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REVIEW

Fluoride in drinking water and diet: the causative factor of chronic kidney diseases in the North Central Province of Sri Lanka

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Abstract A significant number of people in the North Central Province of Sri Lanka suffer from chronic kidney diseases (CKD), and the author revisits existing literature related to CKD to find its causative factor. There is a direct connection between high fluoride levels in drinking water and kidney disease, and there are unhealthy levels of fluoride in the groundwater in Sri Lanka's CKD-affected areas. Based on the following observations, the author believes with confidence that excess fluoride in drinking water and in the locally grown food in the affected areas are the culprits of CKD in Sri Lanka.

- Fluoride excretion rate is considerably lower in children than adults, leading to renal damage of children living in areas with high fluoride.
- Adults who had renal damage due to fluoride in childhood are vulnerable to CKD with continued consumption of water from the same source.
- Patients with chronic renal insufficiency are at an increased risk of chronic fluoride toxicity.
- High content of fluoride in groundwater paves the way to excess fluoride in local food crops, consequently adding more fluoride to the systems of the consumers.
- People who work outdoors for prolonged periods consume excess water and tea, and are subjected to additional doses of fluoride in their system.
- In the mid-1980s, the increase in water table levels of the affected areas due to new irrigation projects paved the way to adding more fluorides to their system through drinking water and locally grown foods.

Keywords Fluoride · Drinking water · Food · Children · CKD · Irrigation projects · Water table

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Introduction

Over the past two decades, a considerable number of investigations on the etiology of chronic kidney diseases (CKD) in the North Central Province of Sri Lanka have been conducted. However, researchers have not yet come to a solid conclusion on a definite causative factor of CKD. A number of theories have been proposed [1–13], but none have been confirmed due to lack of sufficient scientific evidence [1, 2]. There is an exchange of arguments and counterarguments among the research community, as well as among the Sri Lankan public, especially through electronic and print media. As of yet, there is no solution in the horizon for this burning problem [1, 2].

At present, the only options left for patients suffering from CKD are costly procedures such as dialysis and kidney transplants, and there is not enough proper guidance on the prevention of CKD [1]. Also, kidney dialysis is only a temporary solution, and the patients will have to go through the procedure over and over again. Additionally, it is a serious burden to Sri Lanka's already cash-strapped universal health-care system and the government. Kidney transplant, the other option, is more complicated, and patients have to bear most of the cost as well as the difficult challenge of finding a suitable donor. As almost all CKD patients are from poor farming communities [1–4], they are left with a narrow window for survival. The ideal solution for this problem is finding the root cause of CKD, at which scientists are struggling right now, and taking remedial measures at the national level to prevent healthy people, especially children, from getting sick with CKD.

In this investigation, a comprehensive literature review on kidney diseases was carried out while carefully revisiting previous research reports and publications on CKD in Sri Lanka [1–13]. Through this literature review, the author finds that a considerable number of researchers from Sri Lanka and abroad have investigated CKD in Sri Lanka and that a sizeable amount of data is available in the literature. In addition, articles written by freelance science writers and scientists that appeared in national newspapers in Sri Lanka have also been referred. The objective of the author is to determine the root cause and present a potential solution for the problem of CKD in Sri Lanka by taking a fresh look at the already published data and information [1–13]. The author is of the opinion that a fresh and impartial approach on existing data along with a thorough literature review on CKD worldwide would be helpful to get a sensible answer to this issue, before conducting further field investigations. Hence, the author has decided to revisit the bibliography of CKD in Sri Lanka with a fresh look on available data and observations.

Environmental factors

It is reported that the majority of CKD patients from the North Central Province of Sri Lanka do not show any identifiable causes, such as long-standing diabetes and hypertension, compared to their counterparts elsewhere [1–3]. This observation leads one to conclude that CKD is endemic to the North Central dry zone of Sri Lanka [1–13]. Hence, it is logical to focus on the lifestyle of the said community, along with the environmental factors which are directly associated with their day-to-day life. According to a recent review, 7.5 % of the population in the said region is directly affected by CKD, and the percentage of the population in the said region who suffer from kidney ailments is 12.5 % [1]. Some reports claim that more than 15 % of residents of the affected areas are stricken with CKD [9]. They also highlighted that it is also mainly the working male population who are affected by the disease [1–13].

A number of theories suggest that CKD occur due to fluoride, cadmium, arsenic, aluminum, mercury, uranium, vanadium, algal toxins or phosphates [1–11, 13], but none of these theories have been confirmed due to lack of sufficient scientific evidence [1, 2]. More recent theories are mainly focused on the use of pesticides and fertilizers, especially glyphosate [8] and their adverse effects to the environment, directly from the pesticide or from their potential contaminants such as arsenic, cadmium, and mercury [4, 5, 7, 10]. Another theory proposed talks about the increased ionicity of drinking water resulting from fertilizer runoff into the river system, redox processes in the soil, and features of 'tank'-cascades and aquifers [9].

Cadmium

A recent World Health Organization (WHO) report on CKD stresses cadmium as a causative factor for CKD [7], and human and animal studies suggest that elevation of blood glucose levels due to the exposure of environmental cadmium can lead to some types of diabetes and diabetes-related kidney disease [14]. However, CKD patients from Sri Lanka do not show any indication of long-standing diabetes [1, 2, 4]. Therefore, it is questionable to consider cadmium as the root cause for CKD in Sri Lanka.

Drinking water

Based on the literature review conducted, one thing almost all investigators of CKD in Sri Lanka appear to agree on is the possibility of drinking water having a close association with cases of CKD in Sri Lanka [1–13]. Therefore, upon considering a literature survey on CKD in Sri Lanka and further analysis, the author has decided to focus primarily on drinking water of the affected area [1–13].

Chronic kidney disease

Clinically, CKD is characterized by tubular proteinuria, $\beta 2$-microglobulinuria, and the absence of hypertension and edema. This histological appearance of CKD is "tubulointerstitial" that can be commonly observed in toxic nephropathies [1, 2, 4, 12]. So far, many investigators have generated considerable amount of medical as well as environmental data on this issue [1–13].

Fluoride

It has been reported that fluoride levels in water consumed by CKD patients in affected areas vary from 0.05 to 4.8 mg/L, with the mean value of 0.78 mg/L [1–4], which is well above the 0.5 mg/L, the limit recommended for tropical countries by the WHO [4]. Some reports provide alarming values as high as 3.9−7.3 mg/L fluoride levels in groundwater in some affected areas [3, 9, 11]. Incidentally, it is reported that dental and skeletal fluorosis is also widespread in these areas [4] and, therefore, it is apparent that people in CKD-affected areas in Sri Lanka are already being poisoned by high amounts of fluoride. This is why the author has opted to focus mainly on fluoride in drinking water in CKD-affected areas.

In medical literature, there are considerable amounts of research that warn about potential fluoride poisoning of consumers in municipalities in the USA and other Western countries, and about the addition of ppm amounts of fluoride to drinking water in the areas that do not have enough fluoride in groundwater [15–22]. These warnings are due to a number of health risks including the risk of kidney toxicities that pave the way to CKD. The author came across an article on this subject titled "Fluoridation of drinking water and kidney disease: absence of evidence is not evidence of absence" [16] and trusts that in the case of CKD in Sri Lanka there is ample amount of evidence, but what is lacking is a proper and impartial analysis. Further, the above article highlights a study which has proved that drinking water containing fluoride levels over 2.0 mg/L (which is half the fluoride concentration considered safe by the US Environmental Protection Agency) could in fact damage tubular structures in children [16, 17]. This conclusion is based on an investigation of 210 children in China which found that children drinking water with more than 2 ppm fluoride had increased levels of N-acetyl glucosamine (NAG) and y-glutamyl transpeptidase (yGT) in their urine, both of which are markers of renal tubular damage [17]. Another research publication reported that over 2.0 mg/L fluoride in drinking water can cause renal damage in children, and the degree of damage increases with the fluoride content of drinking water [18]. Another research article titled "Fluoride pharmacokinetics in infancy" explains that infants have impaired ability to excrete fluoride. According to their findings, young children retain a significantly higher percentage (80 %) of an absorbed dose of fluoride compared to adults (50 %), supporting the finding that "renal fluoride excretion rate is lower in children than adults" [19]. According to the research, high fluoride uptake in developing bones during childhood explains this difference in fluoride retention [19].

Therefore, as reported by other researchers, infants and children who are exposed to high levels of fluoride through drinking water and diet are exposed to more fluoride retention in the body, thereby weakening their kidneys and becoming more vulnerable to kidney diseases in their adulthood [16–23]. These particular research investigations explain that there are no known adverse effects associated with relatively low levels of fluoride (1–2 ppm in drinking water) on a chronic basis [17]. However, the actual levels of fluoride intake have to include not only the levels in water, but also in the diet and other fluoride-containing products such as toothpastes, medication, contaminations from pesticides, and more [17]. Also, it is extensively reported that patients with chronic renal insufficiency are at an increased risk of chronic fluoride toxicity [16, 17]. This means that those children who have been affected by fluoride accumulation/toxicity through drinking water and diet with already sick kidneys will become sicker in their adulthood due to further consumption of water and food with high contents of fluoride, ultimately becoming CKD patients. Another research paper states that, "renal fluoride toxicity in human beings is difficult to assess in the literature, but there are experimental studies as well as clinical reports to prove it" [20], and the author has given a case of fluoride intoxication related to potomania of Vichy water, a highly mineralized water containing 8.5 mg/L of fluoride as an example. In this report, features of fluoride osteosclerosis were prominent and end-stage renal failure was present [20]. Further, he mentions that "the young age of the patient, the long duration of high fluoride intake, and the absence of other cause of renal insufficiency suggest a causal relationship between fluoride intoxication and renal failure." Another research paper highlights the toxicity of fluoride in drinking water to human kidneys, and states that the liver and the kidneys are the target organs markedly attacked by excessive amounts of fluoride. It also explains how high doses of fluoride intake lead to the changes of structure, function and metabolism in the liver and kidney [21].

The author strongly believes that this is what is happening in the North Central Province of Sri Lanka, and the above cited research articles are well in agreement with this assumption. More literature is available in science literature worldwide that highlights the relationship between CKD and fluoride in drinking water and the diet.

Why are *men* more prone to get CKD?

Now that the relationship between CKD and fluoride consumption through water and diet has been maintained, the next question becomes, "why are *men* in these affected areas in Sri Lanka more prone to CKD?" [1–3]. Men spend more time in the paddy fields or farms, and dehydration due the exposure to the hot sun make them consume more and more water or their popular beverage, tea, which in turn adds more fluoride to their system. When compared with a normal daily diet, tea is exceptionally fortified with fluoride [23, 24]. A study conducted in the USA showed that the mean fluoride content of the brewed teas $\{3.73 \pm 0.49$ mg/kg $(n = 63)\}$ was 3−4 times higher than the national mean value of fluoride in tap water $(0.71 \pm 0.33$ mg/kg) [24]. According to the US Dietary Reference Intakes (DRI) charts, the tolerable upper intake levels of fluorides for infants, children, and adults (above 13 years) are 0.7 − 0.9, 1.3 − 2.2, and 10 mg per day, respectively [25]. It is estimated that an average farmer's intake of fluoride per day in the CKD-affected areas by just drinking water (3 L from a water source of 2 ppm fluoride) is around 6 mg per day [3]. If an average farmer drinks at least four cups of tea per day, the intake of fluoride per day can reach higher than 12−14 mg just from the liquids. Also, the addition of fluorides from the diet will elevate to very high levels, making them vulnerable to CKD.

Fluoride from diet

Some researchers have been focusing on the heavy metals and the diet of the CKD-affected region [5, 26], when more attention should have been paid to the fluoride content of the locally grown foods and freshwater fish. Green leafy and other vegetables, pulses and products, and fruits are a staple part of the diet of people living in CKD-affected areas [25]. Vegetables, pulses, and other crops grown in this area should contain high contents of fluoride due to high levels of fluoride in both the soil and groundwater. For example, it is reported that amaranth, a cheap and popular vegetable green locally known as "Thampala", excessively absorbs fluoride from the soil [27]. It is obvious that the crops grown in these areas of high fluoride concentrated soil will add more fluoride into the consumers' systems through their diet. Researchers have measured the translocation of fluoride from soil to plant body and found that high fluoride concentrations in soil are indicated by high mean concentrations of fluoride in vegetables that are grown on that soil [27–29]. Therefore, a high concentration of fluoride in the soil is directly linked to the high fluoride in groundwater and surrounding vegetation.

Why the last two decades?

The next question should be, "Why have cases of CKD in the North Central dry zone emerged within the last two decades?" The most plausible explanation considers the irrigation projects launched during the time. During the past three decades, these CKD-affected areas benefited from a number of irrigation projects, including the Accelerated "Mahaweli River Diversity Programme" that brought a new water source to the area causing the groundwater table to elevate. The Mahaweli River basin extended by the accelerated "Mahaweli Project" in the mid-1980s covers most of the CKD-stricken areas [9]. Due to the flat landscape in these irrigation areas, recharge of water led to increases in water table levels, resulting in high salinity levels in groundwater [30, 31]. This assumption is supported by the recent reports claiming that the groundwater in the affected areas have become more saline during the past two decades [8]. This observation was made by the people living in the area, and the report of a gradual but substantial increase in fluoride content of groundwater further validates this observation. In addition to water table increase, the author believes that drilling of large numbers of tube wells in the region can be another factor for this increase in fluoride, as some researchers have also suggested [1].

High salinity levels in groundwater means more fluoride as well as other minerals in groundwater, and all these new saline products make their way into the systems of those who consumed drinking water. At the same time, root systems of agricultural crops also absorb more mineral from the new soil environment, resulting in more minerals—including fluorides—in the food chain. A recent map on the distribution of fluoride in groundwater in Sri Lanka clearly shows that the fluoride in groundwater in CKD-prevalent areas (>3 ppm) is much higher than that of the neighboring farming districts of CKD-prevalent areas (1–3.0 ppm) [32]. This disparity may probably be due to the absence of major irrigation projects in these districts during the last two to three decades, thereby keeping the groundwater table at a stable level, which prevents the increase of fluoride and other minerals in the groundwater as well as in the food crops grown in these areas.

A plausible explanation

The water table of the CKD-affected areas would have been increased due to the Mahaweli River basin extended by the accelerated "Mahaweli Project" in the mid-1980s, paving the way to adding more fluorides and other minerals from the soil to the groundwater already rich in fluoride and other minerals. Hence, the drinking of groundwater as well as diet from the locally grown foods should be the reason for this relatively newly detected CKD in the North Central Province of Sri Lanka. Until Dr. Tilak Absekera reported a pattern of this CKD in these areas in 2003 [33], we would not have known for how long this condition had existed and how many people had perished from the disease.

Below is a summary of the above discussion:

1. A significant number of people living in the North Central dry zone suffer from CKD.
2. High fluoride content in groundwater, which is presently used for drinking and cooking purposes in CKD-affected areas, has been reported, and it has already been proven that dental and skeletal fluorosis is widespread among residents, due to fluoride poisoning.

3. There is enough medical evidence worldwide to prove that there is a direct connection between high fluoride levels in drinking water and kidney disease.
4. Fluoride excretion rate is considerably lower in children than adults, leading to renal damage of children living in areas with high fluoride.
5. Adults who had renal damage due to fluoride in childhood are more vulnerable to CKD by continuing to consume water from the same source.
6. It is also extensively reported that patients with chronic renal insufficiency are at an increased risk of chronic fluoride toxicity.
7. People who work in farms and other outdoor laborious activities for prolonged periods tend to consume more water to hydrate themselves and are subjected to excessive doses of fluoride entering their system. Drinking tea adds even more fluoride to their system, exacerbating the problem.
8. The Mahaweli River basin extended by the accelerated "Mahaweli Project" in the mid-1980s covers most of the CKD-stricken areas, which led to increases in water table levels, resulting in high salinity levels in groundwater, adding more fluoride as well as other minerals to groundwater. All these additional fluorides and other saline products make their way into the systems of the residents, through the drinking water and diet through locally grown crops and freshwater fish.

Conclusion

Based on the arguments and findings given above, the author believes with confidence that the culprit of the so-called "Rajarata Chronic Kidney Disease" in Sri Lanka has to be the excess fluoride in drinking water from the wells and the local foods grown in the affected areas. It is highly recommended that the Sri Lankan Government immediately make arrangements to provide safe drinking water to the people in the affected areas, and until then introduce a temporary potable water supply system to them while educating especially the school children on the root cause of the diseases. For example, mothers of bottle-feeding infants should be encouraged not to use groundwater for formula preparing or any cooking purposes. Also, scientists should analyze food crops from the affected areas for the presence of fluoride and other minerals to have a better idea about the impact of local crops on fluoride toxicity.

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