent and monovalent inorganic ions from water.

Also, it was calculated that such RO treated water could be provided at the doorstep of household within 15 km from the point of production at 0.01 USD per litre using 20 litre capacity food grade water containers. Since 2013, NWSDB has implemented 14 such RO based water supply units managed by community organizations with NWSDB providing necessary technical support (Figures 2 and 3).

Problems associated with brackish water RO treatment systems are concentrate management, product water with low ionic concentration and low pH. It is noted that concentrate concentration is within the drinking water quality standard as the source water is of brackish quality. However this fact is well taken and the maximum size of a RO plant is decided to be 10 cubic meters per day. Such plant is capable of producing 10 cubic meters of drinking water sufficient to feed 500 households per day. If the plant is bigger than this more problems related to concentrate discharge would arise. This RO plant uses pre-treatment, namely sand pressure filtration and activated carbon filtration. These filters are PLC controlled. There is a high pressure pump to feed the raw water to the membrane which is single phase. If the plant is bigger than this, three phase pressure pump will be required. This is not practical for rural situations. Also frequent voltage fluctuations in these areas are arrested by using voltage stabilizers. In the RO technology scaling of membrane is one of the serious problems. In this plant this problem is arrested by the use of anti-scaling solution continuous feeding. The other method iron exchange is not practically possible due to complex operations.

The advantage of the RO treated water is its high palatability due to lack of hardness. This is an important fact as one of the reasons for the disease was identified as limited water consumption by the affected community. According to medical feedback RO water has increased the level of water consumption of the people as well as reversal or stagnation of stage 3 of the disease. The NWSDB is involved in monitoring the performance of these plants with the assistance from the Ministry of Health.
Surface Water Treatment by Slow Sand Filtration

For the treatment of drinking water in tropical areas, particularly for rural or decentralized village supply, the WHO recommends the use of Slow Sand Filters (SSF) as an appropriate and sustainable technology. Their simple design makes it easy to use local materials and skills in their construction, operation and maintenance. No chemicals are used, yet very effective in pathogen removal. The Slow sand filters have an advantage over rapid sand filters in that they produce microbiologically "clean" water and contain no E.coli in a 100 mL sample, thus satisfying the most important bacteriological drinking water quality requirement. However, chlorination can be used as an
additional safeguard. The cost of operation lies mostly in the cleaning of filters, which may be carried out manually, in smaller units.

A granular activated carbon (GAC) sandwich filter is a modified slow sand filter that removes organic material. This filter uses a base sand layer that is approximately 30 cm deep, an intermediate GAC layer approximately 15 cm, and a top sand layer approximately 45 cm deep. The concept was developed in the Thames Water UK and a full scale trial was conducted at the Ashford Common Water Works which effectively removed pesticides, total organic carbon, and THM precursors (Surampalli and Tyagi, 2004).

One of the major problems in the water industry (or any industry for that matter) is convincing decision makers to use simple and cheap technologies. There is always the misconception among decision makers that simple and cheap technologies are either unreliable or do not produce ‘a good image for the organization’. One way forward to overcome such barriers is through positive information to refute the misconceptions. For example, although very reliable in removing E.coli, slow sand filters are considered by some decision makers in developing countries to be inferior technology. As a result, water authorities are very reluctant to adopt these technologies for new treatment plants. Fortunately, such perceptions are slowly changing in the light of the rising demand for higher drinking water quality standards. Consequently, in recent years, there has been a renaissance of interest in the potential use of slow sand filtration throughout the world.

The filter can be built entirely above ground, partly above and partly below ground or basically as a hole in the ground. There are many means of construction that can be adopted. They range from the very simple, suitable for developing countries with limited means and expertise, to the highly sophisticated, incorporating all the most modern mechanical devices. Hence, the method has successfully produced potable water in the United States and Britain for more than a century and even today most London’s surface derived water is slow sand filtered. So why not use it in remote and rural regions where conditions are suitable.

One of the main drawbacks is that the operation of such filters deteriorates during periods of heavy rains when the sources of supply of raw water become extremely muddy. The silts and clays in muddy water will clog the surface layer of sand and fill the pores between the sand grains with a consequent loss of flow capacity and a rapid rise in headloss (pressure drop) across the filter. This shortens the filter runs requiring frequent cleaning and disrupting the water supply.

Thus, to improve performance, it is vital to protect the SSF from such effects during monsoon or heavy rainfall periods by the use of pre-treatment methods. These pre-treatment methods have to meet the criteria of simplicity for application in rural areas. Specifically, they should not involve treatment with imported chemicals due to: their complexity of handling and dosing; and the demands on foreign currency exchange. Although the construction of reservoirs or large settling basins have been considered, and even accomplished in some tropical locations, these are expensive capital projects. Additionally, they may lead to other problems such as excessive algal or weed growth and breeding of mosquitoes.
A novel pre-treatment method called Pebble Matrix Filtration (PMF) developed at University College London, proved to satisfy these conditions and showed promise in laboratory scale (Rajapakse and Ives, 1990) and subsequently field tested in Papua New Guinea (Rajapakse and Ives 2003), Serbia (Rajapakse et al 2005) and Sri Lanka (Rajapakse et al 2007). The PMF can be described as a crude two-layer filter (Figure 4), where a turbid suspension approaching the filter flows downward, first through a layer of pebbles only (L1) and then through a matrix of pebbles and sand (L2). The upper part of pebbles only has some pre-filtering effect, but the improvement in suspension solids concentration is dominated by the pebble-sand mixture.

The PMF and SSF are considered to be an example of ethically sustainable systems suitable for addressing water quality problems in remote and rural settings in Australia and Sri Lanka. Both filters use natural purification processes and can be constructed using local materials, Further, the process does not require costly imported chemicals. Most importantly, their operation and maintenance can be carried out without highly qualified local personnel in rural areas. Schematics of a PMF and a SSF are shown in Figure 4 below and photos of operating the system in a village near Lae in Papua New Guinea are shown in Figure 5.

During 2013 Brisbane floods a pebble matrix filter was operated at Queensland University of Technology’s Banyo Pilot Plant Precinct using flood water from the Brisbane River (Figure 6). The filter was able to remove Natural Organic Matter (NOM) in addition to turbidity and the results of these experiments are yet to be published.

The total costs of a system with fittings, flow meters, manometers, underdrains, filter media and labour but excluding storage where filter tanks are made of galvanized culvert rings was around $15800, $29000 and $41000 (2010 prices) for populations of 400, 1000 and 2000 respectively. Other construction materials such as ferrocement or concrete may keep the costs even lower.

**Catalytic Advanced Oxidation (CAO)**

Advanced Oxidation Process (AOP) based on techniques of generation of highly reactive species (especially the hydroxyl radical OH) that are able to react with a range of compound, even with chemicals that are otherwise very difficult to degrade. In the Catalytic Advance Oxidation (CAO) process, a catalyst powder or granules (such as manganese dioxide, silver, Titanium dioxide, platinum etc.) is added to the solid powder of sodium percarbonate-SPC (the source of hydrogen peroxide). Addition of water to this mixture results in the dissolution of SPC and the release of hydrogen peroxide into the solution, which is instantly decomposed by the catalyst into oxygen or hydroxyl radicals. AOP is capable of removing heavy metals, aromatics, pesticides, petroleum constituents, volatile organic compounds (VOC), petroleum hydrocarbons and chlorinated hydrocarbons, dyes and organic matter. Figure 7 shows a CAO unit at QUT.
Figure 4 Schematic of the Simple PMF and SSF systems
(Source: Rajapakse et.al., 2010)

Figure 5 PMF and SSF Field Trials in a Village near Lae, PNG
(a) PMF
(b) SSF
Figure 6 Pebble Matrix Filter Experiments at Queensland University of Technology Using 2013 Brisbane Flood Water for Turbidity and NOM Removal

Figure 7 Catalytic Advanced Oxidation Unit located at QUT
Electrocoagulation (EC)

Electrocoagulation involves the generation of coagulants in situ by dissolving electrically either aluminium or iron ions from aluminium or iron electrodes respectively. The metal ions generation takes place at the anode and hydrogen gas is released from the cathode. The hydrogen gas would also help to float the flocculated particles out of the water (Figure 8), hence the process is sometimes known as electro flocculation. The EC process has been successfully employed in removing pollutants such as suspended solids, colloidal material, metals, pesticides, dissolved solids and radionuclides from water and wastewaters. This process also removes harmful microorganisms. Due to improved process design (Figure 9) and material of construction, the EC process is being widely accepted over other physicochemical processes. Presently, this process has gained attention due to its ability to treat large volume and for its low cost. Other advantages of electrocoagulation include: high particulate removal efficiency; compact treatment facility; relatively low cost; and possibility of complete automation for remote locations. However, the National Water Supply and Drainage Board (NWSDB) of Sri Lanka have some reservations in adopting this technology in their schemes due to the drawback of releasing Aluminium into the treated water.

Figure 10 shows an EC plant in a remote village in Sri Lanka used for fluoride and hardness removal from a local well supply and operated by a local Community Based Organisation (CBO). The plant supplies water for drinking and cooking only for about 150 families and sells about 2000 L/day at the cost of Rs 1 per litre (in 2012; AU$ 8.20 per 1 KL).
All of these systems meet essential needs but they raise the question: are these technologies the most efficient and effective way to address current and future needs for safe water in rural and remote regions in Australia as well as in vulnerable regions in countries such as Sri Lanka, Papua New Guinea as well as the island nations of the Pacific where there is dependence on ground water supplies?

Figure 9 Electrocoagulation System at QUT

Figure 10 Electro Coagulation (EC) followed by Sand Filtration (Remote Village in Sri Lanka, 2012)
4. ADDRESSING THE NEED FOR DECENTRALISED SYSTEMS AND CONCLUDING REMARKS

Action by Water Research Australia

Water Research Australia (Water RA) recognises that remote and regional communities present significant challenges for water supply and wastewater treatment with regard to cost, lack of funding, lack of skilled operational staff and in-house capability and as a result the level of service (quality and supply reliability) is typically lower in remote and regional communities RFP (2013). In some cases, the water supply for the town is deemed ‘non-potable’. Thus, it has been proposed that decentralised solutions are increasingly viable through a mix of emerging technologies and more sophisticated risk management strategies.

As a response to this situation, in November 2013, Water RA called a ‘Request for Proposals (RFP)’ to develop a knowledge base from case studies across Australia and overseas on decentralised treatment solutions for regional and remote supplies, in order to assist water authorities operating in remote and regional supplies with the best information to better understand the costs, benefits and risks of decentralised supply solutions, including all water quality risks, chemicals and pathogens.

There were a range of issues that Water RA considered important in reviewing the case studies including (Water RA, RFP 2013). These are summarised in Table 5. The project contract was awarded at the beginning of 2014 and the project is still in its early stages and there hasn’t been any documentation produced to date (Rajapakse, 2014). Information generated through the systematic analysis of the issues and questions should provide a body of knowledge that will assist policy makers and practitioners alike in reviewing emerging advanced sewage, waste water and water treatment technologies. Specifically, to assist in determining how well they are suited for application in towns and settlements in remote and very remote regions of Australia and vulnerable and lagging rural regions in Sri Lanka.
### Table 5. Focusing Issues and Questions to be addressed through the Water Resources Australia Project

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<tr>
<th>Focusing Issues</th>
<th>Questions to be Addressed</th>
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<td>Opportunities to improve source water quality.</td>
<td>• Do the same opportunities exist to focus on source water protection as for larger centralised systems?</td>
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</table>
| Actual performance of decentralised water and wastewater systems. There is evidence that remote and regional plants perform poorly compared with centralised plants. | • Is this universally the case?  
• Is there evidence to suggest that emerging process technologies (such as membranes) are bridging the gap and becoming more viable?  
• What is the data and what are the available case studies?  
• Does the existing data support a particular direction? |
| A widely acknowledged problem with decentralised options are very high operational and maintenance (O&M) costs resulting in a very high full life cycle cost. There are many examples of decentralised treatment processes in urban settings including sewer mining, greywater systems, and other recycling processes where the 'true' costs have been significantly higher than the projected costs. | • What are the lessons here and how can the true costs be better estimated?  
• From the case studies, consider whether there are ways of potentially reducing O&M costs for decentralised treatment options? |
| Analogues for comparisons                                                       | • Has there been innovative decentralised treatment options trialled?  
• Is there new data available on decentralised plants that would provide valuable case studies for the industry? |
| Regulatory requirements:                                                        | • How are regulatory requirements and regulatory oversight best achieved for remote and regional solutions?  
• Are there examples of risk management plans, and quality management systems that are well suited to remote and regional authorities? |
| Remote monitoring:                                                              | • How is it most effectively conducted and what is the cost? |
| Hidden failure modes with decentralised treatments.                            | • Are there potentially more hidden failure modes, such as disinfectant failure (UV lamp failure), or membrane failure that can occur for decentralised treatment?  
• How have these failure modes have been addressed, particularly to meet regulatory requirements? |
| Application of risk management and the applicability of ADWG. Operability and robustness are key requirements in remote and regional settings. This may impact on process selection. For example, recently three Electrodiagnosis Reversal (EDR) plants were commissioned in NT by Power and Water recognising their more robust operation compared with Reverse Osmosis (RO) plants. These plants are aimed at achieving specific ion reduction in order to meet ADWG guideline values. | • Are there alternative strategies (including specific risk management approaches) to eliminate the need for these complex treatment barriers? |
| National and international experience and opportunities to trial approaches.     | • What is the experience in Australia and overseas with the uptake of decentralised treatment options?  
• Are there specific examples of the cost effective, robust and sustainable uptake of decentralised water and waste treatment processes that have not been taken up in Australia?  
• Is there merit in trialling these? |
| Consideration of training requirements.                                         | • Is it worth including consideration of training requirements of local communities and ownership of the facility to improve performance? |
Concluding Remarks

Proper sanitation and safe water is critical in reducing environmental and population health risks to people living in remote-very remote Australia and rural Sri Lanka. Appropriate water treatment is pivotal to meeting these societal objectives. Often attention is focused more on water purification than providing suitable treatment and disposal of sewage biosolids and effluents. Where ever possible adequate sewage and waste water treatment should be used prevent discharges of faecal contaminants to surface and groundwater. In turn, this measure can help to reduce the cost of treating water to potable standards.

Approximately 2.5 percent of the Australian population live in remote and very remote areas and Indigenous communities comprise 48 percent of the population in very remote areas, and 15 percent in remote areas. In contrast, 80 percent of the total population of Sri Lanka live in rural regions with 30 percent in provinces considered to be vulnerable or lagging. The majority of the water supplied for these areas is from on groundwater, followed by rain water. Purification of raw surface and groundwater to safe water (potable) standards is an essential requirement for sustaining economic and social development across much of regional Australia and in lagging and vulnerable regions in Sri Lanka.

A new generation of advanced water treatment technologies such as solar powered RO systems, Advanced Oxidation Processes, Electrocoagulation, improved GAC sandwich slow sand filtration and new generation filter media are positioned to make a major impact on the provision of safe potable water in rural and remote regions in Australia and overseas. Although some of these systems were developed for higher income countries, with careful selection and further research to match local conditions, they can equally be used for decentralised remote communities in developed countries such as Australia and developing nations such as Sri Lanka.

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