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Comparative analysis of drinking water quality in a CKDu endemic area versus a reference area in Sri Lanka: a topographic perspective

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Abstract

Chronic kidney disease of unknown cause (CKDu) is a serious health issue affecting Sri Lanka's farming communities. Continuous assessment of physico-chemical parameters and trace metals in drinking water sources is crucial for exploring the root cause of CKDu. This study investigates how geographical distribution affects trace metal and fluoride contamination in CKDu endemic Naminigama Grama Niladhari Division (GND) and Sulugune GND (reference area) in the same Divisional Secretariat (DS). Preliminary analysis indicates that trace elements, major elements, and fluoride concentrations of drinking water are within Sri Lanka's water quality guidelines in both areas. However, long-term exposure to metals may generate risks. This study analysed well water samples from these sites for trace elements (cadmium, lead, chromium, arsenic, zinc, copper, iron) and major elements (sodium, potassium, aluminum) using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Additionally, fluoride, magnesium, and calcium levels were measured. Pb, Cd, As, and Cr were within permissible limits according to Sri Lankan water quality guidelines in both areas. However, aluminum levels exceeded limits in both areas. Statistical analysis showed significantly higher concentrations of Na, Mg, Ca, Zn, Cr, As, and Cd in Naminigama than the reference area. In Naminigama, agricultural fields are at higher elevations compared to residential areas, whereas opposite in Sulugune. The metal distribution variation may be due to the geographical condition of the reference area, where surface runoff attenuates agricultural waste, thereby reducing contamination of its drinking water sources. These findings suggest that topography plays a crucial role in water contamination, providing insights into improved water quality management.

Keywords: *CKDu, Drinking water, Fluoride, Topography, Toxic metals*

Introduction

Chronic kidney disease of unknown etiology (CKDu) is known as a major health problem that affects thousands of lives in farming communities in Sri Lanka. It seems a problem concentrated in the Northcentral province and spreading over North-western, Eastern, North, Central and, Uva provinces (Bandarage, 2013). According to the National Renal Registry report, the number of CKDu patients increased throughout the last decade. There were reported 6093 male patients and 3081 female patients in the year 2016 (Bhadrani, 2017). The program of Surveillance on CKD in Sri Lanka started a screening program to detect asymptomatic individuals in the pre-clinical stages of chronic kidney disease (Paliha-wadana, 2017). Over the past 17 years, the scientific community has undertaken numerous studies, and a

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large body of research has been established. As there was no interconnection between the studies, the present scientific community has intricate ideas about the etiology of chronic kidney disease. Geographical mapping indicates a massive relationship between CKDu and agricultural irrigation water sources in the suspected areas (Rajapakse et al., 2016). Most of the studies on CKDu focused on causative agents in drinking water contaminants related to agricultural practices and natural inorganic distribution. Studies have been done to assess the relationship between CKDu and nephrotoxic elements (As, Cd, Pb, and U) in drinking water (Rango et al., 2015). It is hypothesized that high levels of fluoride in freshwater can support the intake of Cd by rice and freshwater fish (Bandara et al., 2008). High uranium (U) contents were found in some fertilizer samples, and it may cause nephrotoxic effects in relation to CKDu (Chandrajith et al., 2010). It is also hypothesized that there is the possibility of synergic effects between fluoride, cadmium, and hardness of the water on the etiology of disease (Wasana et al., 2016). Another study has shown the possibility of the pathogenesis of CKDu via long-term Cd exposure, Se deficiency, and genetic susceptibility for disease. And, it has divided the pathogenesis into four stages depending on Glomerular Filtration Rate (GFR) (Jayatilake et al., 2013). At the same time, different studies have shown opposing ideas about heavy metals and the involàvement of ions in the water. None of the Cd, As, and Pb showed significantly higher concentrations in cases compared with controls. And found evidence for major genetic susceptibility to CKDu (Nanayakkara et al., 2014). Analysis of biological samples including urine, hair and, renal tissue did not provide evidence to support Cd or As toxicity for CKDu (Nanayakkara et al., 2019). It has shown increased urine As concentrations were associated with increased albuminuria in a renal US population (Zheng et al., 2013). A study assessed the suitability of groundwater for drinking water separately in dry and wet seasons in CKDu affected areas. Elevated values of hardness, fluoride, salinity, alkalinity, and dissolved organic carbon (DOC) were observed during the dry season than the wet season (Cooray et al., 2019). During the dry season, the concentration of anions and cations (F^-, Cl^-, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}) increases in the groundwater. It is hypothesized that the resultant ion toxicity could damage kidneys (Manthrithilake, 2015). Another study result clarifies the origin of CKDu due to the joint presence of fluoride and magnesium ions in drinking water (Dharma-wardana, 2018). Studies have blamed the geological conditions which would be responsible for natural contaminants in groundwater as the main causative factor for CKDu (Edirisinghe et al. 2017). A review on CKDu in Sri Lanka has concluded the etiology of CKDu can be

1) Excess fertilizer use;
2) Excess amount of ion contents in irrigation water due to dissolved fertilizer residues;
3) Prolonged use of water with an excess number of ions(Dharma-wardana et al., 2015).

Meanwhile one of the studies has critically evaluated potential etiology factors of CKDu of multifactorial origin under that ionicity, heavy metals, fluoride, agrichemicals based on previous studies (Wimalawansa, 2016). Chronic nephrotoxic agent of As was found in urine samples of CKDu patients and hypothesized the possible As source as agrochemicals since not reported the presence of As in the bedrocks in Sri Lanka (Jayasumana et al., 2013). Another study hypothesizes higher Na and Ca in fluoride-rich drinking water as another major cause of chronic renal failure in CKDu (Chandrajith et al., 2011). Dissolution of Aluminium from cooking utensils under high fluoride stress in drinking water has been proposed as a possible risk factor for CKDu (Ileperuma et al., 2009). In relation to this, another study has concluded AlF_x or Al and F ions do not support as causative for CKDu (Wasana et al., 2015). Excess fluoride in drinking water from the wells and local foods grown in the affected areas has taken as the major culprit of CKDu (Dharmaratne, 2015). However, intense agricultural practices may influence the drinking water safety of the agriculture-oriented areas (Dharma-wardana et al., 2015) and the geographical pattern of the area may be critical for drinking water contamination. Even, there are so many studies that have focused on the influence of topography on the water quality of rivers and streams, drinking water sources and topography correlation has not concerned. This study is to evaluate the quality and safety of drinking water in a CKDu endemic area comparing with a reference area in the same Divisional secretariat (DS) area in Sri Lanka and assess the influence of geographical variation on contamination of drinking water sources of the selected two sampling areas Finally to investigate the influence of the topography of areas for the quality of the drinking water sources based on CKDu distribution patterns.

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Materials and Methods

Sample collection

Based on the information obtained from the Ministry of Health, Sri Lanka, Naminigama Grama Niladhari division (GND) was selected as CKDu endemic area and Sulugune Grama Niladhari division (GND) was selected as a reference area where no CKDu patient has been reported so far (2019). Both sites have been in the Wilgamuwa DS area, Mathale district, Sri Lanka. Naminigama, Sri Lanka, is situated at an elevation of 106 meters above sea level. Geologically, it consists of flat terrain and experiences a tropical climate characterized by distinct dry and monsoon seasons. In contrast, the reference area, Sulugune at an elevation of 152 meters, is in Sri Lanka's highlands. It features mountainous terrain and locates within the same climatic zone (Dry zone of Sri Lanka) as the Naminigama. Sampling points for the drinking water sample collection were selected from shallow drinking water wells (dug wells) located in the home gardens of the residents which are the main sources of water consumption in their daily life. Thirty (30) dug wells were selected randomly for the water sampling and all the sampling sites were located within the same climatic zone (Dry zone of Sri Lanka). The sampling procedure was carried out within July–2019 (dry season) for all selected study areas. Thirty drinking water samples from each sampling area were collected in triplicate and stored in uncontaminated Teflon bottles (125 mL). The samples were preserved by adding Conc. Nitric acid (0.10 mL) and stored at 4^0C.

Analysis of Chemical parameters

pH, conductivity, and Dissolved Oxygen (DO) of the collected water samples were measured as on-site measurements. Concentrations of trace elements (cadmium, lead, chromium, arsenic, zinc, copper, iron) and major elements (sodium, potassium, and aluminum) were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS-7800-Agilent, Germany). Multi-element ICP-MS standards (Accu Standard, USA) were used for the instrumental calibration. Two calibration series (0.1 ppb – 10 ppb and 10 ppb to 1000 ppb) were prepared using multi-element standard and acidified water samples filtered through 0.45µm syringe filters before the insertion to the ICP-MS. During the running procedure of the samples, relevant calibration series was inserted after each ten cluster of the samples. Fluoride concentrations of water samples were measured as on-site measurements using a calibrated fluoride meter (EUTECH INSTRUMENT-pH 510) and when taking the readings, TISAB (III) buffer was used with water sample in 1:1 ratio to stabilize the pH of the medium. Magnesium and calcium concentrations in water samples were determined using a flame atomic absorption spectrophotometer (GBC 5000). A series of standard metal solutions were prepared (10 ppm-1000 ppm) separately using both Mg and Ca metal ion standards (1000 ppm, Bibby Scientific) to obtain the calibration curve and the concentrations of Mg and Ca of each water sample.

Geographical data treatment and statistical data analysis

ArcGIS 10.2.2 software package was used to perform surface interpolation for all sampling sites using estimated mean values to measure the impact of water contamination in the study area. Statistical analysis was done using Minitab Statistics software. Descriptive statistics were performed on the data sets and Two-sample T-tests were carried out to determine the differences or similarities of the chemical parameters recorded in each sampling location at the 0.05 of significance levels. Pearson correlation analysis was conducted to assess the strength and direction of linear relationships among chemical parameters.

Results and Discussion

Analysis of drinking water quality

When it closely heed the patients' distribution within a single district, it can be seen that some of the areas in the same district are not affected while other areas are affected with chronic renal failure (Ranasinghe et al., 2019). Wilgamuwa divisional secretariate is one of the divisional secretariates in Matale district, which is further divided into 39 fourth-order administrative Grama Niladhari (GN) divisions and according to the data obtained from the ministry of health Sri Lanka, among these GN divisions, the prevalence of CKDu was uneven. The Sulugune GN division (CKDu nonprevalent) and Naminigama GN division (CKDu prevalent), were distant by 9.36 kilometers away from each other. Because of this reason, Sulugune GN division and Naminigama GN division were subjected to further investigation. And Table 1 summarizes the results of trace metals, fluoride ion concentrations, and basic physicochemical parameters of selected well water samples which have obtained from Naminigama GND, and Sulugune GND (reference

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Table 1. *Descriptive statistics of metallic elements, Fluoride, and Physico-chemical parameters of dug well water (Drinking) samples in the sampling locations; Naminigama GND, Sulugune GND*

Parameters	Naminigama GND Endemic Site			Sulugune GND Reference Site			SLS STANDARDS SLS 614:2013
	Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum	
Na (mg L^{-1})	6.76 ± 1.08*	4.40	7.89	1.50 ± 0.13*	1.22	1.76	200
Mg (mg L^{-1})	10.3 ±1.59*	8.02	13.5	5.71 ±0.73*	4.48	6.98	30
Al (mg L^{-1})	0.34 ± 0.01*	0.02	0,58	0.59 ± 0.06*	0.48	0.66	0.2
K (mg L^{-1})	0.16 ± 0.05*	0.81	2.94	0.45 ± 0.09*	0.29	5.62	N/A
Ca (mg L^{-1})	5.67 ± 0.75*	4.03	7.03	2.71 ± 0.39*	1.95	3.36	100
Cr (μg L^{-1})	0.89 ± 0.12*	0.67	1.20	0.28 ± 0.04*	0.21	0.36	50
Fe (μg L^{-1})	62.9 ± 7.68	50.2	74.7	58.3 ± 11.2	30.9	78.6	300
Cu (μg L^{-1})	0.56 ± 0.14	0.10	0.77	0.60 ± 0.17	0.23	0.87	1000
Zn (μg L^{-1})	66.8 ± 8.09*	51.2	79.9	27.6 ± 4.64*	21.4	37.3	3000
As (μg L^{-1})	0.38 ± 0.09*	0.15	0.50	0.05 ± 0.04*	0.02	0.33	10
Cd (μg L^{-1})	0.04 ± 0.007*	ND	0.06	0.02 ± 0.005*	0.02	0.04	3
Pb (μg L^{-1})	0.23 ± 0.07*	0.11	0.39	0.62 ± 0.13*	0.40	0.92	10
Fluoride (mg L^{-1})	0.85 ± 0.61	0.23	2.80	0.33 ± 0.27	0.11	0.51	1.0
pH	6.82 ± 0.87	6.02	7.76	6.15 ± 0.65	5.76	6.77	6.5-8.5
Conductivity (μS cm^{-1})	602 ± 350	102	1098	188 ± 5.0	48	193	N/A
Dissolved Oxygen (ppm)	5.63 ± 1.56	4.08	6.35	4.29 ± 1.12	3.13	5.09	N/A

* $p < 0.05$, ND - Not Detected, N/A – Not Available

site) respectively compared with the permissible limits (SLS 614: 2013). When considering the causative factors of CKDu, toxic elements are the most important concern including cadmium, chromium, and lead (Kazancioğlu, 2013). According to Sri Lankan drinking water quality standards, the Maximum Permissible Levels (MPL) of toxic elements such as Pb, Cd, As, and Cr were not exceeded in Naminigama (CKDu prevalent area) and Sulugune GND (reference area). Among analyzed metals, the mean aluminum concentration of the dug well water has exceeded the permissible limits in both GN areas. Additionally, Fluoride can occur naturally in water above desirable levels and fluoride has also been suggested as a cause of CKDu (Dharma-wardana et al., 2015). However, the mean fluoride concentrations of selected dug wells in both areas have not been exceeded the permissible limits defined by Sri Lankan water quality standards. Despite this, 20% of selected dug wells in Naminigama GND was reported to exceed MPL of fluoride content and a wide range of fluoride concentrations were reported in dug wells (0.23 mg/L – 2.80 mg/L). Another remarkable difference has been reported in the conductivity values of the water samples in two areas. The mean conductivity value of water samples from Naminigam GND was 602 ± 350 μS cm^{-1}. This value is significantly lower than that of the reference's conductivity values (188 ± 5.0 μS cm^{-1}). As the toxic metal ion concentrations and fluoride content were not exceeding the permissible limits (SLS 614: 2013), the Two-Sample T-test was applied to determine whether the difference between the population means is statistically significant. A significance level of 0.05 was used in the procedure. After estimation of the differences in the population means under a 95% confidence interval, the metal ion couples from the two sites were subjected to determine whether the differences of means are statistically significant. According to the results, Na, Mg, Al, K, Ca, Cr, Zn, As, Cd, and Pb ion concentration differences were statistically significant in the two sites (Table 1) Meanwhile, Na, Mg, Ca, and Zn, concentrations as well as some of the recognized nephrotoxic elements

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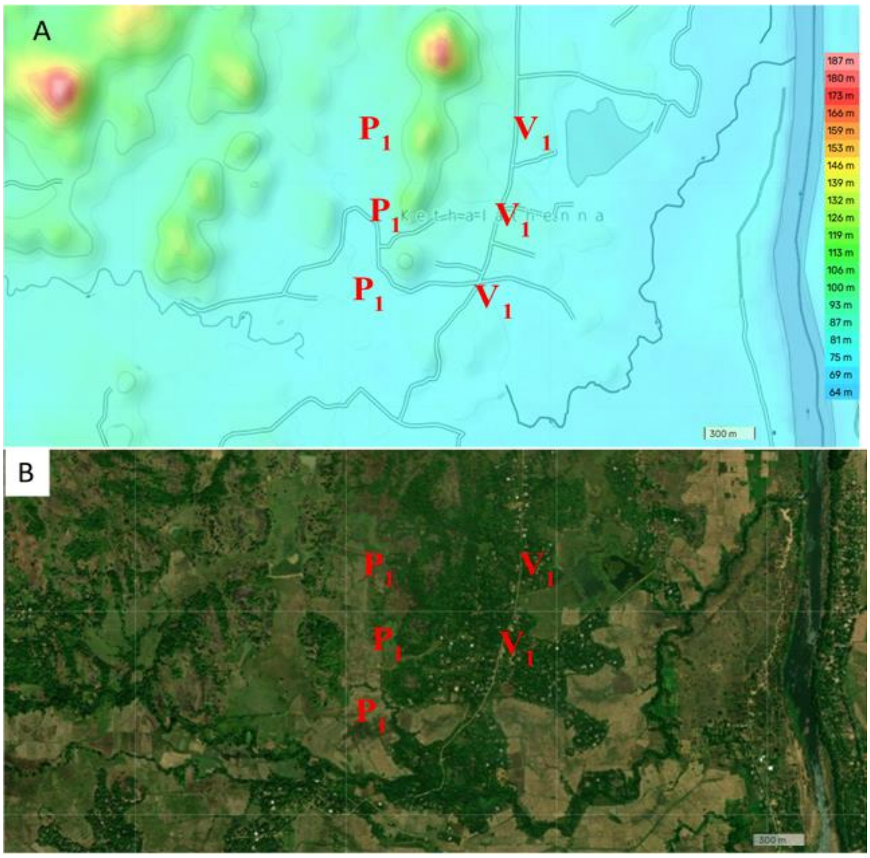

Figure 1
A) *Elevation map of Naminigama GND (CKDu endemic area), contour line offer a sense of the topography or hilliness of the are the map depicts. Each contour line represents a given elevation above sea level. And also in the given elevation maps, the base elevation is given in the map legend with relevant colours. The colours within the sections denote a particular elevation.*
B) *Satellite map of Naminigama GND.*

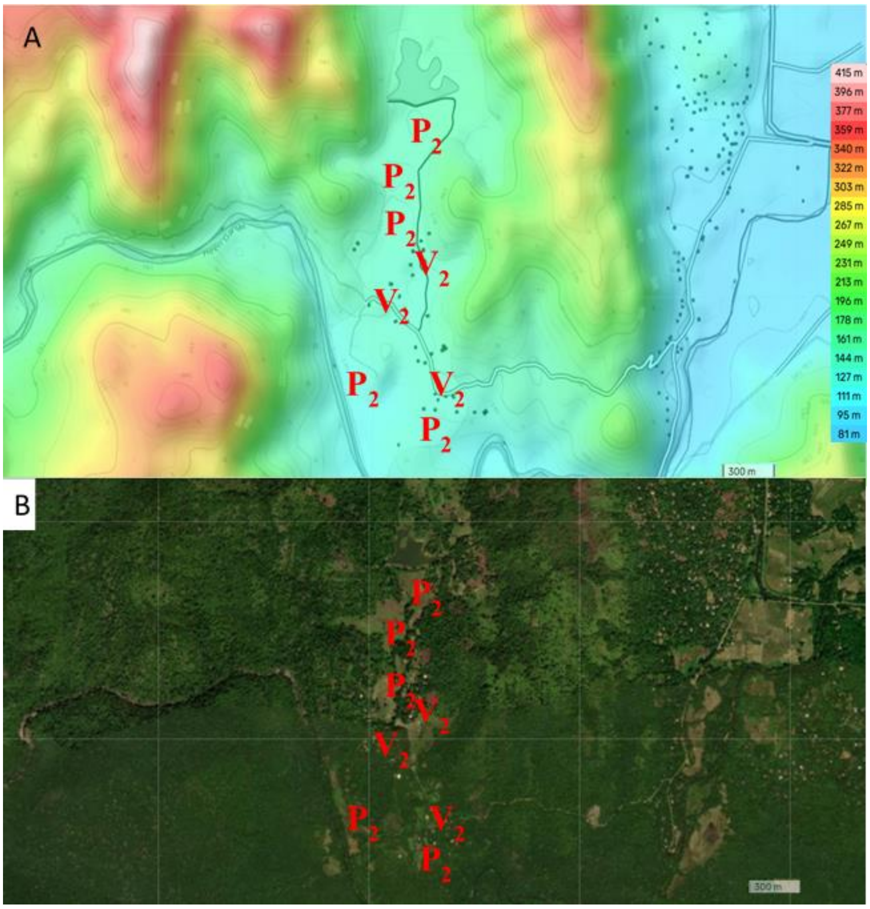

Figure 2
A) *Elevation map of Sulugune GND (reference area), contour line offer a sense of the topography, or hilliness of the area the map depicts. Each contour line represents a given elevation above sea level. And also in the given elevation maps, the base elevation is given in the map legend with relevant colours. The colours within the sections denote a particular elevation.*
B) *Satellite map of Sulugune GND.*

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such as Cr, As and Cd were higher in Naminigama GND (CKDu high prevalent area) than the Sulugune GND (CKDu non-prevalent area). However, high mean Pb concentration was reported in the drinking water samples of the reference site than the endemic site. Even if, mean concentrations of the trace elements such as Cr, As, Cd and Pb have not been exceeded the MPLs, long-term exposure to those elements via drinking water may critical for damaging of soft tissues of some organs like kidneys (Reyes et al., 2013). There was no considerable correlation between trace elements and other Physico-chemical parameters. Apart from that, both selected areas are agricultural regions including paddy cultivation. Many agrochemicals, such as fertilizers and pesticides used in agricultural fields, produce excessive quantities of toxic metals (Gimeno-García et al., 1996). Mainly, due to the persistence of elevated amounts of toxic metals in the fertilizers, paddy soil, tank sediments as well as natural water resources may expose contamination with various heavy metals/metalloids. Exceeded threshold values for certain toxic metals (Cd, As, Pb, and Cr) in selected tank sediments indicate that there may be a risk to toxic heavy metal circulation in the selected CKDu endemic region in Sri Lanka (W. P. R. T. Perera et al., 2021). Furthermore, elevated levels of the toxic metals/metalloids such as Cr, As, Cd, and Pb have been reported in frequently applied fertilizers (Urea, Triple Super Phosphate, and Murate of Potash) in Sri Lanka (R. T. Perera et al., 2020) . Additionally, most of the toxicants carried by runoff may be released into existing water Columns (Khan et al., 2008). However, both selected CKDu prone GND and reference areas are agricultural oriented rural areas. But there is a remarkable difference regarding CKD patients since none of the CKD patients has been reported in the reference GND. To find an etiological answer for this scenario, it is important to analyze the geographical features (topographic maps and satellite maps) (Alvioli et al. 2018) in the Sulugune GND and Naminigama GND.

Topographic evaluation

The topographic map of the Naminigama GND shows a possible reason to increase some metal ion concentrations in dug well water. Their agricultural lands, $\mathbf{P_1}$ (Paddy fields) are located at higher elevation levels compared to their village residential sites $\mathbf{V_1}$ (Figure 1). According to the topography of the area, the topography map of Sulugune GND (Figure 2) is different from Naminigama GND. The map of Sulugune GND depicted that residents and water sources ($\mathbf{V_2}$) are located at higher elevation levels than their paddy cultivation lands ($\mathbf{P_2}$). Hence, this phenomenon could distract the surface runoff and leaching of the fertilizers and pesticides to the water columns or drinking water resources (Kweon and Kanade 1994).

Conclusions

Consumption of safe and quality drinking water has become a grievous issue in Sri Lanka in some areas including CKDu endemic areas. Although toxic elements such as Cd, Pb, Cr, Zn, and as well as fluoride levels in both of CKDu endemic and reference areas have not been exceeded Sri Lanka water quality guidelines, most of the metal ions such as Na, Mg, Ca, and Zn, as well as some recognized nephrotoxic elements such as Cr, As and Cd were significantly higher in Naminigama GND than in the non-prevalent area. This variation may be attributed to the differences in topography between the two regions. Since residential areas in the reference regions are located at higher elevations than their paddy fields, surface runoff is slowed, which helps reduce the contamination of surface water with agricultural waste. In contrast, in CKDu-endemic regions, paddy fields are positioned at higher elevations than dug wells. Hence, further investigation is needed to be carried out on topographic differences and drinking water quality to locate the new dug wells and other drinking water sources in appropriate places in the land.

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References

ALVIOLI M., MONDINI A.C., FIORUCCI F., CARDINALI M., MARCHESINI I. (2018) Topography-driven satellite imagery analysis for landslide mapping. Geomatics, Natural Hazards and Risk, 9(1): 544-567. http://doi.org/10.1080/19475705.2018.1458050

DOI: 10.6092/issn.2281-4485/21341

BANDARA J.M.R.S., SENEVIRATHNA D.M.A.N., DASANAYAKE D.M.R.S.B., HERATH V., BANDARA J.M.R.P., ABEYSEKARA T., RAJAPAKSHA K.H. (2008) Chronic renal failure among farm families in cascade irrigation systems in Sri Lanka associated with elevated dietary cadmium levels in rice and freshwater fish (Tilapia). Environmental Geochemistry and Health, 30(5):465–478. https://doi.org/10.1007/s10653-007-9129-6

BANDARAGE A. (2013) Political Economy of Epidemic Kidney Disease in Sri Lanka. Sage Open, 3(4): 2158244013511827. https://doi.org/10.1177/2158244013511827

BHADRANI J.M. (2017). Ministry of Health annual health bulletin. Ministry of Health. https://www.health.gov.lk/wp-content/uploads/2022/12/AHB_2016.pdf

CHANDRAJITH R., DISSANAYAKE C.B., ARIYARATHNA T., HERATH H.M.J.M.K., PADMASIRI J.P. (2011) Dose-dependent Na and Ca in fluoride-rich drinking water - Another major cause of chronic renal failure in tropical arid regions. Science of The Total Environment, 409(4): 671–675. https://doi.org/10.1016/j.scitotenv.2010.10.046

CHANDRAJITH R., SENEVIRATNA S., WICKRAMAARACHCHI K., ATTANAYAKE T., ATURALIYA T.N.C., DISSANAYAKE C.B. (2010) Natural radionuclides and trace elements in rice field soils in relation to fertilizer application: Study of a chronic kidney disease area in Sri Lanka. Environmental Earth Sciences, 60(1): 193–201. https://doi.org/10.1007/s12665-009-0179-1

COORAY T., WEI Y., ZHONG H., ZHENG L., WERAGODA S.K., WEERASOORIYA R. (2019) Assessment of Groundwater Quality in CKDu Affected Areas of Sri Lanka: Implications for Drinking Water Treatment. International Journal of Environmental Research and Public Health, 16(10): 1698. https://doi.org/10.3390/ijerph16101698

DHARMARATNE R.W. (2015) Fluoride in drinking water and diet: The causative factor of chronic kidney diseases in the North Central Province of Sri Lanka. Environmental Health and Preventive Medicine, 20(4): 237–242. https://doi.org/10.1007/s12199-015-0464-4

DHARMA-WARDANA M.W.C. (2018) Chronic kidney disease of unknown etiology and the effect of multiple-ion interactions. Environmental Geochemistry and Health, 40(2): 705–719. https://doi.org/10.1007/s10653-017-0017-4

DHARMA-WARDANA M.W.C., AMARASIRI S.L., DHARMAWARDENE N., PANABOKKE C.R. (2015) Chronic kidney disease of unknown aetiology and groundwater ionicity: Study based on Sri Lanka. Environmental Geochemistry and Health, 37(2): 221–231. https://doi.org/10.1007/s10653-014-9641-4

GIMENO-GARCÍA E., ANDREU V., BOLUDA, R. (1996) Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. Environmental Pollution, 92(1): 19–25. https://doi.org/10.1016/0269-7491(95)00090-9

ILEPERUMA O.A., DHARMAGUNAWARDHANE H. A., HERATH K.P.R.P. (2009) Dissolution of aluminium from sub-standard utensils under high fluoride stress: A possible risk factor for chronic renal failure in the North-Central Province. Journal of the National Science Foundation of Sri Lanka, 37(3): 219 https://doi.org/10.4038/jnsfsr.v37i3.1217

JAYATILAKE N., MENDIS S., MAHEEPALA P., MEHTA F.R. (2013) Chronic kidney disease of uncertain aetiology: Prevalence and causative factors in a developing country. BMC Nephrology, 14(1): 180. https://doi.org/10.1186/1471-2369-14-180

JAYASUMANA M.A.C.S., PARANAGAMA P.A., AMARASINGHE M.D., WIJEWARDANE K.M.R.C., DAHANAYAKE K.S., FONSEKA S.I., RAJAKARUNA K.D.L. M.P., MAHAMITHAWA A.M.P., SAMARASINGHE, U. D., SENANAYAKE V. K. (2013). Possible link of chronic arsenic toxicity with chronic kidney disease of unknown etiology in Sri Lanka. Journal of Natural Sciences Research, 3(1), 64.

KAZANCIOĞLU R. (2013). Risk factors for chronic kidney disease: An update. Kidney International Supplements, 3(4): 368–371. https://doi.org/10.1038/kisup.2013.79

KHAN S., CAO Q., ZHENG Y.M., HUANG Y.Z., ZHU, Y.G. (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution, 152(3): 686–692. https://doi.org/10.1016/j.envpol.2007.06.056

KWEON I.S., KANADE T. (1994). Extracting topographic terrain features from elevation maps. CVGIP: image understanding, 59(2): 171-182. https://doi.org/10.1006/ciun.1994.1011

NANAYAKKARA S., SENEVIRATHNA S., ABEYSEKERA T., CHANDRAJITH R., RATNATUNGA N., GUNARATHNE E., YAN J., HITOMI T., MUSO E., KOMIYA T., HARADA K.H., LIU W., KOBAYASHI H., OKUDA H., SAWATARI H., MATSUDA F., YAMADA R., WATANABE T., MIYATAKA H., KOIZUMI A. (2014) An Integrative Study of the genetic, social and environmental determinants of chronic kidney disease characterized by Tubulointerstitial Damages in the North Central Region of Sri Lanka. Journal of Occupational Health, 56(1):28–38. https://doi.org/10.1539/joh.13-0172-OA

DOI: 10.6092/issn.2281-4485/21341

NANAYAKKARA S., SENEVIRATHNA S.T.M.L.D., HARADA K.H., CHANDRAJITH R., HITOMI T., ABEYSEKERA T., MUSO E., WATANABE T., KOIZUMI A. (2019) Systematic evaluation of exposure to trace elements and minerals in patients with chronic kidney disease of uncertain etiology (CKDu) in Sri Lanka. Journal of Trace Elements in Medicine and Biology, 54: 206–213. https://doi.org/10.1016/j.jtemb.2019.04.019

MANTHRITHILAKE H. (2015). CKDu: Are we shooting the right target? International Water Management Institute (IWMI)

PALIHAWADANA. (2017) Weekly Epidemiological Report. Epidemiology Unit Ministry of Health, Nutrition & Indigenous Medicine, 44(7).

PERERA R.T., DAYANANDA N., BOTHEJU S., LIYA-NAGE J., RANASINGHE A., KARUNARATHNA R.H., KUMARA G.W.G.P. (2020) Heavy metal contami- nation in surface sediments of major tanks in Anuradha-pura district; A CKDu endemic district in Sri Lanka. EQA - International Journal of Environmental Quality, 40-48 . https://doi.org/10.6092/ISSN.2281-4485/11001

PERERA W.P.R.T., DAYANANDA M.D.N.R., DISSA-NAYAKE D.M.U.C., RATHNASEKARA R.A.S. D., BOTHEJU W.S.M., LIYANAGE J.A., WERAGODA S.K., KULARATHNE K.A.M. (2021) Risk Assessment of Trace Element Contamination in Drinking Water and Agricultural Soil: A Study in Selected Chronic Kidney Disease of Unknown Etiology (CKDu) Endemic Areas in Sri Lanka. Journal of Chemistry, 1–10. https://doi.org/10.1155/2021/6627254

RAJAPAKSE S., SHIVANTHAN M.C., SELVARAJAH M. (2016) Chronic kidney disease of unknown etiology in Sri Lanka. International Journal of Occupational and Environmental Health, 22(3): 259–264. https://doi.org/10.1080/10773525.2016.1203097

RANASINGHE A.V., KUMARA G.W.G.P., KARUNA-RATHNA R.H., DE SILVA A.P., SACHINTANI K.G. D., GUNAWARDENA J.M.C., KUMARI S.K.C.R., SARJANA M.S.F., CHANDRAGUPTHA J.S., DE SILVA M.V.C. (2019) The incidence, prevalence and trends of Chronic Kidney Disease and Chronic Kidney Disease of uncertain aetiology (CKDu) in the North Central Province of Sri Lanka: An analysis of 30,566 patients. BMC Nephrology, 20(1):338. https://doi.org/10.1186/s12882-019-1501-0

RANGO T., JEULAND M., MANTHRITHILAKE H., McCORNICK P. (2015) Nephrotoxic contaminants in drinking water and urine, and chronic kidney disease in rural Sri Lanka. Science of The Total Environment, 518–519: 574–585. https://doi.org/10.1016/j.scitotenv.2015.02.097

REYES J.L., MOLINA-JIJÓN E., RODRÍGUEZ-MUÑOZ R., BAUTISTA-GARCÍA P., DEBRAY-GARCÍA Y., NAMORADO M.D.C. (2013) Tight Junction Proteins and Oxidative Stress in Heavy Metals-Induced Nephrotoxicity. BioMed Research International, 3: 1–14. https://doi.org/10.1155/2013/730789

WASANA H.M.S., PERERA G.D.R.K., DE GUNAWAR-DENA P.S., BANDARA J. (2015) The impact of aluminum, fluoride, and aluminum–fluoride complexes in drinking water on chronic kidney disease. Environmental Science and Pollution Research, 22(14): 11001–11009. https://doi.org/10.1007/s11356-015-4324-y

WASANA H.M.S., ALUTHPATABENDI D., KULA-RATNE W.M.T.D., WIJEKOON P., WEERASOORIYA R., BANDARA J. (2016) Drinking water quality and chronic kidney disease of unknown etiology (CKDu): Synergic effects of fluoride, cadmium and hardness of water. Environmental Geochemistry and Health, 38(1), 157–168. https://doi.org/10.1007/s10653-015-9699-7

WIMALAWANSA S.J. (2016. The role of ions, heavy metals, fluoride, and agrochemicals: Critical evaluation of potential aetiological factors of chronic kidney disease of multifactorial origin (CKDmfo/CKDu) and recommenda-tions for its eradication. Environmental Geochemistry and Health, 38(3):639–678. https://doi.org/10.1007/s10653-015-9768-y

ZHENG L.Y., UMANS J.G., TELLEZ-PLAZA M., YEH F., FRANCESCONI K.A., GOESSLER W., SILBER-GELD E.K., GUALLAR E., HOWARD B.V., WEAVER, V.M., NAVAS-ACIEN A. (2013) Urine Arsenic and Prevalent Albuminuria: Evidence From a Population-Based Study. American Journal of Kidney Diseases, 61(3): 385–394. https://doi.org/10.1053/j.ajkd.2012.09.011