International Journal of Research in Environmental Science (IJRES)
Volume 1, Issue 2, Jul-Sep 2015, PP 1-18
www.arcjournals.org

Protection of Watersheds, and Control and Responsible use of Fertiliser to Prevent Phosphate Eutrophication of Reservoirs

Shehani A. Wimalawansa[1] and Sunil J. Wimalawansa[2] *

[1]School of Business, Rutgers University, New Brunswick, N.J., U.S.A
[2]Cardio Metabolic Institute, Somerset, N.J., U.S.A
**suniljw@hotmail.com*

Abstract: *Because of its unique chemical structure, water dissolves almost any substance and thus is easily polluted. Environmental pollution continues to escalate in emerging economies such as in Sri Lanka. This is aggravated by anthropogenic activities, including deforestation, soil erosion, and irresponsible use of agrochemicals, and overuse of phosphate fertiliser. The latter has led to leaching of large amounts of phosphate from vegetable farmlands in hill countries into streams, and eutrophication of irrigated reservoirs in dry zone. This has become an important environmental issue in low elevations in the dry-zonal areas in Sri Lanka. This unhindered environmental damage is mainly caused by the reckless use of fertiliser secondary to large governmental subsidies, which encourage farmers to overuse fertiliser. Since the excess phosphate fertiliser added would not retain in the soil, these leach out into the waterways ending up in waterbodies, including reservoirs. Excess phosphate in water facilitates cyanobacterial algae blooms, which have significant adverse effects on freshwater marine life and perhaps, in people, Governments and society must initiate actions to protect and preserve the precious watersheds, curb the overuse of agrochemicals, and preserve watesheds and the environment for current and future generations.*

Keywords: *Agrochemicals, Agriculture, Contamination, Human diseases, Nutrients, Premature death, Prevention, Policies, Politics, Pollution, Sri Lanka, Water*

1. Introduction

As a result of not taking proper actions by individuals, corporations, states, and local communities, water and environmental pollution have become the norm in many countries. Among the causes of water pollution and related environmental health hazards includes, decrease in forested cover, increased cultivation of annual crops on erosion-prone lands mostly driven by concern for profits, excessive use of fertiliser, indiscriminate and irresponsible use of pesticides, and the unsafe disposal of chemicals and materials, and containers containing heavy metals and other toxins.

These anthropogenic actions adversely affect all living beings, the biodiversity of fauna and flora [1], the biophysical environment [2], and food sources [3]. In agricultural regions, one of the common sources of water pollution is the runoff from inorganic and organic fertilisers, as these have been over used. Environmental and agricultural authorities need to understand how the different ecosystems function in different watersheds at different elevations, and how anthropogenic activities and other externalities affecting these ecosystems.

The term agrochemicals refers to a broad range of compounds, including fertilisers, pesticides (insecticides, herbicides, and fungicides), as well as chemical growth-promoting agents, hormones, and animal manure. The last three items are key contaminants of water and the food chain in many industrialised countries. Indiscriminate use of agrochemicals leads to major environmental threats to soil and surface water. Many farmers apply fertiliser more frequently than necessary in higher doses than recommended by their Departments of Agriculture (DoA) and the manufacturers.

Protection of the watersheds is extremely important not only for protecting aquatic life but also for providing clean freshwater for human and animal consumption. Laws and actions taken to protect watersheds must include attention to hydrological, chemical, and biological factors. In addition, it is necessary to integrate this type of defence with protection of the soil-water environment and restoration of aquatic systems [4]. Environmental protection agencies need to implement all aspects of pertinent laws and regulations, including those related to the functioning of ecosystems, ecological health indicators, assessment and mitigation of future risks, and assessment and monitoring of the health of rivers, lakes, estuaries, coasts, and wetlands [4]. This review addresses the effects of phosphate [phosphorus] eutrophication of water and the effects of the overuse of fertiliser on marine life in particualar. Review focuses on issues affecting Sri Lanka as an example. However, the current state of affairs and the lessons learned are applicable to most other countries and agricultural societies; especially the protection of watersheds as a modes of preventing human diseases.

2. Phosphate and Aquatic Life

Phosphates [PO4 3-] are derivatives of the element phosphorus (P) and exist in three forms: orthophosphate, metaphosphate, and organically bound phosphate. Each compound contains phosphorus in a different chemical formula and is produced by natural processes. Ambient phosphates are not toxic to people or animals unless they are exposed in high levels. Digestive problems can occur from ingestion of high levels of phosphate containing water or food. In freshwater aquatic systems, phosphorus is in the form of orthophosphate, which is a limiting aquatic plant growth. Thus, if all available phosphorus is utilised, no matter how much nitrogen is available in the water or soil, plant growth will cease.

The two largest sources of excess phosphate leaching into water are disproportionate use of phosphate-containing fertiliser and manure from large-scale intensive livestock farming. While the former is applicable to developing countries and emerging agriculture-based economies like Sri Lanka, the latter is a major issue in many European countries today. There are different kinds of phosphates present in water. However, the total phosphate phosphorous level is what is needed to measure as a water quality indece, with reference to its effects on marine life. The natural background level of total phosphorus in freshwater are less than 0.03 mg/L, whereas the natural orthophosphate levels range from 0.005 to 0.05 mg/L [5]. Table 1 illustrates the standard way of categorizing water samples for phosphate content:

Table 1. *Categorizing water samples for phosphate content*

Grade	* Phosphate content in water	Interpretation
1	0.01–0.03 mg/L	Expected levels in uncontaminated water bodies
2	0.025–0.1 mg/L	Level at which plant growth is overstimulated (decreasing oxygen levels in water)
3	0.1 mg/L	Maximum acceptable level (MAL) to avoid accelerated eutrophication and potential harm to marine life
4	> 0.1 mg/L	Accelerated plant and cyanobacterial and algae growth and consequent harmful outcomes. (water in Sri Lanka's NCP tanks comes under this category)

* This classification is based on information from multiple sources [6-9]. In addition to this, in 1986, the United States Environmental Protection Agency (US-EPA) recommended the following for acceptable levels of total phosphorus in water bodies [10]; the recommendation continues to be the standard used globally. for updated information on water quality criteria for nutrients, see- [10].

1. No more than 0.1 mg/L for streams that do not empty into reservoirs;
2. No more than 0.05 mg/L for streams discharging into reservoirs; and
3. No more than 0.025 mg/L for reservoirs (this is the MAL that is applicable to the tanks in NCP).

3. Regulation of Phosphorus Fertiliser

Phosphate fertilisers generally are made of rock minerals that have been treated with strong acids, such as sulphuric acid to make them water soluble. Due to the chemical, rock phosphate naturally contains heavy metals. The process of acid-solubilization of rock phosphate (P) also solubilizes heavy metals. Moreover, the inferior quality of sulphuric acid made from iron pyrites instead of sulphur) further adds to the heavy metal content of phosphate fertiliser. Therefore, chemical fertilisers made out of rock phosphate of any kind, such as triple super phosphates (TSP) are contaminated with a number of heavy metals [11, 12]. For example, TSP contains between 25 and 40 ppm of arsenic and cadmium, whereas the largest phosphate deposit in Sri Lanka, Eppawala rock phosphate contains approximately 15 ppm of arsenic.

Excess phosphorous fertiliser applied to crop soil is not retained. Some phosphates from fertiliser get adsorbed to soil particles, but the rest flows out with surface runoff into streams and rivers, and ends up in reservoirs in paddy-growing regions in the country, including those in North Central Province

(NCP). Although TSP contains approximately 50% of phosphorous pentoxide (P2O5), single super phosphate (SSP) contains only 18% phosphorous, and locally manufactured Eppawala rock phosphate contains approximately, 29% phosphorous. The lowest phosphorous content (11% phosphorous) is in the ammonium phosphate. For rice and vegetables, primarily use the imported granular phosphorous fertiliser, TSP. The locally produced Eppawala rock phosphate has low solubility and are mostly used for longer term, perennials crops, such as tea, rubber, and coconut [13].

4. Over Use of Phosphate Fertiliser Incentivised by Governmental Subsidy

Imports and sale of fertiliser in Sri Lanka are governed by the Regulation of Fertiliser Act No. 68, of 1988, with some later minor modifications. However, the Act is not strictly enforced. Because fertiliser use (for paddy in particualr)is highly subsidized by the government and maintains a uniform price, its usage is much higher than that needed for cultivation. For example, a 90% subsidy is provided to paddy fertiliser, whereas fertiliser for other crops either subsidized or discounted less than 65%. Annually, these subsidies cost taxpayers more than 55 billion rupees.

Currently a 50-kg bag of fertiliser used for paddy cultivation [a mixture that contains urea, phosphorous, and Muriate of Potash] is marketed at 350 Rupees (approximately USD ~3), which is 10% of its open market value. While harming the environment due to over use, fertiliser subsidy scheme enhanced agricultural output of farmers, and sales and profitability of the fertiliser companies, and markedly increase cost to the government [20]. The main reason why farmers overuse fertiliser is the marked subsidy that the government continue to provide and the ignorance that more is not always better for output.

5. Agricultural Practices in Sri Lanka

Sri Lanka is an emerging economy and predominantly an agricultural country, located just north of the equator. It has successfully used traditional agricultural practices for more than 2,500 years and has maintained self-sufficiency in rice for most of the time. Farmers have used the traditional agriculture wisely, in harmony with the nature, for the people's need. Over-exploitation of the environmental and environmental pollution have been avoided.

However, in the mid-20th century, coinciding with the population explosion, the need to enhance crop output became a priority. With the Green Revolution in the mid-1960s came the increasing use of chemical fertilisers and pesticides. Consequently, during the past five decades, the landscape, agricultural practices, and values and behaviour of farmers have markedly changed in the country.

6. Sri Lanka’s Successful Agricultural History and Recent Calamity

Since the mid-1990s, a major, non-infectious epidemic of chronic kidney disease of multifactorial origin (CKDmfo) [14] has emerged in Sri Lanka for which no cause has been identified yet [15]. This disease has killed thousands of people; it has killed more than the 48,000 people thought to have died during the 2004 tsunami [16]. The disease predominantly affects agricultural regions, flat lands in the dry zonal areas of the country, where more than a third of vegetable and rice farming is done [14, 17]. Less than 5% of the region has a pipe-borne water supply, and more than 90% of the affected families consume water from shallow wells, tube wells, and streams.

Many investigators have suggested contamination of surface water in this region as a probable factor in the development of this epidemic [18, 19]. Circumstantial evidence suggests an association of excessive and irresponsible use of agrochemicals with this disease. However, a direct connection between agrochemical and CKDmfo has not been established. Nevertheless, this appears to be a classic public heath example of how water contamination can lead to serious human disease [20] that has gone out of control.

Under the British rule, some rehabilitation of the ancient irrigation systems began mostly in late nineteenth and the early part of the twentieth century [21, 22]. However, the modern irrigation schemes were commenced only after 1948 following the country’s independence [23, 24]. These includes, the Gal Oya Scheme, the Walawe Ganga Scheme, the Mahaweli Ganga Development Scheme, and the Kirindi Oya Development Scheme. In parallel, there was an expansion of constructing hydroelectric schemes associated reservoirs in the hill-country. Plans have also been made for the development of the Kalu Ganga, the river which has the highest annual discharge.

Currently, most of the large reservoirs in the NCP are supplied by Mahaweli River; these are diagrammatically illustrated in the figure 1.

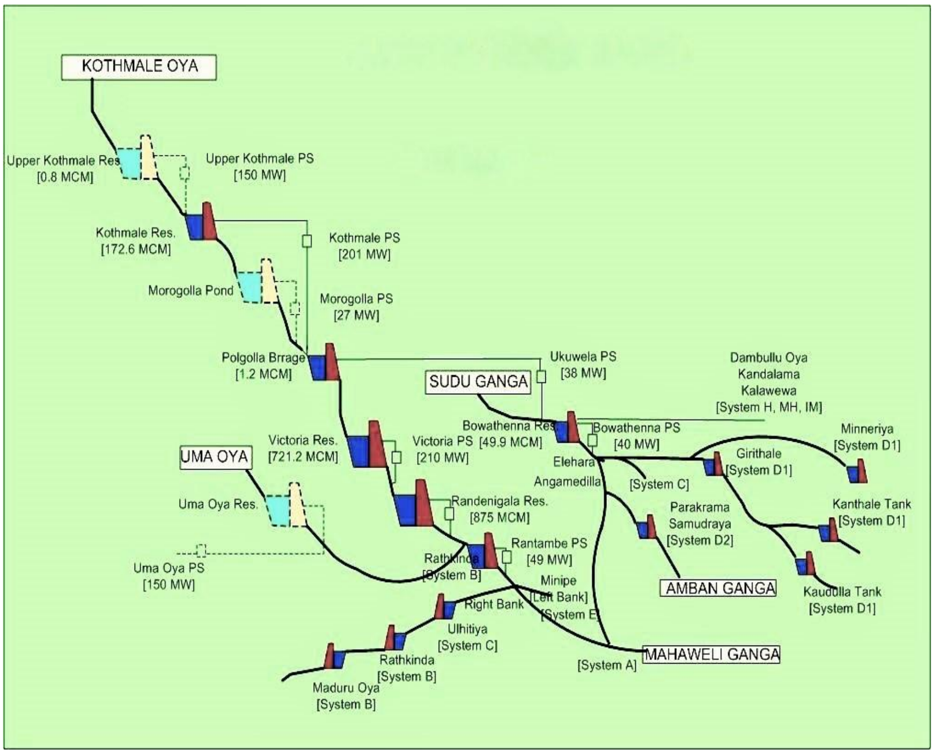

Figure 1: *Cascade of large reservoirs in Sri Lanka that is supplied by the River Mahaweli (modified from http://www.mahawelicomplex.lk/sys.htm).*

Some of the changes that occurred in the recent past in the dry zonal regions of Sri Lanka are adversely affecting water quality, fauna and flora, and human health. In addition, certain negative behavioural changes have also occurred, including excessive use of synthetic, poor-quality, and contaminated agrochemicals (particularly, phosphate fertiliser and pesticides), decreased forest cover, increased soil erosion, unsafe disposal of toxic human waste, and eutrophication of reservoirs. This study focuses on phosphate eutrophication of reservoir water in relation to the overuse of fertiliser and its potential negative effects on human health.

7. Phosphate Eutrophication

Eutrophication is an ecological response to the incorporation of artificial or natural substances and nutrient contaminants in water bodies [25]. Globally, phosphorus is the commonest plant nutrient that causes eutrophication of water. Nutrient eutrophication increases phytoplankton and algae blooms of water bodies [26-28]. It also promotes excessive plant growth and decay, favouring the growth of algae and plankton over more advanced plants, causing impairment of water quality.

Moreover, when algae decompose, their nutrients and organic matter are converted into inorganic forms by microorganisms. This decomposition process consumes oxygen, which reduces the concentration of dissolved oxygen in water that negatively affect the growth and the survival of the freshwater fish [26]. Nevertheless, phosphorus is an essential nutrient for plant life, and is a key limiting factor for plant growth in many freshwater ecosystems.

8. Phosphate Eutrophication of Water

In addition to the use of plant nutrients, other source of excess phosphate in water includes, detergents, and industrial and domestic run-off [26]. Phosphate and/or nitrate contamination occur most commonly because of the excess use of fertiliser [29, 30] but in some instances it can caused by human or animal (e.g., pig farming) sewage [31]. Meanwhile, the continuous addition of phosphorous to farmlands brings phosphorous pollution in water bodies [31, 32].

Phosphate (and also nitrate) related cyanobacterial/ algae blooms in reservoirs and water bodies, [29, 30, 33, 34], produces over 50 cyanobacterial toxins, some of which are known adversely affecting humans and animals [30, 35, 36]. Some of these incidences can be severe, as in the 2013 closure of

Grand Lake, in Ohio (United States), a key tourist destination [37], so as the closure of other lakes and major rivers across the world [31, 36, 38, 39], and total closure of the pipe-borne drinking water supply in Toledo, Ohio, in 2014. It has been suggested that CKDmfo in the NCP in Sri Lanka is linked to cyanobacterial toxins, but this is not proven and is unlikely.

9. CHARACTERISTICS OF WATER

Water has a unique characteristics due to its' two hydrogen atoms attached to an oxygen atom [40]. Since the oxygen atom has two lone pairs of electrons, it makes the water molecule non-linear, with an angle of 105 degrees, between the OH bonds [40]. The bent structure of the molecule makes it uniquely positive on one side and negative on the other, facilitating to make extra hydrogen bonds (Figure 2A). Each water molecule form four hydrogen bonds with four other water molecules (Figure 2B) [40]. This gives water a distinctive solubilising properties, including the ability to dissolve almost any substance; thus, water is easily polluted.

Figure 2C illustrates the critical point at which soil phosphorous starts to leach into runoff. Phosphate binds tightly to soil, so it is mainly decipated by soil erosion, ending up in lakes and reservoirs. The extraction of phosphate into water from suspended and dissolves particles is slow, hence the difficulty of reversing the effects of eutrophication. At a soil phosphate level of around 60 ppm, careful evaluation and consideration of actions are necessary [37], as a significant increase of phosphorus runoff is expected that threatens the environment.

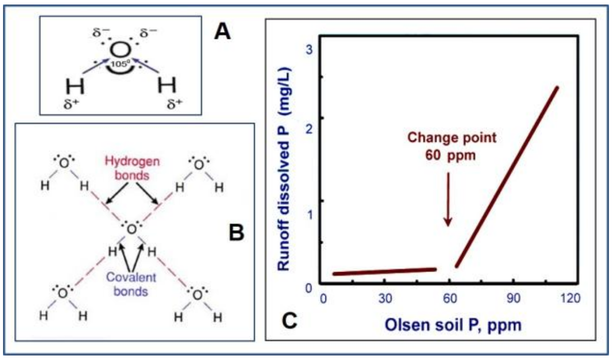

Figure 2: *(A) Chemical structure of the water molecule and, (B) a lattice of hydrogen bonds between water molecules (Source: Schwartz, 1997 [40]), and (C) The effect of soil phosphate concentrations on its runoff (Source: Heckrath et al [41]).*

In addition to the soil phosphorous concentration (i.e., levels beyond 60 ppm), leaching of phosphate also depending on the climatic conditions, temperature, and the soil composition. This further illustrates the importance of the need for the soil analysis on a stipulated time frame and careful evaluation of the needs in a given area [37, 42] to assess the current soil nutrient requirements. The dramatic increase of phosphorous runoff as illustrated in Figure 2C threaten the environment, as first demonstrated using the Park Grass experiment at Rothamsted, England [43], but its applicable to an equatorial country such as Sri Lanka is however, not yet clear.

Global environmental organizations and agricultural agencies emphasise that no farm soil should be allowed to go beyond the above-mentioned critical level [31, 32, 34], but the majority of farm soils in the hill country in Sri Lanka have already exceeded this critical phosphorus level (data from the DoA). This principle of exceeding nutrient threshold levels may also be applicable to other plant nutrients [42], as well as other substances in the soil, including heavy metals [44]. Nevertheless, the knowledge regarding such "change points" in soil for heavy metals is limited [45].

10. EUTROPHICATION OF RESERVOIRS

Environmentally friendly and sustainable approaches are needed to minimize the negative impacts from population growth and the development of large-scale irrigations systems. In addition, the prosperity and sustainability of new human settlements also depend upon avoiding or at least minimising the negative impacts on social, economic, and human health.

Globally, one of the major emerging threats to clean water is the excessive and haphazard use of chemical fertilisers and pesticides, particularly the overuse of nitrogen and phosphorous fertilisers. The excessive use of phosphorous is particularly important in paddy cultivation region in dry zone (where the CKDmfo is affected predominantly). However, the vast majority of this excess phosphate from potato cultivations in the centrally located hill country in Sri Lanka. However, the hilly part of the country is subject to frequent rain, and as a result there is a large-scale leaching of phosphorous into streams from phosphorous-rich soil. Because soil can absorbed and adsorb only a limited quantity of phosphorous, excess phosphorous invariably leaches out, causing pollution of rivers, downstream water bodies, and reservoirs hundreds of miles away [46-48]. It is noteworthy, that although the farmers in hill country overuse agrochemicals, they are not affected by this deadly disease, CKDmfo..

11. Consequences of Phosphate Eutrophication of Water

It is well known that excess phosphorous and nitrogen loads in stagnant water lead to algal blooms [49-52], making the water unhealthy for freshwater marine life and aquatic and terrestrial animals, including humans [35, 36, 53]. Due to the limitation of oxygen, it hinders the propagation of freshwater fish. Nutrient-eutrophication related rapid growth of aquatic plants necessitates frequent cleaning up of canals and reservoirs, which is time consuming and expensive.

Therefore, instead of spending money on such cleaning activities, proactive actions should be directed to identifying and eliminating the root causes of water pollution. Such actions among others, would prevent phosphorous and other nutrients from over-burdening the reservoirs that are mostly used for agricultural activities and for inland fishery in the region.

Such efforts need to be integrated with research and to implement sustainable ways to protect the watersheds to meet the clean water needs of current and future generations. Eutrophicated water enhance algae and cyanobacterial growth and aquatic plant growth. As the nutrients increase, bacterial growth flourishes on large quantities of dead algae and aquatic plants, which swiftly consumed dissolved oxygen in the water. The depletion of dissolved oxygen thus suffocates other marine life, particualry fish, and prevents their progression.

The overuse of phosphate fertiliser thus, has several unintended consequences, including eutrophication of reservoir waters and algae bloom, and harming freshwater fish [51, 54]. Despite this, phosphate (hyper)eutrophication of water is not uncommon in many emerging economies in which agriculture is the main source of revenue. This is in part due to overuse of fertiliser caused by governmental subsidies for agriculture and uncontrolled dumping of sewage and animal waste into waterways.

12. The Reservoirs in Sri Lanka

Reservoir water is used for many purposes, including bathing, washing, transportation, irrigation, fish farming, generation of power and steam, and recreation, such as swimming, angling, and boating. Furthermore, water table near reservoirs is continuously recharged from the reservoir water and is a major source of surface water for shallow wells, especially during the dry season. Sri Lanka has more than 18,000 large and small reservoirs [55]. Basic information on some of these reservoirs, listed according to their capacity, is provided in Table 2. Some of these reservoirs are more than 2,000 years old, reflecting Sri Lanka’s long successful history of agricultural irrigation.

Table 2: *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 [55].*

In the NCP region, water is taken directly from the supply tributaries, reservoirs, and canals or through recharges of ground or surface water for human consumption. In this region alone there are 29 large water treatment plants. These are mostly located close to reservoirs. Water is purified using basic treatment methods and supplied to local cities from these plants. Many of these sites get water from protected watersheds, thus, only need to undergo traditional purification methods.

These system serves approximately, 5% of the households in the NCP. The rest rely on surface water from wells and streams. However, these waters are polluted with small molecules and toxic components, and therefore, the use of traditional methods (i.e., size-exclusion, coagulation followed by chlorination protocol) routinely carryout by the National Water Supply & Drainage Board (NWS&DB) is not sufficient to produce safe drinking water for the regions.

13. Contamination of Waters in Rivers and Reservoirs

In addition to the large quantity of pollutants conveyed by the Mahaweli River, contaminants discharged from agricultural and livestock activities, households and farms, and industries in the region also contaminate reservoirs. The main source of water for the reservoirs in the NCP region is the Mahaweli River. The river accumulates water from rainfall, local streams and tributaries, that include runoffs from watersheds and also water tanks (constructed for power generation) located at higher elevations in the hill country.

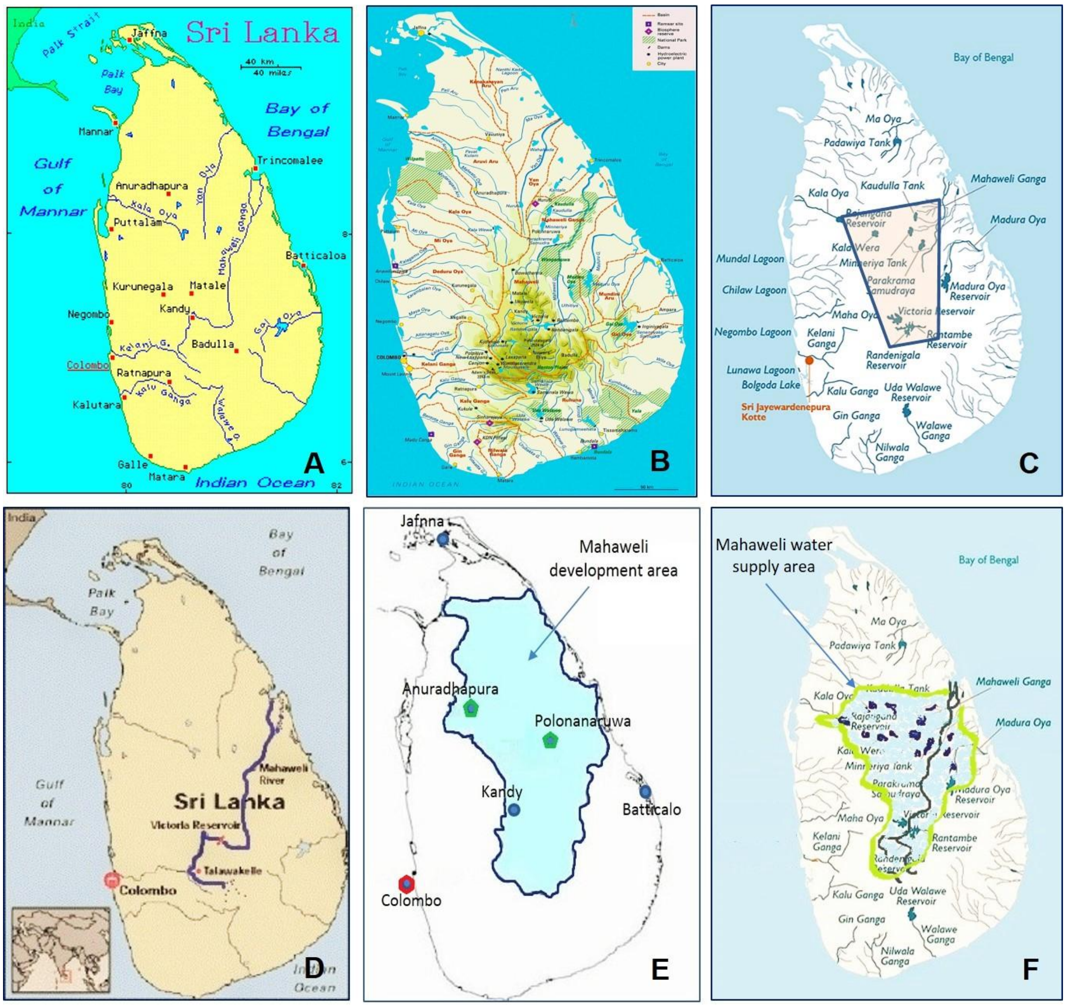

Figure 3. *Illustrates a hydrological maps of Sri Lanka; (A) Major rivers in Sri Lanka, (B) Illustrates the hill country (in green) where most of these rivers originate, (C) Rivers in Sri Lanka; shadowed illustrate approximate area that is supplied with water from River Mahaweli, (D) The River Mahaweli from the origin to the end and The drainage pattern, (E)) The Mahaweli irrigation development and human settlement areas, and The total areas that are fed the Mahaweli River water (which is also the most affected regions with the chronic kidney disease of multifactorial origin (CKDmfo) in, the country (constructed from various publically available data and domains).*

Almost all large rivers in the country originate from the hill country in the Central Province, where rainfall is the highest. The rivers run through villages, communities, and cities, where many have been tapped and the water diverted to reservoirs or for generating power and irrigation needs. Consequently, pollutants from even faraway places travel downstream and enter reservoirs located in the flat, low land hundreds of kilometers away in the NCP region. Such secondary pollutants include household waste, fertilisers, pesticides, soil, metallic components from workshops, sewers, and constituents of batteries and other pollutants from vehicle repair and mechanics' shops, and waste from industry [56-61]. Figure 3D illustrates the geographical areas supplied by the River Mahaweli and locations of large reservoirs and in the region.

14. Build-Up of Excess Phosphate in the Soil and Reservoir Water

The studies conducted by the DoA have shown that many farmers in the up country, especially potato growers, add five to ten times the phosphorous fertiliser recommended by the same organization, (also from Dr. S. Amarasiri and author's personal field observations) [62]. Farmers in vegetable-growing areas in the hill country, particularly in the Nuwara Eliya region, also use high quantities of pesticides more frequently, solid and liquid fertiliser, and organic manure. In this regard, local scientists have published several important documents, including a book in three languages; Sinhala, Tamil, and English, titled "Caring for Water" by Dr. Amarasiri, and a manual on "The physical, chemical, and biological properties of soil," compiling methods adopted in Sri Lankan laboratories and published by the Soil Science Society of Sri Lanka.

15. Causes for Phosphate Eutrophication of Water

There are several reasons for overuse of phosphorous fertiliser by farmers:

(1) Potato cultivation is very profitable, so growers want to ensure that plant nutrients are not a limiting factor in increasing yields;

(2) Fertiliser prices are very low because of a heavy state subsidy [20, 63], so it costs only a few thousand rupees per hectare, in comparison to about 300,000 rupees per hectare spent on purchasing seed potatoes;

(3) The abolition of professional, village-level agricultural-extension officers three decades ago,with no replacements or replaced people with no relevant knowledge in agricultural methods;

(4) Provincialisation of agricultural extension programs, which has weakened the advisory services to the farming community; and

(5) As a consequence of the last two items, farmers are following the advice of local fertiliser "dealers," rather than the DoA experts (whom farmers have little or no access to), in determining the type and the amounts of fertiliser to apply [64].

16. Dangers of Phosphate Eutrophication

The excessive addition of phosphate fertiliser on vegetable lands in the upcountry is the key cause of soil phosphorous build-up. DoA research stations at Nuwara Eliya and Bandarawela have reported that 70% to 80% of the soil analysed from potato cultivation fields had more than 30 ppm phosphorous(Fig. 3), the level beyond which addition of phosphorous fertiliser are considered unnecessary and unprofitable [65, 66], with diminution of returns [20].

More than 50% of the soil samples analysed had phosphorous values in excess of 60 ppm, the environmentally critical value [37, 41], beyond which most of the added phosphorous, particularly from the soluble phosphorus fertilisers such as TSPs, would rapidly move out of the soil into water bodies [37, 67-71]. Moreover, all 310 soil samples from farms analysed by the DoA in 2013, had phosphorous in excess of 60 ppm [66, 70]. Thus, the entire agricultural approach used in the hill-country has become unsustainable and harmful. Yet no tangible action has been taken by the authorities to alleviate this problem.

Beyond the 60-ppm soil phosphorous value, the so-called change point [72], the addition of phosphorous fertiliser hastens eutrophication and leads to the formation of algal blooms in drainage areas, leading to discolouring water and causing an unpleasant odour [32, 36, 51]. Some of the toxins secreated by algae bloom related cyanobacteria cannot be removed by boiling or traditional filtering of water [35]. Domestic water purification methods and methods used by the NWS&DB. A recent survey conducted by the Institute of Fundamental Studies in Kandy, Sri Lanka, reported that waters in 61 major inland reservoirs tested were polluted with toxin-producing cyanobacteiral/algae [27] that is related to phosphorous eutrophication of water. Thus, phosphate eutrophication poses a threat to the environment and must be attend to.

17. Classification of Phosphorous eutrophication of Water

Publication in 2002 by the European Union Joint Research Centre in Italy "eutrophication classification" [43], water as, oligotrophic, mesotrophic, eutrophic, or hypereutrophic, depending on the phosphorous content of water. For example, if a water body has more than 0.1 mg phosphorous per litre, generally accepted as the critical limit, is termed hypereutrophic (i.e., highly polluted with phosphorous).

Since 2005, the NWS&DB has analysed water samples from several key reservoirs in the Anuradhapura district in the NCP (Figure 2). In 2012, it reported the phosphorous content of water. In this study, water samples were collected on a monthly basis during the dryer season (from February through August) in Anuradhapura district. Their data are summarised in Table 3.

Table 3: *Phosphorus (P) content* (mg/L) of reservoir water in NCP, Sri Lanka (2012)*

Reservoir	Feb	Mar	Apr	May	Jun	Jul	Aug
Thuruwila	**0.10**	**0.15**	**0.11**	**0.21**	**0.18**	**0.19**	0.09
Tissawewa	**0.13**	**0.11**	**0.19**	**0.13**	0.07	0.07	0.07
Nuwarawewa	0.02	**0.15**	**0.12**	**0.12**	**0.11**	**0.10**	**0.11**
Nallachchiyawewa	0.09	0.08	**0.18**	**0.18**	**0.28**	**0.11**	**0.10**
Galnewawewa	**0.13**	**0.11**	**0.18**	**0.21**	**0.36**	**0.17**	**0.16**
Eppawelawewa	0.01	0.07	**0.19**	**0.20**	**0.33**	**0.20**	**0.18**
Kalawewa	**0.11**	**0.14**	**0.14**	**0.15**	**0.15**	0.05	**0.15**
Mahakandarawa	**0.12**	**0.14**	0.03	**0.17**	**0.19**	**0.17**	**0.20**
Habaranawewa	**0.16**	0.03	0.08	0.07	**0.18**	**0.11**	0.06
Kiriwadunawewa	0.03	0.08	**0.14**	0.06	**0.20**	**0.14**	**0.16**
Padaviyawewa	0.06	0.09	**0.14**	0.07	**0.14**	**0.13**	0.03
Jayanthiwewa	**0.14**	0.09	**0.15**	**0.15**	**0.15**	**0.13**	0.08
Wahalkadawewa	**0.11**	**0.13**	0.06	0.08	0.07	**0.10**	0.08
Kebitigollawawewa	0.07	**0.10**	0.08	0.07	0.06	0.05	0.05
ParakramaSamudraya	**0.20**	0.06	**0.13**	0.08	**0.14**	**0.13**	**0.23**
Minneriyawewa	**0.43**	**0.16**	0.05	**0.28**	0.06	0.06	0.09

**Numbers in bold indicate hypereutrophic status [i.e., highly polluted (exceeding the recommended maximum level of 0.1 mg/L) according to the European Union Classification of phosphorous content in water)] [Source: NWS&DB].*

18. European Union Classification and Interpretation of Data

Although the European Union (EU) classification is based on total phosphorous, the NWS&DB data are for dissolved reactive phosphorous (DRP) [73]. Because total phosphorous in a water sample is equal to or higher than DRP, a water body exceeding 0.1 mg/L of dissolved reactive phosphorous is considered "hypereutrophic" by the EU classification. Figure 4 illustrates the mean phosphorous content in reservoir water in the 16 large reservoirs tested in the Anuradhapura district in the NCP province in Sri Lanka.

Eighty-one percent of the major reservoirs tested in the NCP (located in a dry zone) were affected with phosphates eutrophication. However, the reservoir phosphate levels do not tally with the geographical distribution of the prevalence of CKDmfo in that region. For example, while Kabithigollawa village has low prevalence, Padaviya area has very high prevalence of CKDmfo [14]. Reservoirs in both these areas had lower than the safe recommended limit of phosphate in water as per the EU-EPA standards.

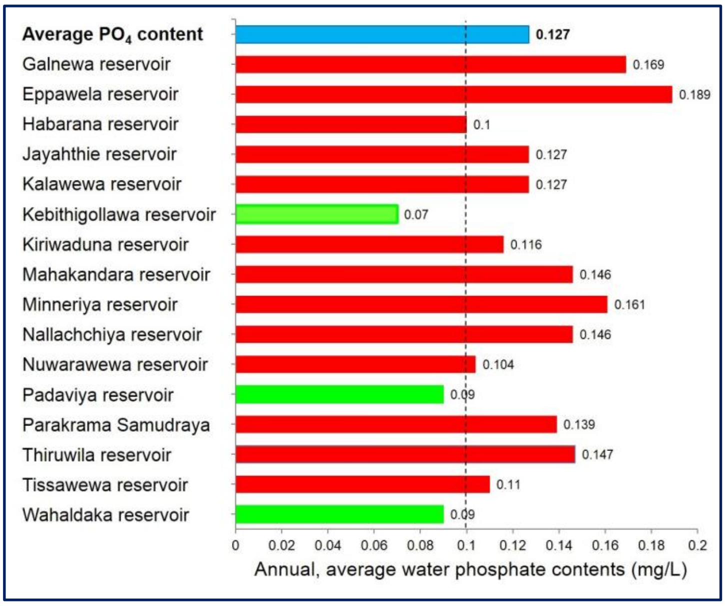

Figure 4: *Mean phosphorous content of the reservoir water in the North Central Province (NCP), the region that is most affected with CKDmfo. The blue bar indicates the total average for the region; red bars indicate the phosphorous hype eutrophicated reservoirs per the European Union (EU) classification of phosphorous content greater than 0.1 mg/L of water; and green bars indicate phosphorous content within acceptable limits [Source: National Water Supply & Drainage Board (NWS&DB)].*

19. Implication of Phosphate Eutrophication of Reservoirs in Sri Lanka

These data demonstrate that all the reservoirs have been hypereutrophic during some time of the year. Such high phosphorous content in a water body leads to ecological imbalance and cause harm to marine lives (fauna and flora) [35, 38, 54, 74, 75]. The recent water sample analysis by the DoA from Kalawewa, Nuwerawewa, Minneriya, and Parakrama Samudraya, the remaining largest reservoirs in the country, all located in the NCP. Their phosphorous levels three to four times higher than those documented in 1964–1965 [76].

This increased phosphorous levels in reservoir water (that is supplied by the River Mahaweli; the region most affected by CKDmfo) [13] suggests that phosphorous in reservoirs in the NCP [13], the region most affected by CKDmfo, results from excess use of phosphorous fertiliser in hill country as the main cause. The average phosphate levels in water are the average phosphate levels in water in all reservoirs in the NCP, the average phosphate levels in water are at or above ~ 0.12 mg/L, above the safe threshold (MAL) that should be considered as harmful to marine life. It is known that when the phosphate levels in water are high, the water can cause digestive problems in humans. However, no known human ailment or disease, including renal failure has been attributed or caused by consuming water with phosphate levels at or above ~ 0.1 mg/L, levels typical of the NCP region.

In most countries, the non-point sources of plant nutrient pollution through agricultural practices are the main reason for eutrophication [38, 54, 75]. Nevertheless, implementation of regulations with reference to agrochemicals and animal waste, lags behind scientific research [77, 78]. In addition to the excess use of nitrates and phosphorous fertilisers, the slackness of implementing laws that regulate the treatment and discharge of sewage has led to further increase in eutrophication of waterbodies in certain countries. On the other hand, the countries that implement regulations demonstrate a marked reduction in nutrient content in water bodies [79].

To minimize environmental and occupational health hazards, the participation of all stakeholders, including the public and private sectors, technocrats, legislators, agencies, and environmental organizations [80] is essential [38, 54, 81, 82]. Recent data suggest that the use of organic farming has decreased leaching of phosphates and nitrates into water bodies, in comparison to the use of chemically fertilisers [83], but not everyone agrees with this conclusion [84].

20. Health Effects from the Increase Ionic Constituents in Water

Phosphate pollution of irrigation water [13] and phosphorous-mediated higher ionicity of water in NCP reservoirs has been hypothesised as a factor in the development of CKDmfo [85, 86]. However, those who live within the NCP rarely drink water from reservoirs or its canals but consume water from home-based shallow wells that contain much lower levels of phosphorous but has other contaminants.

Moreover, people living outside the NCP region, who drinks water containing much less phosphate in water and there are no reservoirs or receiving water from the River Mahaweli also have CKDmfo. This hypothesis is further discounted by the evidence of other agricultural regions, such as the Jaffna peninsula and large areas in north-eastern and north-western coastal regions in Sri Lanka, where the iconicity, salinity, and the hardness of water are much higher than that of the NCP, but have little evidence of CKDmfo.

Because of tight physiological feedback mechanisms (i.e., a number of adaptive renal and extra-renal compensatory activities that allow the maintenance of physiologic homeostasis), ingestion of higher amounts of phosphorous in the drinking water do not cause harm or cause hyperphosphataemia [87]. Physiologically and mechanistically, it is unlikely that ingestion of water containing phosphorous levels below 1.5 mg/L, as suggested by some researchers [85], causing CKDmfo. However, irrespective of the type of water intake, once renal failure is established, serum phosphorous levels increase [88] because of the inability of the kidneys to excrete phosphorous. However, acute renal failure could occur following a very high oral phosphorous overload [89].

21. High Ionicity or High Electrical Conductivity in Water Per Se Does Not Cause Chronic Renal Failure

Although the described iconicity hypothesis is theoretically attractive, there is no medical evidence that drinking water containing approximately, 0.12 mg/L of phosphorous (or similar amounts of sodium chloride) or tolerable higher ionicity in NCP reservoirs causing renal failure [14]. This suggests that causes other than iconicity are associated with the manifestation of kidney failure in the NCP region. Irrespective of the ionicity of water, excess phosphorous or nitrogen levels in stagnant water and reservoir waters in the presence of the right temperature and pH can facilitate the growth of algae blooms-associated cyanobacterial growth [35, 36].

While eutrophication of reservoir water with phosphate over 0.1 mg/L is known to harm the marine life, the levels of phosphorous in NCP reservoirs waters are (between 0.7 and 1.5 mg/L) is too little to harm human. Moreover, the contribution of phosphorous) to the electrical conductivity [(ranging between 300 and 800 micro-Siemens (μs)] or to the total water ionic strength little. In fact, [the recommended upper limit of electrical conductivity in drinking water as per the SLS standard, 614:1983 and LSL standard is 750 μs].

Although the phosphate contents in water secondary to fertiliser run off in reservoirs and regolith-fed drinking water exceed the EU-EPA standards (and seems unhealthy to consume) during the dryer period in the NCP (Table 2), there are no clinical indications or systematic data suggesting that people in the NCP experience hyper phosphataemia as a consequence of drinking such water in the absence of CKD. In addition, no data has been reported on any major organ-related adverse effects to human health, including the occurrence of renal failure after consumption of water containing these levels of phosphorous.

22. Water Pollution with Plant Nutrients and Human Health

The two plant nutrients of environmental concern, in most agricultural communities, including that of Sri Lanka, are nitrogen and phosphorous [25]. DoA data suggest that the nitrogenous fertilisers added to the sandy soils in areas such as Kalpitiya and Jaffna have led to an increase in nitrates in well water [90] beyond safe limits stipulated by the Sri Lanka Standards Institute (SLSI) [69]. However, CKDmfo is not a major concern in these areas.

In most other regions, eutrophication of water from nitrogen is not a major concern. On the other hand, according to DoA and NWS&DB data, phosphorous levels in reservoir waters have continued to increase during the past three decades, particularly waterbodies in the NCP (Table 2). If unchecked, this may escalate to an uncontrollable, further increase of cyanobacterial, harmful algal blooms and other unintended consequences that may affect the livelihoods and human health.

The average phosphate levels documented in NCP reservoirs is 0.12 mg/L (ranged between 0.07 and 0.15 mg/L; Figure 3), most likely due to the over use of large quantities of phosphate fertilisers[13]. Such water is considered as eutrophication and is unhealthy for marine life [31, 75, 91, 92]. Virtually all reservoirs in the NCP are now eutrophicated with phosphate (levels above 0.1 mg/L); the same regions that are the most affected by the CKDmfo.

Phosphate (phosphorus) levels above 0.1 mg/L in water bodies has detrimental effects on the ecological, on freshwater fauna and flora, but there is no evidence that it harm to humans. In spite of recent claims [85], even the routine consumption of phosphate containing water at these levels (i.e., up to mg/L) does not cause renal damage or cause CKDmfo in the presence of normal renal functions.

23. Need for Soil Testing to Keep the Ecology N Inbalance

Soil test results provide the basis for determining the amounts of plant nutrients that should be applied to a soil to obtain the best cost-effective crop output. These tests assist not only in optimising crop output but also prevent water and environmental pollution, help to maintain soil health, and give insight into best soil management practices. For example, if soil tests indicate that the phosphorouslevel is high, the current phosphorous fertiliser application may be reduced or stopped for an appropriate period to bring back the right nutrient balance.

24. Importance of Regular Soil Testing as a Means to Prevent Eutrophication of Water

High phosphorous levels in farm soils is a worldwide problem, but legal instruments are in place in some countries to prevent such problems [93, 94]. Idaho is the largest potato-growing area in the United States; farmers there are required to have their soils chemically analysed every 5 years. Phosphorous-based fertiliser is allowed to be added to the soil based on plant nutrient requirements and soil conditions [44, 93, 95], which prevent fertiliser runoffs. Similar issues exist in the hill country in Sri Lanka, where potato farmers are using five to ten times more phosphorous fertiliser than is recommended [14, 85]; it is time for authorities to take right actions to minimize this hazard. Restricting or banning importation of TSP fertiliser is not the right approach.

In the United States, it is common to see plant nutrient management plans in partnership with state authorities implemented before each crop season [96]. These well-tested methods could be adapted for the needs of Sri Lanka and other agricultural countries in an effort to prevent environmental harm and nutrient eutrophication of water, and to decrease the irresponsible overuse of fertilisers.

However, when chemical fertilisers are used appropriately and in recommended amounts, their absorption to soil particles and subsequent absorption into plants is maximised. Thereby, the runoffs, potential harm from excess fertilisers to the environment, and marine lives are minimised [41]. In this regard, “excess” addition of even organic fertiliser can be harmful to the environment [71]. In general, the application of fertiliser without soil testing data may harm plants, be wasteful, and be hazardous to the environment and people. To avoid these problems, it is recommended that fertiliser release and use be based on soil testing conducted every 3 to 5 years in all larger-scale agricultural lands.

25. The Use of Organic Fertilisers

The release of nutrients from natural or organic fertilisers depends on the soil microbial activity, the moisture present, soil and water contents, and weather conditions. Unlike with chemical fertilisers, the nutrient release from organic fertilisers occurs slowly, over a period of time and in part dependent on the soil microbial activity. Organic modifications and compost, whilst adding microbes, are good soil conditioners that act to improve the physical and biological properties of soil. However, it is a misconception to assume that organic fertilisers poses no risk to the environment. Organic fertilisers are safe when used properly; over-application can pollute water supplies, just as is true for the over-application of inorganic fertilisers. Use in moderation is the way forward.

26. The Need for Modelling and GIS to Understand the Spread of Plant Nutrient Pollution of Reservoirs

Several models have been proposed for simulating the transport of phosphate and other nutrient pollutants to lakes and reservoirs, and other elements of hydrological systems [97, 98]. A common limitation of the simulations is the lack of adequate data for the parameterization of models such as the physical, chemical, and biological properties of the soil, land use, rainfall, or a complete mapping of all elements of the hydrological system including their topological relationship in a hydrological system [98].

Thus, existing databases such as those represented[98] by Table 2 are increasingly being linked to these models, often as a geographical information system (GIS), which permits large-scale simulations of the results of changes in any of the parameters as well as spatial analysis of the relationship between occurrences of the disease and polluted water. Such modelling examples and the integration of soil Water Assessment Tool (SWAT) and GIS have been described previously [97-99]. This type of linking and analysis is highly informative and urgently needed for the study of the CKDmfo epidemic in Sri Lanka [100].

27. Discussion

Continuation of the overuse of agrochemicals, soil erosion, and the lack of enforcement of environmental laws result in significant water and environmental pollution and cause unmeasurable damage to the country’s economy. Such damage cannot be measured in financial terms alone [14]. The agrochemical and other industries have a corporate social responsibility to invest in providing clean water to these communities and educating farmers on the proper use of plant nutrients and pesticides and providing them with protective gear.

However, farmers are ultimately accountable for the use of agrochemicals in a responsible manner, protecting themselves and the people around them and the environment, and safeguarding the food chain. Therefore, have a direct responsibility to the consumers providing healthful and safe food. One needs to address these needs via multiple approaches, including education of farmers and the corporate sector, control of fertiliser imports and sales, and gradual reduction of fertiliser subsidies that entice farmers to overuse fertilisers.

Fresh water is a national treasure, and it must be protected. Globally, most of the efforts to privatise water have failed, especially in developing countries. Considering historical failures and a number of other factors, water should never be privatised in developing countries. While the governments should be the guardian of water, it must be accountable , and should adopt national water policies and clean drinking water acts to provide safe water to all of a nation’s inhabitants.

The lack of personal, community, and state responsibility undoubtedly facilitate water and environmental pollution. The multiple factors mentioned in this article contribute to the increased water pollution and other environmentally harmful changes that have occurred in the recent past and that are continuing today. Such changes include the continual reduction of forest area, increased cultivation of annual crops on erosion-prone lands, excessive use of fertiliser, indiscriminate use of pesticides, mining industries, and increased use and unsafe disposal of chemicals and heavy metals. All of these practices can adversely affect the health of humans and animals, and thus, need to be controlled.

The propagation of polluting industries and the establishment of new human settlements and large-scale irrigation systems without adequate environmental safeguards and sustainable practices are environmentally damaging, are disaster for human health. These harmful habits and lack of policies and law enforcement further encourage pollution. While, the phosphate eutrophication of water secondary to overs use of fertiliser can be corrected relatively easily by adhering to the above mentioned recommendations, it does not seem associated with the CKDmfo in Sri Lanka. Nevertheless, causes major negative environmental issues on freshwater fish and flora.

If pollution continues at the current rate together with ongoing climate changes and the population explosion, with its associated human needs will results in a calamity due to natural and man-made disasters in the future. Many of the escalating incidences of non-communicable diseases prevalent in developing countries and CKDmfo in Sri Lanka, are resulting from environmentally related issues initiated decades ago, have begun to manifest due to unhealthy practices and deviations from traditional habits. Diseases that are unknown today may be in the offing in the future.

28. Conclusions

Water and environmental pollutions continue to increase in the presence of agrochemicals over use, soil erosion, and deforestation, etc. The lack of enforcement of environmental laws aggravate this situation. The agrochemical and manufacturing industries (so as the textile/apparel, rubber, chemical, and other water-polluting industries) have a corporate social responsibility not only for protecting the environment, but also to investing to provide clean water to affected communities and educating farmers on the proper use of fertiliser and pesticides and providing them with protective gear, etc. The Government, corporate and the public sector, and farmers, all must take the responsibility of preserving the environment and be accountable for the use of agrochemicals in a responsible manner. Every one of us have the responsibility to ensure healthy lives of self and others, and promote well-being of all humans and animals. Taking proactive actions now will protect the environment for future generations.

ACKNOWLEDGEMENTS

The authors thank Drs. Sarath Amarasiri, Stanley Weeraratne, Douglas Olcott, and Ms. Chamandika Warusavitharana for their helpful input on an earlier version of this manuscript.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

REFERENCES

[1] Worm, B., et al., Impacts of biodiversity loss on ocean ecosystem services, Science, 314(5800): 787-90 (2006).

[2] Sahney, S., M.J. Benton, and P.A. Ferry, Links between global taxonomic diversity, ecological diversity and the expansion of vertebrates on land. Biol Lett, 6(4): 544-7 (2010).

[3] Kümmel, R., Energy as a factor of production and entropy as a pollution indicator in macroeconomic modeling. Ecological Economics, 1(2): 161–180 (1989).

[4] Zhang, H., Luo,Y.M., Assessment system for watershed ecological health in the United States: development and application. Ying Yong Sheng Tai Xue Bao, 24(7): p. 2063-72 (2013).

[5] Yuan, Y., et al., Phosphorus losses from agricultural watersheds in the Mississippi Delta. J Environ Manage, 115: 14-20 (2013).

[6] Anonymous, Joint Research Centre, European Union, EPA clasificaion of phosphate in water, J.R. Centre, Editor, European Union (1992).

[7] Group, W., Environmental problems and developing countries (PO4),. Finance Dev,. 29(2): 22-23 (1992).

[8] WHO, WHO, Guidelines for drinking water quantity Edition 2(1) World Health Organization, Geneva (1983).

[9] Phosphate. Water, Water Everywhere. HACH Company. Second Edition. EPA (1983). : http://www.water.ncsu.edu/watershedss/info/phos.html;http://www.who.int/water_sanitation_health/dwq/fulltext.pdf;http://www.chemsoc.org/exemplarchem/entries/2001/duncan/page-3.htm.

[10] US-EPA. http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/index.htm. (1986).

[11] Wahlqvist, M.L. and K.N. Kuo, Securing health through food systems: an initiative of the nutrition consortium of the National Health Research Institutes in Taiwan and Asia Pacific regional partners as a network. Asia Pac J Clin Nutr, 18(4): 472-9 (2009).

[12] Dissanayake, C.B., Chandrajith, R, Phosphate mineral fertilizers, trace metals and human health. J. Natn. Sci. Foundation Sri Lanka, 37(3): 153-165 (2009).

[13] Bandara, J.M., et al., 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): 439-53 (2011).

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

[15] Wimalawansa, S.J., 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 in Olcott Memorial Oration, Ananda Collage: Colombo, Sri Lanka. 1-12 (2013b).

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

[17] WHO-Group: Jayathilaka N, M.P., Mendis S, Mehta FR, Dissanayake LJ, Janakan N. , Investigation and evaluaiton of chronic kidney disease of uncertain aetiology in Sri Lanka

(Final Report), in http://www. lankaweb.com/ news/items12/WHO%20 final%20report %20on %20CKDu%20SL.pdf, W.H. Organization, Editor, Colombo, Sri Lanka (2013).

[18] Chandrajith, R., et al., Chronic kidney diseases of uncertain etiology (CKDue) in Sri Lanka: geographic distribution and environmental implications. Environ Geochem Health, 33(3): 267-78 (2011).

[19] Senevirathna, L., et al., 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): 191-8 (2012).

[20] Wimalawansa, S.A., Wimalawansa, S.J, 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 (2014a).

[21] Brohier, R., Ancient irrigation works in Ceylon. Colombo. Vol. Voume I, Ceylon Government Press (1934).

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

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

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

[25] Paerl, H.W. and J. Huisman, Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environ Microbiol Rep, 1(1): 27-37 (2009).

[26] Schindler, D., Vallentyne, JR, Over fertilization of the world's freshwaters and estuaries, University of Alberta Press (2004).

[27] Wimalasurendre, C., Amarasiri, S. Scientists warn of time bomb: Phosphate and algae boom in reserviours in Sri Laka, http://www.island.lk/index.php?page_cat=article-details&page=article-details&code_title=90856; Available from: http://www.island.lk/index.php?page_cat=article-details&page=article-details&code_title=90856 (2013).

[28] Organization, W.H., Cyanobacterial toxins: Microcystin-LR in drinking water, World Health Organization: Geneva, Switzerland (2003).

[29] Codd, G.A., L.F. Morrison, and J.S. Metcalf, Cyanobacterial toxins: risk management for health protection. Toxicol Appl Pharmacol, 203(3): 264-72 (2005).

[30] Ibelings, B.W. and I. Chorus, Accumulation of cyanobacterial toxins in freshwater "seafood" and its consequences for public health: a review. Environ Pollut, 150(1): p. 177-92 (2007).

[31] Carpenter, S.R., Eutrophication of aquatic ecosystems: biostability and soil phosphorus. Proc Natl Acad Sci U S A, 102(29): 10002-05 (2005).

[32] Carpenter, S.R., Phosphorus control is critical to mitigating eutrophication. Proc Natl Acad Sci U S A, 105(32): 11039-40 (2008).

[33] Pereira, P., et al., Accumulation and depuration of cyanobacterial paralytic shellfish toxins by the freshwater mussel Anodonta cygnea. Aquat Toxicol, 68(4): 339-50 (2004).

[34] Metcalf, J.S., et al., Effects of physicochemical variables and cyanobacterial extracts on the immunoassay of microcystin-LR by two ELISA kits. J Appl Microbiol, 89(3): 532-8 (2000).

[35] Rouco, M., et al., Evolutionary changes in growth rate and toxin production in the cyanobacterium Microcystis aeruginosa under a scenario of eutrophication and temperature increase. Microb Ecol, 62(2): 265-73 (2011).

[36] Li, Y., et al., Nutrient sources and composition of recent algal blooms and eutrophication in the northern Jiulong River, Southeast China. Mar Pollut Bull,. 63(5-12): 249-54 (2011).

[37] DOW, Division of Surface Water-Ohio Lake Erie phosphorus task force final report, Ohio Environmental Protection Agency, 109 (2010).

[38] Le, C., et al., Eutrophication of lake waters in China: cost, causes, and control. Environ Manage, 45(4): 662-8 (2010).

[39] Patz, J.A., et al., Climate change and waterborne disease risk in the Great Lakes region of the U.S. Am J Prev Med, 35(5): 451-8 (2008).

[40] Schwartz, A., Truman,C., Chemistry in Context. The Wonder of Water. W.M C. Brown (1997).

[41] Heckrath, G., Brookes,P.C., Poulton,P.R., Boulding,K.W.T., Phosphorus leaching from soils containing different concentrations in the Broadbalk experiment. J. Environmental Quality 24: 904-910 (1995).

[42] Hutchison, F. and C.M. Wai, Cadmium, lead, and zinc in reclaimed phosphate mine waste dumps in Idaho. Bull Environ Contam Toxicol, 23(3): 77-80 (1979).

[43] Heckrath G., B.P.C., Poulton P.R., Goulding K.W.T, Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk Experiment. J. Environmental Quality, 24: 904-910 (1995).

[44] Hutchison, F., et al., Distribution of cadmium, lead and zinc in soil around two phosphate processing plants in Pocatello, Idaho. Bull Environ Contam Toxicol, 22(3): 426-9 (1979).

[45] Ishaque, A.B., et al., Assessment of individual and combined toxicities of four non-essential metals (As, Cd, Hg and Pb) in the microtox assay. Int J Environ Res Public Health, 3(1): 118-20 (2006).

[46] Yuan, Y., et al., Assessing the long term impact of phosphorus fertilization on phosphorus loadings using AnnAGNPS. Int J Environ Res Public Health, 8(6): 2181-99 (2011).

[47] Wang, X., et al., Study of the distribution of non-point source pollution in the watershed of the Miyun Reservoir, Beijing, China. Water Sci Technol, 44(7): 35-40 (2001).

[48] Fleifle, A., et al., Optimization of integrated water quality management for agricultural efficiency and environmental conservation. Environ Sci Pollut Res Int, 21(13): 8095-111 (2014).

[49] Yakasai, I.A., Effect of sodium/potassium salt (potash) on the bioavailability of ibuprofen in healthy human volunteers. Eur J Drug Metab Pharmacokinet, 28(2): 93-9 (2003).

[50] Turrentine, J.W., Composition of potash fertilizer salts for sale on the American market. Industrial & Engineering Chemistry (American Chemical Society), 26(11): 1224–1225 (1934).

[51] Heffernan, J.B., et al., Algal blooms and the nitrogen-enrichment hypothesis in Florida springs: evidence, alternatives, and adaptive management. Ecol Appl, 20(3): 816-29 (2010).

[52] Jahan, R., et al., Study of harmful algal blooms in a eutrophic pond, Bangladesh. Environ Monit Assess, 170(1-4): 7-21 (2010).

[53] Eberlein, K., Risk of anthropogenic nitrogen and phosphorus entry into the North Sea ecosystem. Zentralbl Hyg Umweltmed, 196(4): 285-311 (1994).

[54] Lewis, W.M., W.A. Wurtsbaugh, and H.W. Paerl, Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. Environ Sci Technol, 45(24): 10300-5 (2011).

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

[56] Damalas, C.A. and I.G. Eleftherohorinos, Pesticide exposure, safety issues, and risk assessment indicators. Int J Environ Res Public Health,. 8(5): 1402-19 (2011).

[57] Wittmer, I.K., et al., Significance of urban and agricultural land use for biocide and pesticide dynamics in surface waters. Water Res, 44(9): 2850-62 (2010).

[58] Rice, P.J., B.P. Horgan, and J.L. Rittenhouse, Evaluation of core cultivation practices to reduce ecological risk of pesticides in runoff from Agrostis palustris. Environ Toxicol Chem, 29(6): 1215-23 (2010).

[59] Meyer, B., et al., Concentrations of dissolved herbicides and pharmaceuticals in a small river in Luxembourg. Environ Monit Assess, 180(1-4): 127-46 (2011).

[60] Chen, L.D., et al., Seasonal variation of nitrogen-concentration in the surface water and its relationship with land use in a catchment of northern China. J Environ Sci (China), 17(2): 224-31 (2005).

[61] Belden, J.B., C.S. Hofelt, and M.J. Lydy, Analysis of multiple pesticides in urban storm water using solid-phase extraction. Arch Environ Contam Toxicol, 38(1): 7-10 (2000).

[62] Kodikara, K.M.S., Wijesunderra,S.M., Yatagama,S.M.K.G. . Selected chemical characteristics of soils in potato growing areas of upcountry intermediate zone in Sri Lanka, in Proc. National Symposium. Faculty of Agriculture, University of Ruhuna, Sri Lanka (2008).

[63] Wimalawansa, S.J. Agriculture and chronic kidney disease: http://www.island.lk/ index.php? page_cat=article-details&page=article-details& code_ title= 98247; http:// www. dailynews. lk/ features/knocking-kidney-killer;http://www.sundayobserver.lk/2013/11/24/fea06.asp] Available from: http://www. island. lk/index.php?page_cat=article-details&page=article-details&code_ title= 98247; http://www.dailynews.lk/features/knocking-kidney-killer; http://www. Sunday observer.lk/2013/11/24/fea06.asp (2014a)

[64] Wimalawansa, S.J., Agrochemicals and Chronic Kidney Disease of Multi-Factorial Origin: An Occupational Exposure Disease (submitted) (2015a).

[65] Upali, W.S.P.Y., Nugaliyadde,M.M., A.C.G. Babu,A.C.G. . Need for a soil test based fertilizer recommendation for potato cultivation in Sri Lanka. in Global Potato Conference. New Delhi

[66] Kodikara, K.M.S. Chemical analysis of soils of cultivators' fields. . in Seasonal Reports. Regional Agricultural Research and Development Centre, Bandarawela (2013).

[67] Glennie, E.B., Littlejohn,C., Hayes,A., Palfrey,R., Sivil,D., Wright,K. , Phosphates and alternative detergent builders. , E.E. Directorate, Editor. 186 (2002).

[68] Sharpley, A.N., Daniel,T., Sims,T., Lemunyon,J., Stevens,R., Parry,R., Agricultural phosphorus and eutrophication., D.o.A. United States, Editor,U.S.A., 94 (2003).

[69] Institute, S.L.S., Drinking water standards S.L.S. Institute, Editor, Colombo (1983).

[70] DOA, Agricultural Phosphorus and Eutrophication., U.S.D.o. Agriculture, Editor, Agriculture Research Service: Washignton D.C. 43 (2003).

[71] Tunney, H.B., Coulter,K., Daly,C., Concon,D., Jeffrey,P., Mills,G., Kiely,G, Morgan.G. , Final Report on quantification of phosphorus loss from soil to water., in Environmental Research (2000).

[72] Rodhe, W., Crystallization of eutrophication concepts in North Europe. Eutrophication, Causes, Consequences, Washington D.C: National Academy of Sciences (1969).

[73] WritingGroup, Environmental problems and developing countries. Finance Dev, 29(2): 22-3. (1992).

[74] Jarvie, H.P., et al., Phosphorus mitigation to control river eutrophication: murky waters, inconvenient truths, and "postnormal" science. J Environ Qual, 42(2): 295-304 (2013).

[75] Li, Q.H., et al., Eutrophication control in local area by physic-ecological engineering. Huan Jing Ke Xue, 33(7): 2303-8 (2012).

[76] Amarasiri, S.L., A study of some rice irrigation waters in Ceylon. Tropical Agriculturalist, 121: 1-17 (1965).

[77] Costantini, V.P., et al., Effects of different animal waste treatment technologies on detection and viability of porcine enteric viruses. Appl Environ Microbiol, 73(16): 5284-91 (2007).

[78] Mackie, R.I., P.G. Stroot, and V.H. Varel, Biochemical identification and biological origin of key odor components in livestock waste. J Anim Sci, 76(5): 1331-42 (1998).

[79] Smith, V.H., G.D. Tilman, and J.C. Nekola, Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environ Pollut, 100(1-3): 179-96 (1999).

[80] U.N., Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication, in United Nations Environment Programme, Newsletter and Technical Publications. International Environmental Technology Centre (2000).

[81] Joborn, A., et al., Integrated water management for eutrophication control: public participation, pricing policy, and catchment modeling. Ambio, 34(7): 482-8 (2005).

[82] Wimalawansa, S.A., Rajapakse, S., Wimalawansa, S.J., Environmental Pollution Related Escalating Occupational Diseases. International Research Journal of Public and Environmental Health Research (submitted) (2014).

[83] Kramer, S.B., et al., Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. Proc Natl Acad Sci U S A, 103(12): p. 4522-527 (2006).

[84] Williams, A.G., Audsley, E. and Sandars, D.L. , Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities, in Defra Research Project IS0205. Bedford: Cranfield University and Defra: Bedford (2006).

[85] Dharmawardana, M.W., et al., Chronic kidney disease of unknown aetiology and ground-water ionicity: study based on Sri Lanka. Environ Geochem Health, 37(2): 221-31 (2014).

[86] Jayasekera, J., Dissnayake DM, Ratnayake P, Wikramasinghe, W, Radella, YA, Palugaswewa, WB. The effects from concenrated water on reservoirs of high prevelance areas on CKD of unknonw origin in Sri Lanka on mice (Abst.). http://issuu.com/slmanews/docs/ ckdu_ abstract_ book(2012).

[87] Alcazar Arroyo, R., Electrolyte and acid-base balance disorders in advanced chronic kidney disease. Nefrologia, 28(3): 87-93 (2008).

[88] Albaaj, F. and A. Hutchison, Hyperphosphataemia in renal failure: causes, consequences and current management. Drugs, 63(6): 577-96 (2003).

[89] Markowitz, G.S. and M.A. Perazella, Acute phosphate nephropathy. Kidney Int, 76(10): 1027-34 (2009).

[90] Nagarajah, S., Emerson,B.N., Abeykoon,V., Yogalingam,S, Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution. Tropical Agriculturist, 144:61-78 (1988).

[91] Sun, G. and L. Sheng, Ecological engineering for eutrophication control in lake. Ying Yong Sheng Tai Xue Bao, 12(4): 590-92 (2001).

[92] Middlebrooks, E.J., Pearson, E.A., Tunzi, M., Adinarayana, A., McGauhey, P.H., Rohlich, G.A, Eutrophication of surface water: Lake Tahoe. Water Pollution Control Federation, 43(2): 242–251 (1971).

[93] Zvomuya, F., S.C. Gupta, and C.J. Rosen, Phosphorus leaching in sandy outwash soils following potato-processing wastewater application. J Environ Qual, 34(4): 1277-85 (2005).

[94] Andersen, H.E., G. Heckrath, and H. Thodsen, Mapping areas at risk of diffuse phosphorus losses to water: a pilot study of Lake Haderslev Dam, Denmark. Water Sci Technol, 58(11): 2173-8. (2008).

[95] Johnson, R., et al., Uranium in soil around phosphate processing plants in Pocatello, Idaho. Bull Environ Contam Toxicol, 24(5): 735-8 (1980).

[96] Sheffield, R., Brown,B., Chahine,M., de Haro Marti M., Falen,C., Mitigating high phosphorus soils. , in Extension Bulletin, University of Idaho, U.S.A., (2008). .

[97] Navas, J.M., T.C. Telfer, and L.G. Ross, Spatial modeling of environmental vulnerability of marine finfish aquaculture using GIS-based neuro-fuzzy techniques. Mar Pollut Bull, 62(8):1786-99.(2011).

[98] Goodchild, M.e.a., GIS and environmental modeling: Progress and research. John Wiley and Sons (1996).

[99] Gorman, J., D. Pearson, and P. Whitehead, Assisting Australian indigenous resource management and sustainable utilization of species through the use of GIS and environmental modeling techniques. J Environ Manage, 86(1): 104-13 (2008).

[100] Null, S.E. and J. Medellin-Azuara, Escriva-Bou, A., Lent, M., Lund, J. R., Optimizing the dammed: water supply losses and fish habitat gains from dam removal in California. J Environ Manage, 136: 121-31 (2014).