A Major Irrigation Project (Accelerated Mahaweli Programme) and the Chronic Kidney Disease of Multifactorial Origin in Sri Lanka

Stanley Weeraratne[1], Sunil J. Wimalawansa[2]

[1]Emeritus Professor of Agronomy, Ruhuna University, Sri Lanka
[2]Cardio Metabolic Institute, Somerset, New Jersey, U.S.A.

Abstract— *The Mahaweli River is the longest river in Sri Lanka. In 1978, the government of Sri Lanka launched the Accelerated Mahaweli Development Programme, under the purview of Mahaweli Authority of Sri Lanka, the largest irrigation program in the country. It is a multi-purpose development scheme designed for the generation of hydroelectricity, irrigation, and water for domestic consumption. Since the mid-1990s, a major, non-infectious epidemic of chronic kidney disease of multifactorial origin (CKDmfo) has been reported in Sri Lanka for which no cause has been identified. This disease predominantly affects dry zonal, agricultural regions, particularly the North Central Province (NCP). During the past two decades, thousands of people have died due to this disease. This article assesses whether there is a relationship between this environmental impact from this major irrigation project and the deadly disease of CKDmfo. Water in the Mahaweli River is known to be polluted with various compounds, including phosphates coming from the excessive use of fertiliser in the hill country. However, the levels of phosphate in the Mahaweli River and in the NCP reservoirs are less than 0.15 mg/L. Such levels can cause ecological harm but are not a threat to human health nor causes renal failure. In addition, there are large regions outside the Mahaweli-fed localities where people are affected with CKDmfo. Thus, it is unlikely that water from the Mahaweli River itself is directly related to the occurrence of CKDmfo, but its harmful environmental impact is noticeable. Nevertheless, excess phosphates can cause algae blooms and cyanobacterial growth in water bodies, which harm aquatic lives and the ecology. Thus, governments and society must take responsibility and initiate actions to minimise environmental harm, protect and preserve the watersheds, curb the overuse of agrochemicals, and preserve water quality and the environment for current and future generations.*

Running header: "River Mahaweli and CKDmfo"

Keywords— About five key words in alphabetical order, separated by comma.

I. INTRODUCTION

Water contamination issues are not new to Sri Lanka (Mertens, Fernando et al. 1990, Dharmagunawardhane HA 1993, Guruge and Tanabe 2001), where industrial development and colonization have occurred since the 1950s in areas that previously were forested, particularly in the North Central Province (NCP). This development together with the accelerated Mahaweli project started in the mid-1970s have dramatically altered the ecology of the NCP (Panabokke 2000).

Conserving water is particularly crucial to agriculture because irrigation accounts for more than 70% of freshwater use. Planners need to think of ways to improve crop efficiency with minimal use of water. In the ever-increasing demand for water for irrigation, such efforts are central to meeting future nutrient needs in a sustainable manner. Man-made water conservation structures (known as tanks or reservoirs) traditionally made of earthen dams are a key resource used in agriculture, especially in the dry zonal areas. Both small and large tanks are important not only for agriculture but also for many other human needs in these regions.

Over the past few decades, freshwater resources have been endangered, not only by over-exploitation but also by neglect, poor management, and man-made pollution, including industry effluents; all of this has led to ecological degradation (Burkart 2007). Nevertheless, naturally occurring and man-made contaminations exhibit marked geographical variations (Anonymous 1979), whereas climate changes exacerbate ill health (Mertens, Fernando et al. 1990, Baumgarten, Steinnes et al. 2009). Degradation of watersheds and catchment areas in wooded and hilly country, deforestation, and the consequent soil erosion have led to harmful ecological changes and the need to dredge canals and reservoirs, which contaminates soil (Wimalawansa 2015a).

History of irrigation systems in Sri Lanka:

In the early 20th century, several key publications reported on the major irrigation schemes in the country (Brohier 1934, Brohier 1937, De Silva 1987, Rajapakse 2013), including the historical aspects of the development of ancient irrigation schemes and irrigation heritage in Sri Lanka (Brohier 1934, Brohier 1937, Fernando 1979, Perera 1984). In addition, Arumugam provided constructional details of each major irrigation scheme in the country (Arumugam 1969). The construction of Sri Lankan ancient irrigation systems dates to King Parakrama Bahu the Great (1153–1186 AD) (Nicholas 1954-55), who constructed one of the largest man-made reservoirs in Sri Lanka, the Parakrama Sammudraya in Polonnaruwa, Sri Lanka.

Ancient Sri Lankan irrigation systems are considered a cultural and economic heritage and a model for water and soil conservation ecosystems. Almost all of the reservoirs in Sri Lanka, with the exception of those recently constructed for the generation of hydroelectricity, support agricultural and food production in the country.

The ancient and current reservoir systems of Sri Lanka are a culturally integral part of the country and its agriculture-based economy, and the diversity of the reservoirs is unparalleled elsewhere in the world (Mendis 2002). In addition to being the heart of the supply of irrigation water, the network of small and large reservoirs is an important fishery resource and income for the local communities in Sri Lanka.

The 28 major rivers in the country discharge a total of 36,089 × 106 m3, or 92.5% of the total discharge, to the sea (Manchanayaka 1999). The Mahaweli River is the longest river in Sri Lanka, and its basin covers approximately one sixth of the island (De Silva 1985). Paddy cultivation occupies 12% of the land (800,000 hectares) in Sri Lanka and is highly connected with water management. The role of water in the rice–paddy ecosystem goes beyond providing water to the roots of paddy plants. It is a way of life to villagers.

By controlling the flow of water into terraced fields, the farmers are able to create several important cycles. The cycles of wet and dry phases alter soil pH and include a cycle of aerobic and anaerobic conditions in the soil that regulates the activity of micro-organisms and micro-nutrients, and fosters the growth of nitrogen-fixing cyanobacteria, minimizes growth of weeds, and controls pests (Dharmasena 2009). The contrast between the hydraulic engineering perspective and the ecosystems perspective lies in a fundamental difference in perception of water. To hydraulic engineers, water is inanimate and active, whereas to farmers and agro-scientists, including ecologists, water is animate and passive (Mendis 2002).

TABLE 1
THE MAJOR RESERVOIRS IN SRI LANKA

Reservoir	Associated river	Period (year) of construction (A.D.)
Senanayake Samudraya	Gal Oya	1952
Victoria	Mahaweli Ganga	1984
Randenigala	Mahaweli Ganga	1988
Maduru Oya	Mahaweli Ganga	1983
Kotmale	Mahaweli Ganga	1985
Kantalai	Own catchment	604–614
Minneriya	Amban Ganga	274–301
Parakrama Samudraya	Amban Ganga	1153–1186
Iranamadu	Kanaganayan Aru	1922
Rajangana	Kala Oya	1957
Kalawewa	Dambulla Oya	455–473
Padaviya	Mora Oya	531–551
Nachchaduwa	Malwathu Oya	531–551
Nuwerawewa	Malwathu Oya	114–136
Mahakanadarawa	Maradankadawela Oya	274–301
Bowatenne	Mahaweli Ganga	1976
Giant’s Tank	Malwathu Oya	455–473

Source: Amarasiri, S. L., 2008 (Amarasiri 2008) and http://www.fao.org/docrep/003/t0028e/t0028e03.htm.

Development of Mahaweli River [Ganga] irrigation systems:

Sri Lanka has more than 18,000 reservoirs. Basic information about some of these reservoirs, listed according to their capacity, is provided in Table 1 (Manchanayaka 1999, Amarasiri 2008). Some of the reservoirs are more than 2,000 years old, reflecting Sri Lanka's long history of agricultural irrigation. Table 1 provides information on large reservoirs in Sri Lanka, their feeder rivers, and the period in which they were built.

In 1978, the government of Sri Lanka launched the Accelerated Mahaweli Development Programme, which encompass seven administrative districts; covers approximately one sixth of the island. It facilitated the establishment of several new settlements under the purview of Mahaweli Authority of Sri Lanka, which was established in 1979 by an act of Parliament. It is a multi-purpose development scheme that incorporates some existing reservoirs into the system and also involves the construction of a number of major reservoirs for the generation of hydroelectricity, irrigation, and domestic water consumption.

The Mahaweli River development also consists of two other river basins (i.e., the Maduru Oya and Kala Oya basins; see Figure 1). It is a multi-purpose development scheme that incorporates some existing reservoirs but also involves the construction of a number of major reservoirs for the generation of hydroelectricity and for irrigation (De Silva 1985).

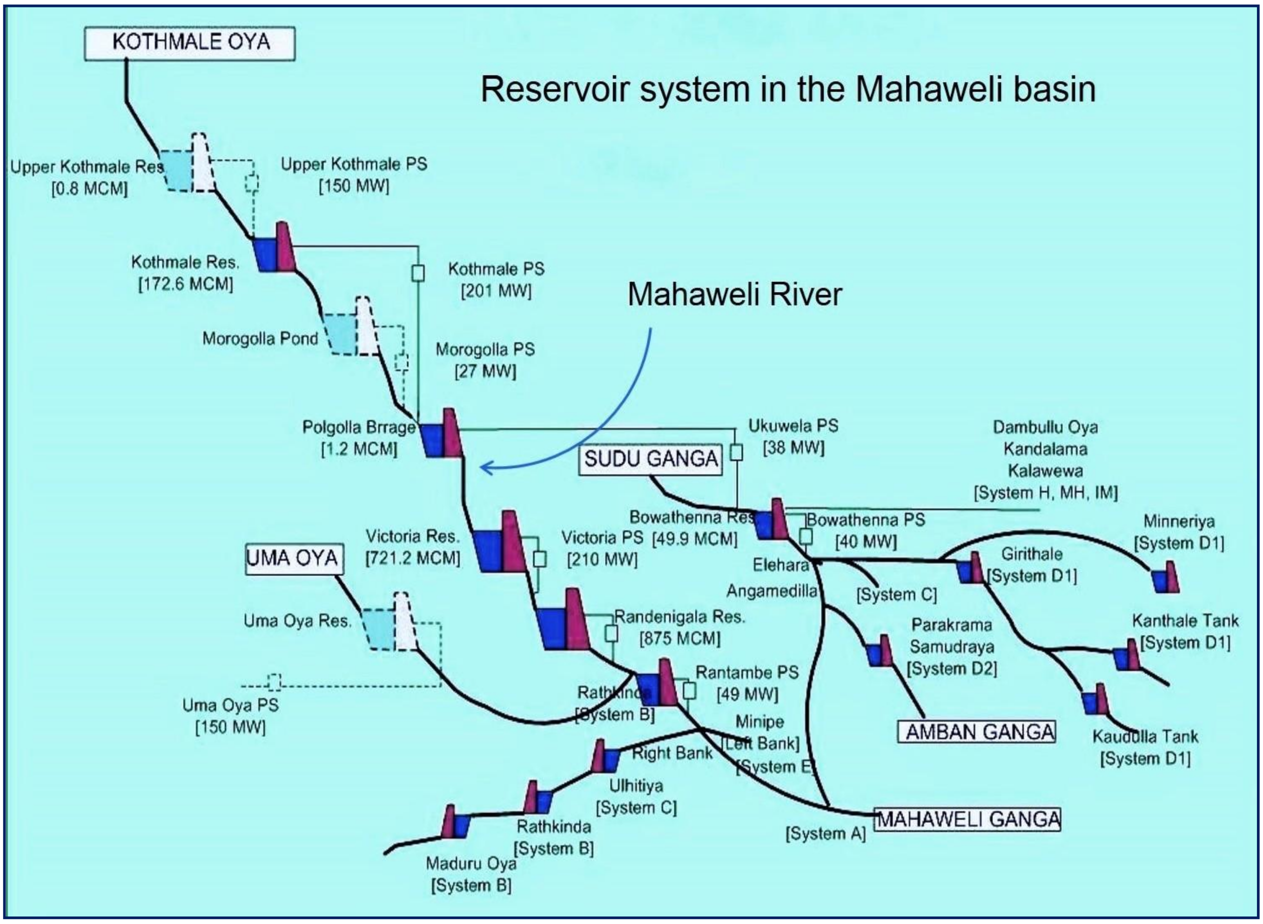

FIGURE 1: CASCADE OF LARGE RESERVOIRS IN SRI LANKA SUPPLIED BY THE MAHAWELI RIVER
[modified from http://www.mahawelicomplex.lk/sys.htm; and (Wimalawansa 2015b)].

II. THE ACCELERATED MAHAWELI DEVELOPMENT PROGRAM

When the Accelerated Mahaweli Development Programme was launched, seven reservoirs were developed simultaneously, with assistance from a number of foreign countries, to provide irrigation and generate hydroelectric power. The programme covered around 25,500 sq. km. of land in the administrative districts of Nuwara Eliya, Kandy, Matale, Badulla, Polonnaruwa, Anuradhapura, and Vavuniya (Manchanayaka 1999).

Under this major programme, a series of reservoirs and hydroelectricity plants were developed. This facilitated the establishment of several new settlements. The dams related to the hydropower generation were constructed and managed by the Sri Lanka Electricity Board. Figure 2 illustrates the reservoirs in the upper Mahaweli region created specifically for the generation of hydroelectricity.

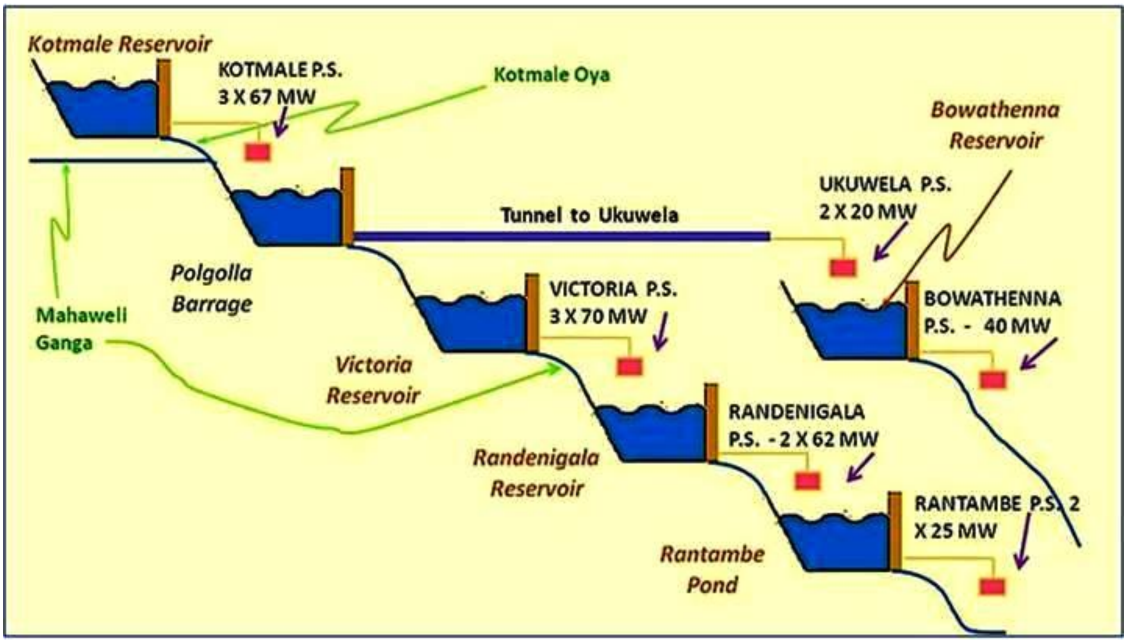

FIGURE 2: CASCADE OF RESERVOIRS CONSTRUCTED IN THE RECENT PAST FOR THE GENERATION OF HYDROELECTRICITY BY TAPPING THE UPPER CATCHMENT REGION OF THE MAHAWELI RIVER IN SRI LANKA
[modified from http://www.mahawelicomplex.lk/sys.htm]

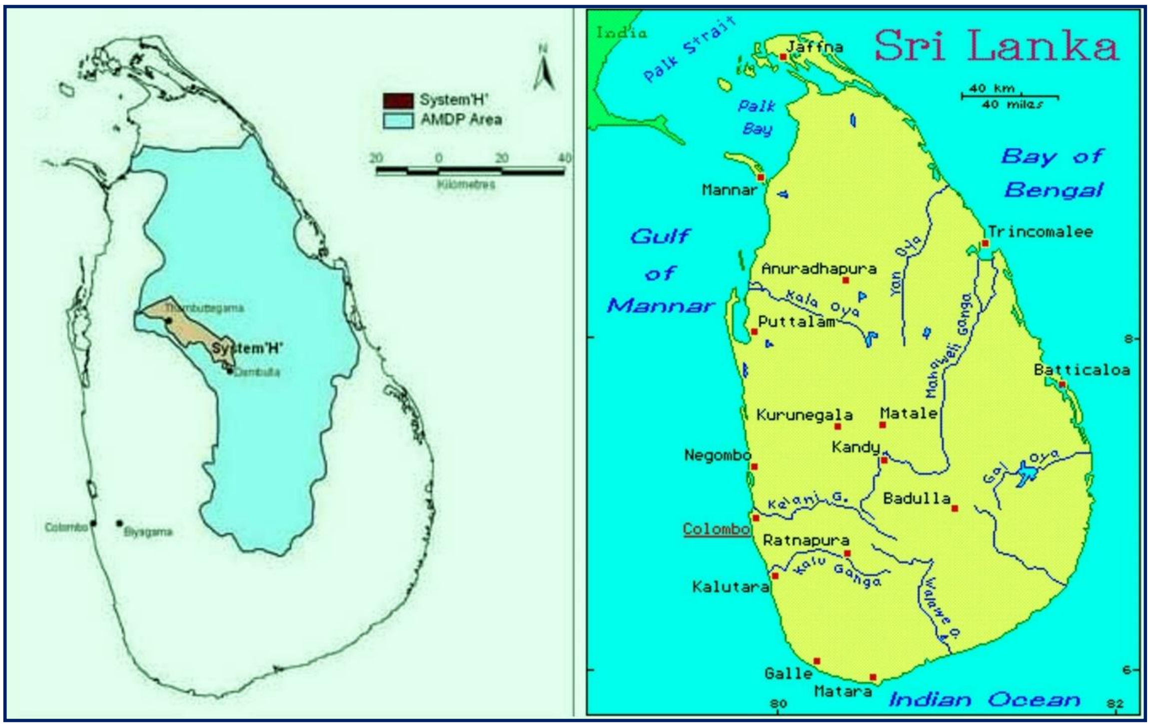

FIGURE 3: THE (A) MAHAWELI ACCELERATED PROGRAMME REGION IN THE NORTH CENTRAL PROVINCE AND (B) LOCATIONS OF THE MAJOR RIVERS IN SRI LANKA (FROM PUBLIC DOMAIN).

Irresponsible farming practices in the hill country and actions of the corporate sector have led to sediments, phosphate, agrochemicals, and other toxins in the water of the Mahaweli River in the NCP region (Bandara, Wijewardena et al. 2010, Bandara, Wijewardena et al. 2011). The extended Mahaweli River basin and the irrigation supplied by it covers most of the areas in the NCP affected by chronic kidney disease of multifactorial origin (CKDmfo), which is also known as CKDu (unknown/uncertain origin) (Figure 3). For the other major rivers in Sri Lanka, except for the River Walawe, water coming from the hill country drains directly to the sea, without being tapped for irrigation or drinking purposes. No water-related major health outbreaks have been observed in these other river basins.

Environmental pollution is escalating in emerging economies such as Sri Lanka and is aggravated by anthropogenic activities, such as new construction, mining, and deforestation (which exacerbate soil erosion) and the irresponsible use of agrochemicals, especially the overuse of phosphate fertiliser. This has led to leaching of large amounts of phosphates from farmlands into streams and the eutrophication of reservoirs, which has become an important environmental issue in the dry zones in Sri Lanka. The following section describes the phosphate eutrophication of reservoirs in the NCP secondary to the overuse of phosphate fertiliser in the hill country, where the Mahaweli River originates.

Mahaweli River and phosphate eutrophication of reservoir water:

Cyanobacterial algae blooms in reservoirs in the NCP are caused by the overuse of phosphate fertilisers by farmers; this environmental damage has its roots in government subsidies for fertiliser. Fertilisers are provided at a subsidised rate mostly to small-scale paddy farmers, but vegetable cultivators, particularly potato farmers in the Hill Country, routinely use amounts of fertiliser that far exceed the Department of Agriculture's recommended levels for cultivation. These fertilisers are used in addition to organic fertilisers, such as cow dung.

Water contamination with plant nutrients, primarily phosphates and nitrates, occurs because of the excessive use of fertiliser (Codd, Morrison et al. 2005, Ibelings and Chorus 2007), but in some instances pollution may occur secondary to human or animal sewage (e.g., pig farming) (Carpenter 2005). The continuous addition of phosphorous to farmlands leads to phosphorous pollution in water bodies (Carpenter 2005, Carpenter 2008, Wimalawansa 2015b). Excess phosphate leaches from the farm soil in fields into streams and ends up in reservoirs, causing cyanobacterial blooms (Metcalf, Hyenstrand et al. 2000, Pereira, Dias et al. 2004, Codd, Morrison et al. 2005, Ibelings and Chorus 2007).

Phosphate fertilisers are made by treating rock phosphates with strong acids, such as concentrated sulphuric acid, to make them water-soluble. Rock phosphate normally contains heavy metals (Wimalawansa 2015b). The process of solubilizing rock phosphate (P) also solubilizes heavy metals.

Over the past three decades, Mahaweli River water has become polluted with various compounds, including phosphate. However, the levels of phosphate in the Mahaweli River or the reservoirs (phosphate levels less than 0.15 mg/L) fed by it do not cause direct harm to humans. Large areas of the country outside of the Mahaweli River water-fed localities, including Polpithigama in Kurunagala district, Mahiyangana in Badulla district, Trincomalee, and Vavuniya, are affected by CKDmfo.

Thus, it is unlikely that water from the Mahaweli River itself is directly related to the CKDmfo in Sri Lanka. Because polluted water causes harm to aquatic lives and the environment, governments and society must take responsibility and initiate actions to protect and preserve the precious watersheds, curb the overuse of agrochemicals, and preserve water quality and the environment for current and future generations. Figure 4 illustrates the regions that are covered by the Mahaweli development programme.

As indicated in Figure 3, the Mahaweli project covers around 25,000 sq km, which is about 38% of the total land area of Sri Lanka. The Mahaweli River has its source in four small streams. Three of these converge to form Kotmale Oya, and the other, Dick Oya, converges to form Mahaweli proper. The project proposed to use 5,800 million cubic meters of water from the annual flow of the Mahaweli River for agricultural development of around 364,000 ha in the dry zone. In 1968, the estimated cost of the entire project was approximately Rs. 6,700 million.

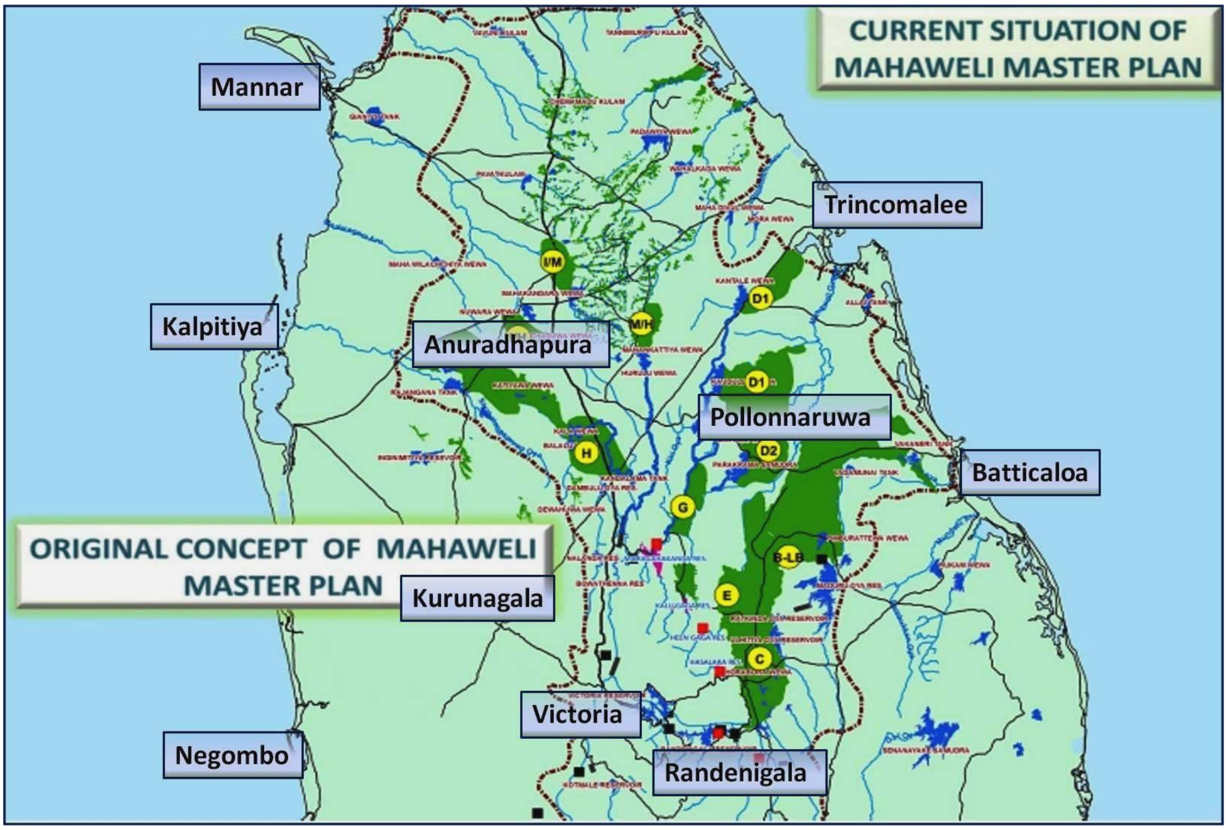

FIGURE 4: AREAS COVERED BY THE ORIGINAL MAHAWELI MASTER PLAN AND THE MODIFIED/CURRENT MAHAWELI SCHEMES IN SRI LANKA. THE PROJECT INCLUDED 11 POWER STATIONS; THE INSTALLED CAPACITY OF THE STATIONS WAS 508 MEGAWATTS, WITH TOTAL POWER OUTPUT OF 2,037 MILLION KW/H/YEAR. THE MAIN RESERVOIRS, RANDENIGALA AND VICTORIA, SUPPLY IRRIGATION WATER FOR THE MAHAWELI RIVER BASIN, AND MORAGAHAKANDA, POLGOLLA, AND KOTMALE FOR THE NCP. THE IRRIGATION AREAS INCLUDED IN THE MASTER PLAN ARE GROUPED INTO 14 IRRIGATION SYSTEMS. EIGHT OF THESE (A, B, C, D-1, D-2, E, F, G) ARE LOCATED IN THE BASIN OF THE MAHAWELI GANGA AND MADURU OYA, WITH A TOTAL IRRIGATED AREA OF 470,000 ACRES. THE REMAINING FIVE SYSTEMS (H, I, M, K, J) ARE IN THE NORTHCENTRAL PART.

[Modified from Nawaratne, N.C.M., 2013; (Navaratne 2013).]

Effects of large-scale settlements and irrigation projects on the environment:

Despite the harmful consequences of development, some planners continue to push for massive structural projects and water-management systems, while giving inadequate attention to clean water and sanitation, the environment, and human needs (Wimalawansa 2014b). Such projects continue to add stress and damage the environment and human health (UNDP-HDR 2013).

When rainfall is unpredictable, river flow patterns change in uncertain ways; flood and/or prolonged droughts become frequent; vegetation, crops, and all aquatic lives are affected; and additional electricity and expensive infrastructure are needed for treating and distributing clean water. Many recent examples suggest that planners continue to use outdated rainfall and climatic data to plan mega projects, disregarding the human and environmental consequences (Wilson 2010, Fischhendler, Cohen-Blankshtain et al. 2013).

The burning of fossil fuels and at times petrochemicals contaminates the environment, particularly via agricultural equipment and vehicles, which affect local water supplies (Wimalawansa 2015). Such water contamination has made industrial nations more dependent on increasingly expensive energy and water purification plants, both of which drain precious foreign exchange. Building new power plants that utilise coal or fossil fuel would further add to the environmental pollution and exacerbate the occurrence of non-communicable diseases (Noyes, McElwee et al. 2009, Castleden, Shearman et al. 2011).

A fair balance is needed between the pursuit of happiness and economic advances, and the planning and implementation of future population needs and settlements. At each stage of development, planners must include provisions for protecting the environment, with overall human well-being and public health issues considered as priorities (Wimalawansa 2015).

Poor water quality affects health of humans in the region:

Because of large-scale deforestation and fast-flowing modern irrigation systems, dredging has become a routine part of the maintenance of canals and reservoirs in Sri Lanka. Dredging is expensive, disturbs the ecology, and contaminates surface water with unwanted substances such as heavy meals that have been settled on the bottom of canals and reservoirs for hundreds of years. These subtle water contaminations may not be readily detected by random or even stratified water sampling and testing (Chandrajith, Nanayakkara et al. 2011a, WHO-CKDu-Final Report: Jayathilaka N 2013) unless the timing of the sampling is done with proximity to the dredging.

When applied to soils, urea yield ammonium, which undergoes nitrification to form nitrates in alkaline soils. Exposure to excessive amounts of nitrates, especially in children could cause methemoglobinaemia (blue baby syndrome) (Speijers 2011). High nitrate content in water has been reported in waters in Kalpitiya and Jaffna regions, but not in the NCP in Sri Lanka.

III. CHRONIC KIDNEY DISEASE OF MULTIFACTORIAL ORIGIN (CKDMFO)

Since the mid-1990s, a major, non-infectious epidemic of chronic kidney disease of multifactorial origin (CKDmfo) (Wimalawansa 2014) has emerged in Sri Lanka for which no cause has been identified (Wimalawansa 2013b). This disease has killed thousands of people; it has killed more than the 46,000 people thought to have died in Sri Lanka during the 2004 tsunami (Wimalawansa 2013).

The disease predominantly affects agricultural regions, flat lands in the dry zone areas of the country, where more than a third of vegetable and rice farming is done (Wimalawansa 2014a, Wimalawansa 2014c). Many investigators have suggested contamination of water in this region as a probable factor in the development of the epidemic (Chandrajith, Nanayakkara et al. 2011a, Nanayakkara, Senevirathna et al. 2014, Redmon, Elledge et al. 2014, Wanigasuriya 2014).

Approximately 7% of the households in the NCP region have a pipe-borne water supply, and more than 90% of the affected families consume water from shallow wells, tube wells, or streams (Wimalawansa 2015). Many investigators have suggested contamination of surface water in this region as a probable factor in the development of the epidemic (Chandrajith, Nanayakkara et al. 2011a, Senevirathna, Abeysekera et al. 2012).

One example is the increasing incidence of non-communicable diseases in the region, in part because of surface water and groundwater contamination attributed to the excessive use of plant nutrients (phosphate, nitrates), organic matter, and excessive agrochemicals applied in farmlands that are local and those hundreds of miles upstream on the Mahaweli River (Paez-Osuna 2001, Krauss, Gallenberger et al. 2011, Nair 2011, Sarkar, Patil et al. 2011). The disease is predominantly affecting those residing in the lowland regions (below 270-meter elevation from the sea level) with an annual rainfall of less than 200 cm/year (average annual rainfall in the dry zone is around 150 cm/year in Sri Lanka, most occurring within a 3-month period).

Most of the NCP region has a crystalline complex of rocks with limited shallow groundwater and surface aquifers (Panabokke 2003, Panabokke 2007). These surface water sources are constantly fed by the seepage from cascade systems of small and large reservoirs and streams located at higher elevations (Panabokke 1959, Panabokke 2003, Panabokke 2007). Most rural communities in this region use surface water from shallow wells as the main drinking water source together with tube wells (Chandrajith, Nanayakkara et al. 2011a). The concentration of agrochemicals, heavy metals, and other contaminants in surface water (thus shallow wells) is known to vary temporally and spatially in the region and can spread though the surface water aquifer (Wimalawansa 2015).

Current issues in the NCP:

Various components of the CKDmfo in Sri Lanka have been discussed in recent years (WHO-CKDu-Final Report: Jayathilaka N 2013 , Wimalawansa 2014, Wimalawansa 2015). Recent articles have focused on the excessive use of chemical fertiliser that contaminates water bodies and reservoirs (Chandrajith, Dissanayake et al. 2005, Chen, Krage et al. 2008, Chandrajith, Nanayakkara et al. 2011a, Dharma-Wardana, Amarasiri et al. 2014), exposure of farmers to organophosphate pesticides (Wimalawansa 2014), and pollution of drinking sources, including well water (Athuraliya, Abeysekera et al. 2011, Wimalawansa 2014a, Wimalawansa 2015b), with fluoride, heavy metals, and other agents (Bandara, Senevirathna et al. 2008, Wanigasuriya, Peiris-John et al. 2011, WHO-CKDu-Final Report: Jayathilaka N 2013). Understanding the contamination of well water is relevant in the NCP because approximately 70% of NCP inhabitants drink from shallow wells (Chandrajith, Nanayakkara et al. 2011a) (Figure 1), and more than 85% of those with the disease consumed water from such wells (Wimalawansa 2015).

The researchers argued that the higher cadmium levels in the local reservoir water reported by a few are secondary to higher soil cadmium levels in the NCP region, coming from the waters of the Mahaweli River (Bandara, Wijewardena et al. 2010). Considering this, they suggested that the cascade irrigation system that is fed by the Mahaweli River leads to an increase in dietary cadmium intake through food, thus contributing to CKDmfo (Bandara, Senevirathna et al. 2008, Bandara, Wijewardena et al. 2010). However, this has not been proven.

History may be repeating:

Centuries ago, the NCP region was home to a successful agricultural-based society. It had thousands of man-made irrigations tanks (reservoirs) to support human needs, including agriculture. However, over a period of about two centuries, the region was abandoned by the ruling kings and inhabitants, who moved from one region to another. For example, after abandoning Anuradhapura, people moved to Pollonnaruwa, then to Kurunegala, Dambadeniya, and Yapahuwa (Rajapakse 2013, Wimalawansa 2015). Historians believe that such drastic migration of people and moving of the capital cities from region to region was to protect kings from foreign invaders.

It has been documented that one of the key strategies used by the south Indian invaders in Sri Lanka was to destroy the vast ancient irrigation systems in the NCP. The repeated destruction of large reservoirs devastated the livelihood of local people and their agriculture and food supply. Because most of the land in the NCP region is flat, failure to repair these massive man-made dams in a timely manner led to stagnation of water across the affected region (Wimalawansa 2015). This led to a pandemic of malaria in the region. In the absence of mosquito control programmes and anti-malarial medications during that era, peasants and rulers had no choice but to flee from region to region, first within the NCP, and then to central and southern regions of the country. Thousands of cascade ancient tanks and irrigation systems were abandoned and overgrown with jungle.

What is important is that all of these regions (kingdoms) abandoned at that time are now affected with CKDmfo. During the mid-20th century, people were incentivised to move to this region, but the colonisation was carried out with little attention to human needs. The regions are now the epicentre of CKDmfo (Wimalawansa 2015). These historic facts raise a number of questions, including what is the real reason for the abandonment of this region centuries ago. It is not known if the migration was caused by a pandemic of malaria or if the region was badly affected with a different serious disease similar to CKDmfo or something else. It is not clear whether this is a sheer coincidence or history is repeating.

IV. STEPS TO BE TAKEN TO PREVENT THE SPREAD OF THIS DISEASE

Provision of and affordable access to clean water are essential to keeping a nation healthy. Lack of clean water and safe sanitation increases the incidences of communicable and non-communicable disease. In Southeast Asian countries, 8.5% of deaths are caused by diarrhoea; 88% of those deaths result from poor sanitation and dirty water (WHO and UNICEF) (WHO/UNICEF 2010). While basic scientists solve most of the health issues, health and engineering professionals implement preventative methods (Jayasinghe 2012).

Various aspects of detailed recommendations for the prevention and eradication of this deadly disease from Sri Lanka were presented in three recent reviews on this subject (Wimalawansa 2014, Wimalawansa 2015, Wimalawansa 2015). Based on current knowledge, we recommend implementation of additional broader steps to prevent CKDmfo:

1. Collect relevant data from the Divisional Secretariat/Grama Niladhari divisions where CKDmfo is prevalent. This could be accomplished with the Grama Niladharis, Samurdhi, and Development Assistants in Divisional Secretariats in collaboration with the Ministry of Health offices.

2. Conduct awareness programmes on water quality and its effect on CKDmfo in schools in the affected provinces and include nutrition, nature studies, and environmental protection in the school curricula, in collaboration with the Department of Education.

3. The inequalities in the supply of drinking water should be overcome by implementing a programme to distribute safe water to all in the affected and surrounding areas. Install reverse osmosis (RO) plants in all affected and surrounding villages and use rainwater collections to supplement freshwater. In addition to supplying clean water, authorities in provincial governments also must be accountable for monitoring drinking water quality.
4. Clean drinking water and safe sanitary facilities are basic human rights and should be provided as a priority not only for the NCP but for the entire country.
5. Encourage farmers to use compost and other organic methods of farming, while reducing the reliance on inorganic fertilisers through gradually reducing the fertiliser subsidy.
6. Enact clean water and clean air acts for Sri Lanka and enforce strict environmental protection laws in the country.
7. Conduct a prospective, multi-disciplinary, comprehensive, long-term research study across the entire region to identify the causal factor(s) of CKDmfo and its genesis.
8. Implement a broader educational programme on the responsible use of agrochemicals, the use of protective gear during the handling of chemicals, protecting the environment, and consuming a balanced diet.
9. Initiate a web-based, real-time, GIS-guided, web- or cloud-based surveillance programme, with interactive maps, across the entire region.
10. Establish a fund to assist the patients and their families to procure the necessary services, medicine, and travel to hospitals for dialysis and to support the education of children whose families are affected by the disease.
11. Establish a single, new legal authority for the prevention and eradication of CKDmfo; the entity should be a government-funded, fully independent from ministries. CKD-Eradication Authority must have the authority to plan, coordinate, raise funds, and implement all CKDmfo programmes in the country.

V. CONCLUSION

Since the mid-1990s, a major, non-infectious epidemic of chronic kidney disease of multifactorial origin (CKDmfo) has been reported from a number of provinces in Sri Lanka. The disease predominantly affects agricultural regions in the dry zone. Most of the affected families consume water from shallow wells, tube wells, or streams, which get seepage surface waters from the Mahaweli River, the longest river in the country.

A number of reservoirs supply irrigated water to nearly 365,000 hectares in the dry zone via the Mahaweli Development Programme. Over the past three decades, Mahaweli River water has become polluted with various compounds, including phosphates, which coming from the excessive use of phosphate fertilisers in the hill country (Wimalawansa 2015). It is speculated that drinking water from the Mahaweli River is contaminated with various pollutants, which may contribute to the development of CKDmfo. However, the levels of phosphate (less than 0.15 mg/L) in the Mahaweli River and the reservoirs fed by it can cause ecological imbalance but are not high enough to cause direct harm to human health.

There are large areas in the country affected with CKDmfo outside the Mahaweli water-fed localities, including Polpithigama in Kurunagala district, Mahiyangana in Badulla district, Trincomalee, and Vavuniya. In addition, there is no scientific evidence supporting that consuming Mahaweli River water causes CKDmfo. Thus, despite the high phosphate levels and polluted water, it is unlikely that water from the Mahaweli River itself is directly related to CKDmfo in Sri Lanka.

Nevertheless, excess phosphates in the Mahaweli River may be causing the algae blooms and cyanobacterial growth in NCP reservoirs. Because polluted water causes harm to aquatic lives and the ecology, governments and society must take responsibility and initiate actions to protect and preserve the precious watersheds, curb the overuse of agrochemicals, and preserve water quality and the environment for current and future generations.

CKDmfo is affecting the social and economic life of a large number of people in the country. The families of those who are affected by this disease are in a desperate situation. It is necessary that the basic recommendations indicated here are implemented as early as possible as the first step toward preventing this deadly disease. It is also essential to identify sustainable solutions to the environmental degradation and consequent socio-economic and medical problems in the NCP and entire country.

Conflicts of interest: There is no funding associated with this study, and the authors have no conflicts of interest.

REFERENCES

[1] Amarasiri, S. L. (2008). Caring for Water. Sri Lanka Nature Forum. Nugegoda, Sri Lanka: 161.

[2] Anonymous (1979). "Environmental geochemistry and health." Philos Trans R Soc Lond B Biol Sci 288(1026): 1-216.

[3] Arumugam, S. (1969). Water resources of Ceylon. W. R. B. Publication. Colombo, Sri Lanka, Governmetn of Sri Lanka: 407.

[4] Athuraliya, N. T., T. D. Abeysekera, P. H. Amerasinghe, R. Kumarasiri, P. Bandara, U. Karunaratne, A. H. Milton and A. L. Jones (2011). "Uncertain etiologies of proteinuric-chronic kidney disease in rural Sri Lanka." Kidney Int 80(11): 1212-1221.

[5] Bandara, J. M., D. M. Senevirathna, D. M. Dasanayake, V. Herath, J. M. Bandara, T. Abeysekara and K. H. Rajapaksha (2008). "Chronic renal failure among farm families in cascade irrigation systems in Sri Lanka associated with elevated dietary cadmium levels in rice and freshwater fish (Tilapia)." Environ Geochem Health 30(5): 465-478.

[6] Bandara, J. M., H. V. Wijewardena, Y. M. Bandara, R. G. Jayasooriya and H. Rajapaksha (2011). "Pollution of River Mahaweli and farmlands under irrigation by cadmium from agricultural inputs leading to a chronic renal failure epidemic among farmers in NCP, Sri Lanka." Environ Geochem Health 33(5): 439-453.

[7] Bandara, J. M., H. V. Wijewardena, J. Liyanege, M. A. Upul and J. M. Bandara (2010). "Chronic renal failure in Sri Lanka caused by elevated dietary cadmium: Trojan horse of the green revolution." Toxicol Lett 198(1): 33-39.

[8] Baumgarten, A., E. Steinnes and W. Friesl-Hanl (2009). "This special issue of "Environmental Geochemistry and Health," compiles the output of the Symposium "Soils and their implication on Health." Preface." Environ Geochem Health 31(5): 521-522.

[9] Brohier, R. (1934). Ancient irrigation works in Ceylon. Ceylon Government Press.

[10] Brohier, R. (1937). Ancient irrigation works in Ceylon. Colombo, Ceylon Government Press, Brohier, R.L., 1937 Ancient irrigation works in Ceylon. Vol. II. Colombo, Ceylon Government Press, 43p.

[11] Burkart, M. R. (2007). "Diffuse pollution from intensive agriculture: sustainability, challenges, and opportunities." Water Sci Technol 55(3): 17-23.

[12] Carpenter, S. R. (2005). "Eutrophication of aquatic ecosystems: biostability and soil phosphorus." Proc Natl Acad Sci U S A 102(29): 10002-10005.

[13] Carpenter, S. R. (2008). "Phosphorus control is critical to mitigating eutrophication." Proc Natl Acad Sci U S A 105(32): 11039-11040.

[14] Castleden, W. M., D. Shearman, G. Crisp and P. Finch (2011). "The mining and burning of coal: effects on health and the environment." Med J Aust 195(6): 333-335.

[15] Chandrajith, R., C. B. Dissanayake and H. J. Tobschall (2005). "The abundances of rarer trace elements in paddy (rice) soils of Sri Lanka." Chemosphere 58(10): 1415-1420.

[16] Chandrajith, R., S. Nanayakkara, K. Itai, T. N. Aturaliya, C. B. Dissanayake, T. Abeysekera, K. Harada, T. Watanabe and A. Koizumi (2011a). "Chronic kidney diseases of uncertain etiology (CKDue) in Sri Lanka: geographic distribution and environmental implications." Environ Geochem Health 33(3): 267-278.

[17] Chen, W., N. Krage, L. Wu, G. Pan, M. Khosrivafard and A. C. Chang (2008). "Arsenic, cadmium, and lead in California cropland soils: role of phosphate and micronutrient fertilizers." J Environ Qual 37(2): 689-695.

[18] Codd, G. A., L. F. Morrison and J. S. Metcalf (2005). "Cyanobacterial toxins: risk management for health protection." Toxicol Appl Pharmacol 203(3): 264-272.

[19] De Silva, C. R. (1987). Ancient Ceylon. New Delhi Vikas Publishing House.

[20] De Silva, S. S. (1985). "The Mahaweli Basin." FAO Fish.Tech.Pap. 265: 91–165.

[21] Dharma-Wardana, M. W., S. L. Amarasiri, N. Dharmawardene and C. R. Panabokke (2014). "Chronic kidney disease of unknown aetiology and ground-water ionicity: study based on Sri Lanka." Environ Geochem Health.

[22] Dharmagunawardhane HA, D., CB (1993). "Fluoride problemsc in Sri Lanka." Environmental Management and Health 4(2): 9-16.

[23] Dharmasena, P. B. (2009). Towards efficient utilization of surface and ground water resources in food production under small tank system, Proceedings of the workshop on Food security and small tank system in Sri Lanka. NSF Colombo, National Scienec Foundation.

[24] Fernando, A. (1979). "Major ancient irrigation works of Sri Lanka." J. R. Asiat. Sco. (Sri Lanka branch) 22: 1–24.

[25] Fischhendler, I., G. Cohen-Blankshtain, Y. Shuali and M. Boykoff (2013). "Communicating mega-projects in the face of uncertainties: Israeli mass media treatment of the Dead Sea Water Canal." Public Underst Sci.

[26] Guruge, K. S. and S. Tanabe (2001). "Contamination by persistent organochlorines and butyltin compounds in the west coast of Sri Lanka." Mar Pollut Bull 42(3): 179-186.

[27] Ibelings, B. W. and I. Chorus (2007). "Accumulation of cyanobacterial toxins in freshwater "seafood" and its consequences for public health: a review." Environ Pollut 150(1): 177-192.

[28] Jayasinghe, S. (2012). "Catastrophic neglect of basic sciences in medicine." Lancet 379(9833): 2239-2240.

[29] Krauss, J., I. Gallenberger and I. Steffan-Dewenter (2011). "Decreased functional diversity and biological pest control in conventional compared to organic crop fields." PLoS One 6(5): e19502.

[30] Manchanayaka, P., Madduma Bandara, C.M (1999). Water Resources of Sri Lanka. Colombo, Sri Lanka, National Science Foundation

[31] Mendis, D. L. O. (2002). Water Heritage of Sri Lanka Colombo, Sri Lanka pugwash Group

[32] Mertens, T. E., M. A. Fernando, T. F. Marshall, B. R. Kirkwood, S. Cairncross and A. Radalowicz (1990). "Determinants of water quality, availability and use in Kurunegala, Sri Lanka." Trop Med Parasitol 41(1): 89-97.

[33] Metcalf, J. S., P. Hyenstrand, K. A. Beattie and G. A. Codd (2000). "Effects of physicochemical variables and cyanobacterial extracts on the immunoassay of microcystin-LR by two ELISA kits." J Appl Microbiol 89(3): 532-538.

[34] Nair, P. K. (2011). "Agroforestry systems and environmental quality: introduction." J Environ Qual 40(3): 784-790.

[35] Nanayakkara, S., S. T. Senevirathna, T. Abeysekera, R. Chandrajith, N. Ratnatunga, E. D. Gunarathne, J. Yan, T. Hitomi, E. Muso, T. Komiya, K. H. Harada, W. Liu, H. Kobayashi, H. Okuda, H. Sawatari, F. Matsuda, R. Yamada, T. Watanabe, H. Miyataka, S. Himeno and A. Koizumi (2014). "An integrative study of the genetic, social and environmental determinants of chronic kidney disease characterized by tubulointerstitial damages in the North Central Region of Sri Lanka." J Occup Health 56(1): 28-38.

[36] Navaratne, N. C. M. (2013). Overview of Mahaweli programme to enhance the water security. N. o. A. R. B. O. (NARBO). Colombo, Sri Lanka, Mahaweli Authority of Sri Lanka.

[37] Nicholas, C. W. (1954-55). "The irrigation works of King Parakramabahu." C.H.J. : 52-68.

[38] Noyes, P. D., M. K. McElwee, H. D. Miller, B. W. Clark, L. A. Van Tiem, K. C. Walcott, K. N. Erwin and E. D. Levin (2009). "The toxicology of climate change: environmental contaminants in a warming world." Environ Int 35(6): 971-986.

[39] Paez-Osuna, F. (2001). "The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives." Environ Manage 28(1): 131-140.

[40] Panabokke, C. R. (1959). Soil science 87: 67–74.

[41] Panabokke, C. R. (2000). The nature & properties of small tank system of the dry zone and their sustainable production thresholds. Proceedings of the workshop on Food security and small tank system in Sri Lanka, Colombo, Sri Lanka, NSF, Colombo.

[42] Panabokke, C. R. (2003). "Nature of occurrence and sustainable use of groundwater resources for agriculture in the North Central, North Western and North Eastern regions in Sri Lanka." Tropical Agricultural Research and Extension 6: 8-13.

[43] Panabokke, C. R. (2007). Groundwater conditions in Sri Lanka. Colombo, Sri Lanka, National Science Foundation of Sri Lanka.

[44] Pereira, P., E. Dias, S. Franca, E. Pereira, M. Carolino and V. Vasconcelos (2004). "Accumulation and depuration of cyanobacterial paralytic shellfish toxins by the freshwater mussel Anodonta cygnea." Aquat Toxicol 68(4): 339-350.

[45] Perera, N. P. (1984). Natural resources, settlements and land use. In Ecology and biogeography in Sri Lanka The Hague, The Netherlands, , W.Junk Publishers.

[46] Rajapakse, R. (2013). Concise Mahavamsa; History of Buddhism In Sri Lanka: Simplified Mahavamsa & Culavamsa; http://mahavamsa.org/mahavamsa/simplified-version. Sri Lanka.

[47] Redmon, J. H., M. F. Elledge, D. S. Womack, R. Wickremashinghe, K. P. Wanigasuriya, R. J. Peiris-John, J. Lunyera, K. Smith, J. H. Raymer and K. E. Levine (2014). "Additional perspectives on chronic kidney disease of unknown aetiology (CKDu) in Sri Lanka--lessons learned from the WHO CKDu population prevalence study." BMC Nephrol 15: 125.

[48] Sarkar, A., S. Patil, L. B. Hugar and G. vanLoon (2011). "Sustainability of current agriculture practices, community perception, and implications for ecosystem health: an Indian study." Ecohealth 8(4): 418-431.

[49] Senevirathna, L., T. Abeysekera, S. Nanayakkara, R. Chandrajith, N. Ratnatunga, K. H. Harada, T. Hitomi, T. Komiya, E. Muso and A. Koizumi (2012). "Risk factors associated with disease progression and mortality in chronic kidney disease of uncertain etiology: a cohort study in Medawachchiya, Sri Lanka." Environ Health Prev Med 17(3): 191-198.

[50] Speijers, G. J. A., Fawell, J.K. (2011). "Nitrate and nitrite in drinking-water [Background document for development of WHO guidelines for drinking-water quality], WHO/SDE/WSH/07.01/16/Rev/1." WHO/SDE/WSH/07.01/16/Rev/1.

[51] UNDP-HDR (2013). Beyond scarcity: Power, poverty and the global water crisis. Human Development Report-2013.

[52] Wanigasuriya, K. (2014). "Update on uncertain etiology of chronic kidney disease in Sri Lanka's north-central dry zone." MEDICC Rev 16(2): 61-65.

[53] Wanigasuriya, K. P., R. J. Peiris-John and R. Wickremasinghe (2011). "Chronic kidney disease of unknown aetiology in Sri Lanka: is cadmium a likely cause?" BMC Nephrol 12: 32.

[54] WHO-CKDu-Final Report: Jayathilaka N, M. P., Mendis S, Mehta FR, Dissanayake LJ, Janakan N. (2013). "WHO Sri Lanka CKDu report: Chronic kidney disease of unknown aetiology (CKDu): a new threat to health [http://dh-web.org/place.names/posts/index.html#ckdu] http://www.lankaweb.com/news/items12/WHO%20final%20report%20on%20CKDu%20SL.pdf." from http://dh-web.org/place.names/posts/index.html#ckdu.

[55] WHO/UNICEF. (2010). "Diarrhoea: why children are still dying and what can be done, http://www.who.int/maternal_child_adolescent/documents/9789241598415/en/index.html." September, 2015, from http://www.who.int/maternal_child_adolescent/documents/9789241598415/en/index.html.

[56] Wilson, M. (2010). "Vertical landscraping, a big regionalism for Dubai." Int J Urban Reg Res 34(4): 925-940.

[57] Wimalawansa, S., Wimalawansa, S.J (2014c). "Water pollution associated occupational diseases: Special emphasis on chronic kidney disease of multifactorial origin (CKDmfo/CKDu)." Jacob Journal of Environmental Sci. (submitted).

[58] Wimalawansa, S., Wimalawansa, SJ (2015b). "Protection of watersheds and control of fertilisers to prevent phosphate eutrophication of reservoirs in Sri Lanka." International Journal of Research in Environmental Science 1(2s): 1-17.

[59] Wimalawansa, S. A., Wimalawansa, S.J (2014b). "Impact of changing agricultural practices on human health: Chronic kidney disease of multi-factorial origin in Sri Lanka." Wudpecker Journal of Agricultural Research 3(5): 110-124.

[60] Wimalawansa, S. A., Wimalawansa, S.J (2015a). "Clean water, healthy environment, and preservation of watersheds: Correct, enforceable policies are essential." Jacobs Journal of Hydrology 1(1): 3-15.

[61] Wimalawansa, S. A., Wimalawansa, S.J. (2014a). "Agrochemical-Related Environmental Pollution: Effects on Human Health. ." Global Journal of Biology, Agriculture and Health Sciences 3(3): 72-83.

[62] Wimalawansa, S. J. (2013). Chronic kidney disease in Rajarata, worse than tsunami: [http://www.sundayobserver.lk/2013/11/24/fea06.asp]. Sunday Observer. Colombo, Sunday Times.

[63] Wimalawansa, S. J. (2013b). Water pollution-associated ill health: Special emphasis on chronic kidney disease in Sri Lanka: https://wimalawansa.org/sites/all/files/Olcott_Oration_2013_b.pdf; http://www.anandacollege.net/document/14011809Olcott%20Oration%20Book.pdf Olcott Memorial Oration. Colombo, Sri Lanka, Ananda Collage: 1-12.

[64] Wimalawansa, S. J. (2014). "Escalating Chronic Kidney Diseases in Sri Lanka: Causes, Solutions and recommendations." Environmental Health and Preventive Medicine 19(6): 375-394.

[65] Wimalawansa, S. J. (2015). "Agrochemicals and chronic kidney disease of multifactorial origin: Environmentally induced occupational exposure disease." Int J Nephrol Kidney Failure 1(2): 1-9.

[66] Wimalawansa, S. J. (2015). "Escalating chronic kidney diseases of multi-factorial origin (CKD-mfo) in Sri Lanka: causes, solutions, and recommendations-update and responses." Environ Health Prev Med 20(2): 152-157.

[67] Wimalawansa, S. J. (2015). "The role of ions, heavy metals, fluoride, and agrochemicals: Critical evaluation of potential aetiological factors of chronic kidney disease of multifactorial origin (CKDmfo/CKDu) and recommendations for its eradication." Environmental Geochemistry and Health DOI: 10.1007/s10653-015-9739-3; published online.

[68] Wimalawansa, S. J., Wimalawansa, S.A. (2015). "Chronic kidney disease of multifactorial origin (CKDmfo) in Sri Lanka: Escalating incidence and long-term survival estimates." J. Nephrology & Urology Research (in press).