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Review

Groundwater-Based Drinking Water Supply in Sri Lanka: Status and Perspectives

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Abstract: Drinking water is largely from groundwater in Sri Lanka, so quality management is of great concern. In order to achieve the 6th goal of United Nations (UN) Sustainable Development Goals (SDG), more efforts are being undertaken to secure drinking water quality. In this paper, the current status, challenges and opportunities of groundwater quality management and improvement in Sri Lanka were reviewed and discussed, based on previous studies. There are Ca-HCO_3 type, Ca–Mg-HCO_3 type and Na–SO_4–Cl type groundwater dominated in the wet zone, intermediate and the dry zone, respectively. Elevated levels of hardness, fluoride, DOC, and alkalinity, and salinity are reported in the groundwater in the dry zone controlled by geology and arid climate. Although groundwater in some regions contain significant levels of nitrates, arsenic, cadmium and lead, the majority remain at acceptable levels for drinking purposes. As for treatment technologies, existing membrane-based drinking water treatment technologies such as RO (Reverse Osmosis) stations can produce safe and clean drinking water to the community, but this has still a limited coverage. To achieve a safe drinking water supply for all, especially in rural communities of Sri Lanka under the 6th goal of the UN SDG, more efforts in building up the infrastructure and man power are needed to monitor and assess groundwater quality regularly so as to develop management strategies. Research and development can be directed towards more cost-effective water treatment technologies. Protection of groundwater from being polluted, and educational and awareness programs for the stakeholders are also essential tasks in the future.

Keywords: aquifers; drinking water quality; geogenic; groundwater; nanofiltration; reverse osmosis

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1. Introduction

Groundwater has been playing a vital role in the domestic, industrial, and agricultural water supply around the globe due to its availability and reliability. With the increase of the population and urbanization, water demand is usually increased for domestic, agricultural, and industrial needs. Groundwater usage of Sri Lanka has been widely spreading throughout the country especially in the dry zones, e.g., a significant fraction of the population still use the dug wells (36.4%) and tube wells (3.2%) as their main water source [1]. Drinking purpose is the major usage apart from agricultural usage of groundwater. It was observed that groundwater coverage (39.6%) has not been expanded in the last decade, but pipe-borne water supply has been increased from 36.8% to 51.5%

of the population while reaching 91.6% total safe water coverage within the last decade (2009–2019) (Figure 1) [2]. Usually, pipe-borne water is produced from surface water with less dissolved mineral content by conventional water treatment methods. Groundwater quality management, especially in the dry zone is a critical factor for future sustainability [3].

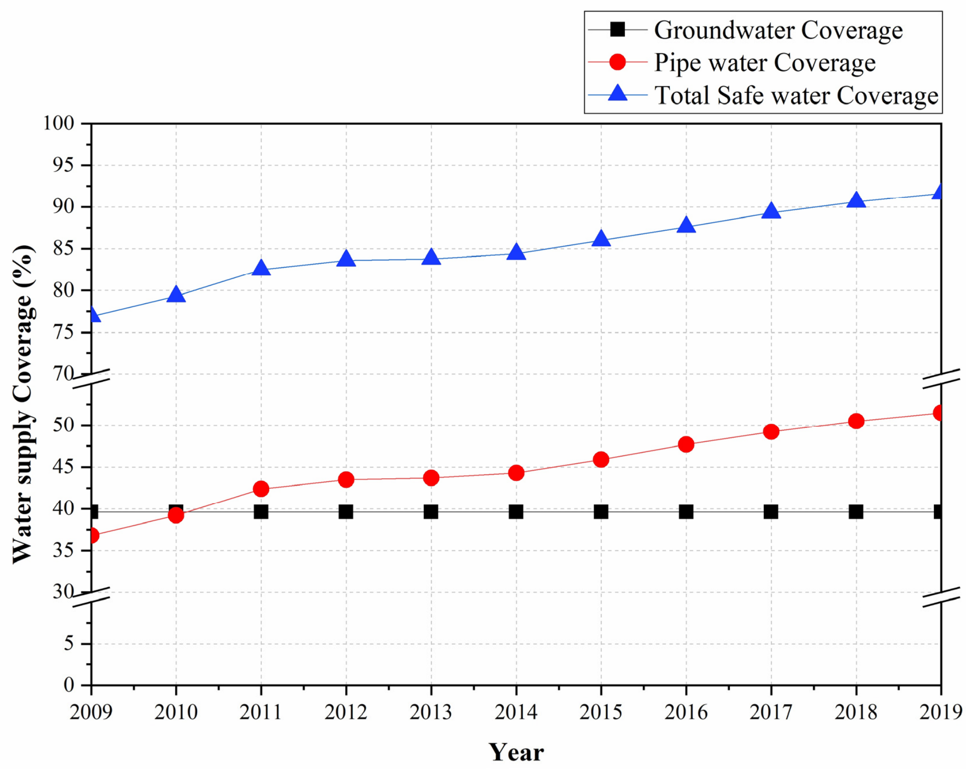

Figure 1. Progress of drinking water supply in Sri Lanka from 2009 to 2019 [2].

Ancient Sri Lanka has fulfilled their water requirements by the man-made tank systems which were built more than one thousand years ago throughout the dry zone to harvest and store the rainwater in large scale [4], but the major drinking water source has slowly changed to the groundwater due to the influence of Western colonization in Sri Lanka in the past few centuries that lasted until 1948 [5]. Usually, the volume of the stored water in the regolith aquifer system and the level of the water table in the central dry zone are depending on the water level of man-made surface water reservoirs. Seasonally, apparent changes in water level in the shallow dug wells can be observed with the water levels in tank cascade systems [4,6,7]. With the increasing population, a rapid increase of extensive agricultural practices and the growing number of industrial facilities has become significant. It creates a huge demand for water resources which leads to a higher extent of groundwater extraction as well as increased pollution of water resources. Over extraction of groundwater has also become a major problem in lowering the groundwater table which may result in different groundwater problems such as seawater intrusion and depletion of the water storages especially in coastal aquifers. Groundwater quality and quantity generally depend on environmental, geological, climatic, and anthropogenic factors, and quite a higher variation of those factors can be observed throughout Sri Lanka [8]. Furthermore, Sri Lanka has been suffering from major health crises over decades due to the drinking water quality, especially direct use of groundwater, e.g., chronic kidney disease of unknown etiology (CKDu) has drawn more attention due to its higher prevalence throughout the country in the past few decades [9–11].

The 6th goal (Clean water and sanitization) of United Nations (UN) Sustainable Development Goals (SDG) was established to ensure availability and sustainable management of water and sanitation for all around the globe [12,13]. To achieve the 6th goal of UN SDG, Sri Lanka has made great efforts and progress by reaching 90.6% of the population (Target

6.1) which have access to safe drinking water [14], 41.2% of them are pipe-borne water supplied by NWSDB, and 48.4% covered by CBOs which are not subjected to regular water quality monitoring. Groundwater supply has been reached for 39.6% of the population. The need for an integrated policy framework for water management in Sri Lanka (Target 6.5) in the Voluntary National Review (VNR) of Sri Lanka (2018) [14] has been highlighted by many stakeholders, and different policies have been established such as the National Drinking Water Policy 2008, the National Policy of Sanitation, the Rural Water Supply and Sanitation Policy, and the Rainwater Harvesting Policy to cover specific subsectors in the water and sanitation sector. The key organization, the Ministry of Water Supply has been working on the drinking water and sanitization issues in cooperation with other responsible organizations such as the National Water Supply and Drainage Board (NWSDB) and the Department of Community Water Supply. In addition, Sri Lanka has become a vulnerable country for the depletion of natural freshwater resources due to climate change, and the National Adaptation Plan (NAP) for Climate Change Impacts in Sri Lanka 2016–2025 [15] as well as the Nationally Determined Contributions (NDCs), Sri Lanka, 2016 [16] which have emphasized the vulnerability of the water sector and covered several measures to address the water scarcity issue in Sri Lanka by climate adaption activities.

Therefore, the purposes of this review focus on summarization and analysis of the groundwater quality and existing issues, and water treatment technologies throughout the country, in order to provide support for implementing and developing the suitable drinking water treatment technologies in rural regions of Sri Lanka in the future.

2. Geology and Aquifers of Groundwater in Sri Lanka

Sri Lanka is an island country which is located in the Indian ocean. Geologically, Sri Lanka consists of five distinct geological zones such as Miocene to quaternary (Cenozoic Cover), Wanni complex, Highland complex, Vijayan complex, and Kadugannawa complex which have different lithological characteristics and origins [17,18] (Figure 2a). The majority (>90%) of regions in Sri Lanka have been covered with Precambrian metameric rocks. Weathering metamorphic bedrock and fracturing has created major aquifers or underground water storages throughout this land [8].

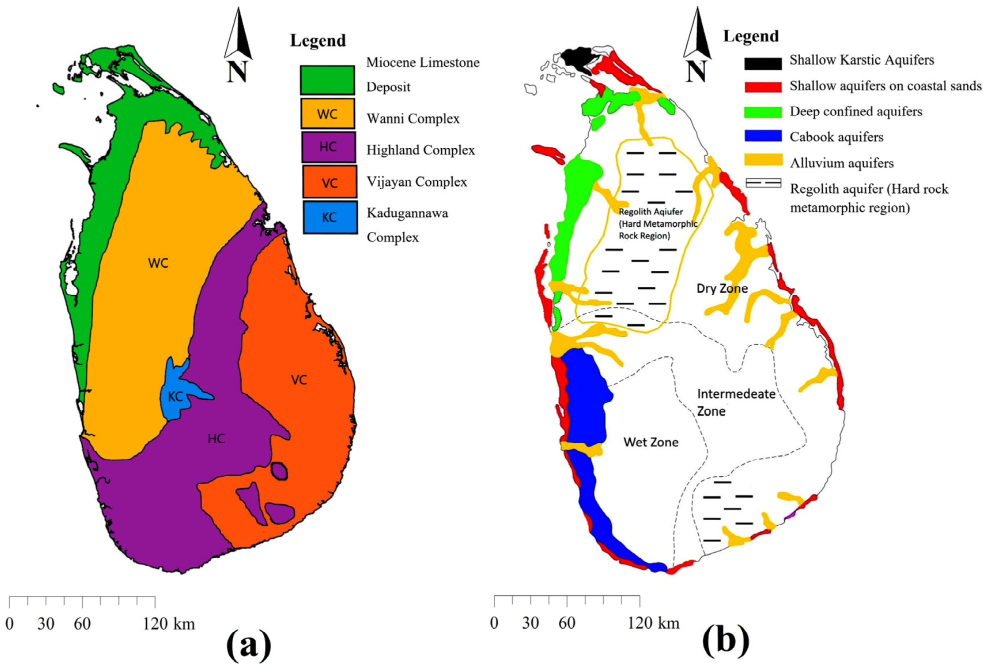

Figure 2. (**a**) Major geological zones in Sri Lanka [19,20]; (**b**) Different types of aquifer systems [8].

Based on the amount of annual precipitation received, four distinct climatic zones have been defined within the island such as wet zone, dry zone, semi-arid zone, and intermediate zone. As a tropical island, Sri Lanka has two major climatic periods such as dry season and wet season. The influence of the climatic variation on the groundwater throughout the year is significantly higher in the dry zone of Sri Lanka because the dry zone is having a longer dry season with significantly higher ambient temperature and a short wet season (October, November and December) with heavy rainfall.

Different types of underline water storages or aquifer systems with diverse geological and geochemical characteristics exist in the lithosphere of Sri Lanka. Generally, six major types of aquifer systems are available in Sri Lanka based on different geo-hydrological characteristics [8]. They are shallow karstic aquifers, coastal sand aquifers, deep confined aquifers, lateritic (Cabook) aquifers, alluvial aquifers, and shallow regolith aquifers in the hard rock region (Figure 2b). Groundwater quality is primarily determined by the geology of the aquifer system depending on the length of the flow path, residence time with the aquifer base materials, and geochemistry. Basically, aquifers in the sedimentary terrain are mainly recharged by the higher elevated meteoric water flowing along regional terrain, while southern lowlands crystalline terrain have groundwater with highlands originated with fast replenished, and in the Eastern North Central lowlands, groundwater is lowland originated and fast replenished [21]. Table 1 shows the different characteristics of each aquifer type with the risk for groundwater contaminations.

Table 1. Characteristics of different aquifer types in Sri Lanka and their vulnerability for contamination.

Type	Regions	Base Rock or Geology	Geochemistry	Recharged by	Risk of Water Pollution	References
Shallow karstic aquifers	Jaffna peninsula, Manner	Weathered Miocene limestone	Calcite- and carbonate- rich rocks (rich in Ca^{2+}, Mg^{2+}, $CO_3{}^{2-}$, $SO_4{}^{2-}$)	Northeast monsoon and inter-monsoonal precipitation	Pollution by intensive agricultural activities and waste disposal in urban areas	[8,21,22]
Shallow regolith aquifers in hard rock regions	Dry zone (north central, Northwestern and Southern Provinces)	Fractured Precambrian metamorphic rocks (crystalline base)	Metamorphic acid rocks with less buffering capability	Recharge by ancient tank cascade systems); warzone	Geogenic contaminants are common (trace metals, fluoride)	[23]
Lateritic (Cabook) aquifer	Southwestern region of wet zone	Laterite formation or Cabook formation	Laterite	Southwest and northwest monsoonal precipitation	Due to higher rainfall in the region, less contaminants in groundwater have been reported	[8]
Alluvial/alluvium aquifers	Around the river basins (Kelani, Deduru, Mahaweli, Walawe, Kirindi, Oya)	Buried river beds (high yield) and underline hard rocks	Nutrients trapped in alluvial sediments	River surface water	Extensive agricultural practices can influence the contamination of stored water	[8,24]
Coastal sandy aquifers	Northwestern, northeastern coastal belts (Kalpitiya, Mannar Island, Kalkudah, Batticaloa, Pottuvil, Nilaweli)	Coastal spits and coastal sand raised beaches	Sand dunes with seawater intrusion effect	Monsoonal rain	High salinization by saltwater intrusion; nutrient pollution by agrochemicals leached in agricultural lands	[8,25,26]

3. Spatiotemporal Variation of Groundwater Quality in Sri Lanka

3.1. Groundwater Classifications

It was the first time that a groundwater geochemical classification for the entire of Sri Lanka was conducted in 1985 [27]. Four types of groundwater were observed throughout Sri Lanka with different dominant chemical species, which were calcium (Ca) type, magnesium (Mg) type, sodium-potassium (Na-K) type, and non-dominant cation (NDC) type with further sub-categories such as chloride (Cl), sulfate ($SO_4{}^{2-}$), bi-carbonate

(HCO_3^-) and non-dominant anion (NDA) types. Characteristics of the aquifer materials (geology), climate variations, seawater intrusion in the coastal regions, and ion exchange process were highlighted as possible governing factors for these quality changes in water types [27].

Aquifers in the dry zone of Sri Lanka are usually metameric hard rock aquifers (regolith) in inland regions, northern coastal limestone karst aquifers, alluvial aquifers, and coastal sandy aquifers. Especially in the northern region (Jaffna), Ca–Cl type groundwater is dominated due to the calcium-rich geology (Miocene limestone deposit) and the effect of saltwater intrusion [27]. The western coastal region in the Northern Province has been reported as dominating Na–SO_4–Cl type in the limestone terrain and Ca–Mg–HCO_3 type in the metamorphic terrain [28]. Seawater intrusion followed by the ion-exchange process is the common factor that governs the dominancy of the constituent in groundwater especially close to the coast within the limestone terrain. In the rest of the Northern Province which belongs to metamorphic terrain, the Ca–Mg type of groundwater is the common species. Weathering and dissolution of magnesium and calcium-bearing minerals such as pyroxene, amphiboles, and localized accumulation of chlorides would be the possible causes for this type of geochemistry of the groundwater [29]. Similarly, another study reported that groundwater in North Central Province in Sri Lanka is mostly composed of Ca–Mg–HCO_3 type which is governed by silicate mineral weathering [10]. Higher concentrations of the dissolved constituents in the groundwater have been reported due to higher evaporation and lower precipitation in the dry zone. In the Malala Oya river basin, which belongs to the southern dry zone of Sri Lanka, the Ca–Mg–Cl type is reported as the major category in the deep groundwater due to the rock–water interaction [30]. However, in the shallow well in this region, the Na–Cl and Ca–Na–HCO_3 types of groundwater are dominant. Silicate weathering has been observed as the major source of the dissolved constituents such as Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- in this region. However, the Walawe river basin which belongs to (both dry and wet zones) the Southern Province, has been reported to have pre-dominant Ca–HCO_3 type groundwater [3]. Deep groundwater in the wet (82%) and dry (67%) zone areas of the basin were dominated by Ca–HCO_3 type with subordinate contributions from the Ca–Na–HCO_3 type, Ca–Mg–Cl type, and Na–Cl rich water. As a result of the most dominant HCO3- ions, alkaline nature is common in this groundwater of the dry zone (Table 2). The study has highlighted the silicate and calcite mineral weathering and ion exchange process as the major processes that control the groundwater geochemistry in the region.

Usually, the wet zone of Sri Lanka is almost covered by hard rock metamorphic geology. A long wet season with heavy rainfall is the main governing factor for the composition of the groundwater followed by geological and anthropogenic factors. Lower dissolved constituent content, lower hardness, and low pH level are the major conditions in the groundwater in this zone compared to the dry zone [29]. Groundwater in this region is commonly available at the saprolite zone and the lateritic caps. Chemical weathering of rocks and the fertilizer leachates are the common sources of the dissolved constituents. HCO_3 type with Na/K-rich groundwater types are common in this region [29]. Similarly, Dissanayake and Weerasooriya, 1985 [27], reported that the Central Highland region belonging to the wet zone was the Ca–HCO_3 type of groundwater due to the presence of $CaCO_3$ containing minerals, and further confirmed the dominant type of groundwater in the wet zone (Ca–HCO_3) by the recent geochemical classification results [3]. The intermediate zone which is the transitional region in between wet and dry zones, showed a mixed nature of groundwater geochemistry and types [29].

Table 2. Alkaline nature and the pH levels of groundwater in different climatic regions of Sri Lanka.

Climatic Zone	Region	Geology and Aquifer Type	Mean pH	pH Range	Alkalinity	pH Controlling Factors	Drinking Water Suitability	Reference
Dry	Jaffna, Chunnakam aquifer	Miocene limestone karst aquifers		7.20–8.26	Slightly alkaline	Presence of higher carbonates and bicarbonates (dissolution of carbonate minerals in the base rocks)	100% below MALs (WHO)	[31]
Dry	Jaffna	Miocene limestone karst aquifers	7.0			Presence of higher carbonates and bicarbonates (dissolution of carbonate minerals in the base rocks)		[32,33]
Dry	Jaffna	Miocene limestone karst aquifers		>7		Presence of higher carbonates and bicarbonates (dissolution of carbonate minerals in the base rocks)		[34]
Dry	Jaffna	Miocene limestone karst aquifers		6.55–8.72	Slightly alkaline	Presence of higher carbonates and bicarbonates (dissolution of carbonate minerals in the base rocks)		[35]
Dry	Anuradhapura (North Central Province)	Metamorphic terrain with regolith aquifers		5.7–8.8	Slightly alkaline	Interaction with carbonate-rich minerals in the bedrock and heavy rainfall in a short wet season increases the pH in a considerable amount due to the dissolution of more earth minerals		[10]
Semi-arid	Mannar Island (Eastern coastal belt in Northern Province)	Coastal sand aquifer with underline limestone bedrock	7.7	6.9–9.0	Neutral to alkaline	Interaction with carbonate-rich minerals in the bedrock and higher evaporation rates due to semi-arid climate		[36]
Semi-arid	Mannar (inland region)	Limestone karst aquifer		6.52–7.93	Neutral to slightly alkaline	Interaction with carbonate-rich minerals in the bedrock and higher evaporation rates due to semi-arid climate	100% below MALs (WHO)	[28]
Semi-arid	Mannar (inland region)	Alluvial aquifer		7.53–7.93	Slightly alkaline	Interaction with carbonate-rich minerals in the bedrock and higher evaporation rates due to semi-arid climate	100% below MALs (WHO)	[28]
Wet zone	Western Province, Central Island and western part of Southern Province	Fractured metamorphic acid rocks, base rock, and laterite Cabook aquifers	7.1	4–7.8	Slightly acidic	Interaction with less soluble metamorphic acid rocks which is lower in acid buffering capability. and dilution by heavy annual rainfall		[37–39]
Semi-arid	The eastern half of the Southern Province (Hambantota)	Fractured hard metamorphic bedrock–regolith aquifer	7.9		Alkaline	Less soluble metamorphic bedrock (marble) and higher evaporation rates due to semi-arid climate	100% below MALs (WHO)	[40]
Semi-arid	Malala Oya river basin (Hambantota)	Alluvial aquifer		6.5–8.1	Slightly alkaline	Less soluble metamorphic bedrock (marble) but higher evaporation rates due to semi-arid climate	100% below MALs (WHO)	[30]

3.2. Major Physicochemical Parameters of Groundwater Quality

3.2.1. Total Hardness

Hardness is normally expressed as the total concentration of calcium and magnesium ions in water units of mg L^{-1} as equivalent $CaCO_3$ [41]. Based on $CaCO_3$ hardness, four categories of water can be identified as following: soft water at below 60 mg L^{-1}, moderately hard water at 60–120 mg L^{-1}, hard water at 120–180 mg L^{-1}, and very hard water at more than 180 mg L^{-1}. Scaling on the cooking equipment resulting in lower heat transfer [42], and scaling inside the pipelines, giving a bitter taste to the drinking water are the major issues with higher hardness in groundwater. Standards of drinking water in Sri Lanka (SLS 614–2013) [43] recommend 250 mg L^{-1} as the maximum permissible limit for hardness. It can also be suggested that there is a relationship between CKDu prevalence and hardness mineral content in the drinking water because a recent study revealed that alkali (Na^+, K^+) and alkaline earth cations (Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}) were relatively higher in drinking water sources used by CKDu patients, compared to the well waters used by healthy individuals in the central dry zone [44].

It was reported that Sri Lankan well water is very hard because 26.9%, 15.0%, 15.8%, and 42.2% of well water were soft, moderately hard, hard, and very hard, respectively [37]. The majority of the areas in the wet zone were reported soft and moderately hard water, while hard and very hard water were reported from the majority of the areas in the dry zone [3]. The highest hardness in groundwater was recorded in Hambantota, Southern Province, while the second and third highest hardness in groundwater occurred in Anuradhapura (North Central Province) and Jaffna (Northern Province) (Figure 3a); 90% of the Malala Oya river basin in the southern semi-arid region (Hambantota) exceeded the MALs of hardness for drinking purpose while ranging from 48 to 1980 mg L^{-1} [30,40]. The semi-arid climatic nature with a higher evaporation rate during the long dry season in the Hambantota area leads to concentrate the multivalent hardness metal cations derived from carbonate dissolution and silicate weathering followed by ion exchange processes [3]. Groundwater in the Anuradhapura district in the dry zone was in hard (16.5%) and very hard (72.8%) range, and exceeded the SLS permissible limit of hardness (250 mg L^{-1}) for drinking purposes in both seasons [10,45]. A seasonal variation of hardness has been identified between the wet season and the dry season, with average hardness levels ($CaCO_3$ mg L^{-1}) at 240.8 mg L^{-1} and 284.3 mg L^{-1}, respectively, controlled by dilution effect during the wet period and the evaporation in the long dry period.

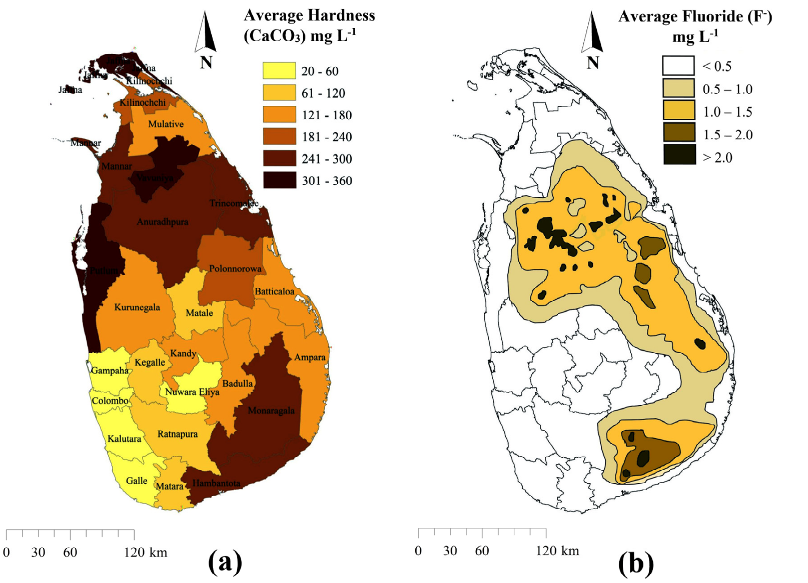

Figure 3. (**a**) Average hardness at $CaCO_3$ [37] and (**b**) fluoride distribution [46] in groundwater in each district in Sri Lanka.

Underline sedimentary limestone geology is the major source of hardness minerals, especially in the northeastern coastal belt including the Jaffna peninsula [8,28]. Many studies reported that groundwater hardness in the Jaffna peninsula ranged from 45.33 to 611.33 mg L^{-1}, and the highest value was recorded at 611.33 mg L^{-1} from Velanai-north [35,47]; 20–23% of the investigated domestic wells in the Jaffna region have exceeded 250 mg L^{-1} of hardness limitation of the SLS drinking water quality standards. Geochemistry of karst aquifer systems directly controls the water hardness minerals due to dissolution of the sedimentary limestone (limestone $CaCO_3$ and dolomite $CaMg(CO_3)_2$) [8,28]. The thin soil layer (<2 m) upon the limestone bedrock allows slightly acidic rainwater to infiltrate easily [8] while dissolving the base minerals which enhance the hardness.

3.2.2. Fluoride (F^-)

Fluoride is an essential element in the drinking water to maintain good dental health, however, excess fluoride leads to dental or skeletal fluorosis disease, and lack of fluoride causes dental decay [48]. WHO recommends fluoride 0.5–1.5 mg L^{-1} as the healthy range for drinking purposes and SLS 614–2013 standard has established 1 mg L^{-1} as the MAL.

In the dry zone of Sri Lanka, fluoride is a dominant geogenic constituent. Drinking hard water with high fluoride content has become one of the major hypotheses for causing high incidences of CKDu in Sri Lanka [49,50]. A recent study has suggested that the consumption of water containing higher Mg^{2+} and F^- may have a direct influence on CKDu, because the elevated Mg^{2+} and F^- levels in hard water lead to formation of complexes that trigger protein denaturation, while causing renal damage [44]. Many studies have reported that the fluoride level of groundwater in the dry zone of Sri Lanka was quite higher (<8.0 mg L^{-1}) compared to those in the wet zone (<0.8 mg L^{-1}) [51,52]. Herath et al. [37] reported that the fluoride concentration of well water in Sri Lanka ranged from 0 to 7.0 mg L^{-1}, and the highest concentration of fluoride at 7.0 mg L^{-1} was recorded in the Anuradhapura district, followed by 6.8 mg L^{-1} in the Monaragala district (Figure 3b). Especially, North Central Province and the semi-arid region of Southern Province have been highlighted in many studies [3,10]. Recent study showed that only 25.7% has been observed as acceptable for drinking purpose based on SLS drinking water guidelines for fluoride [45]. Several studies conducted in Malala Oya and Udawalawa river basins in the southern dry zone reported groundwater fluoride in higher levels ranged from 0.1 to 9.2 mg L^{-1} [30,53], with groundwater in 53.3% of the locations in Malala Oya basin, and in nearly 52% of deep wells and 40% of shallow wells in the dry region of Walawe river, the basin exceeded 1 mg L^{-1} of SLS 614–2013.

Fluoride content in groundwater in the central dry zone is mainly derived by weathering of basement rocks consisting of fluoride-bearing minerals such as amphiboles, biotite, and apatite, which are ubiquitous in the high-grade metamorphic terrains [10,17,46,48,54]. Higher evaporation rate governed by the semi-arid climate in the southern dry zone is also a major reason for higher fluoride content [3]. Thus, dental fluorosis due to the consumption of high fluoride groundwater is quite common among the rural community in this region [55].

3.2.3. Nitrate (NO_3^-)

Nitrate and phosphate concentration in the groundwater in Sri Lanka are mostly controlled by anthropogenic factors rather than natural factors, and the primary sources of nitrate and phosphate in groundwater are fertilizers, septic systems, and manure storage or spreading operations (Table 3) [56]. From 1985 to 2017, the extent of agricultural practices and production of crops has been increased due to the rapid population increase [57], as well as the increasing amount of land used for farming crops. Correspondingly, usage of synthetic fertilizers containing a higher content of nitrates and impurities such as heavy metals has skyrocketed with the increase of a government fertilizer subsidy [58]. The scale of leaching excess fertilizer from the agricultural land to shallow aquifers has been rapidly growing during 1985–2017 while deteriorating the quality of fresh groundwater sources by nutrients and heavy metal impurities. Thus, extensive farming regions such as Jaffna, Puttalam, Mannar, and Batticaloa, have reported significantly higher contaminant levels in the present than a few decades ago [37,59] (Table 4). Shallow wells in these regions on the sedimentary terrain are mostly artesian wells which are dominantly recharged by higher elevated meteoric water flowing along regional and longer flow paths through fractured basement rocks while having 50 years of residence time [60]. Thus, contamination by surface runoff with agricultural contaminants could be possible.

Table 3. Anthropogenic activities affecting the groundwater quality in different regions of Sri Lanka.

Anthropogenic Factors	Subcategory	Major Source of Contaminant	Contaminants	Contamination Mechanism	Major Causes	Affected Regions	Health Effects due to Drinking Groundwater	Related References
Agricultural Impacts	Intensive agricultural practices	Overuse of inorganic fertilizers	Nutrients (nitrate and phosphate) Heavy metal pollution	Contaminant leach from soil to shallow groundwater by rainwater infiltration	Lack of awareness about the productivity of the crops, the dosage of fertilizers Availability of low-cost, poor-quality fertilizers	Karst limestone aquifer systems in the Jaffna peninsula Sandy aquifers located along the coastal belt	Kidney failures (e.g., CKDu) Blue baby syndrome Typhoid fever Diarrhea	[61–64]
		Overuse of pesticides and insecticides	Heavy metal and organic contaminants such as glyphosate	Degradative residues from the agrochemical used in agricultural lands can infiltrate the groundwater table in the wet season	Lack of awareness about the effectiveness and dosage of pesticides Availability of poor, unacceptable quality agrochemicals in Sri Lanka	North Central Province Uva Province Northern Province	Kidney failures (e.g., CKDu)	[65–70]
Urbanization	Improper waste disposal	Open waste dumping sites	Nutrients (nitrate and phosphate) Heavy metals Microbial pathogens	Contaminants leached from open waste dumping sites around Sri Lanka	Unavailability of a proper waste management system Higher production of waste due to increasing population	Urban areas in Kandy, Batticaloa Western Province (Colombo)		[71–76]
	Unsuitable sanitary practices	Sanitary soakage pits	Nutrients (nitrate and phosphate Ammonia Microbial pathogens	Contaminants leached from soakage pits due to inadequate distance between drinking water sources (shallow dug wells) and the toilet pits, and vertical distance between the bottom of the soakage pit and the groundwater	Lack of awareness Not following proper guidelines for building sanitary soakage pits (18 m minimum distance from drinking water source, accepted by Health Ministry) Lack of proper disposal methods for sanitary practices The high population density in rural areas	Rural regions such as Northern Province (Jaffna) and Central Province Highland regions	Typhoid fever Diarrhea	[35,77,78]

The nitrate concentration in Sri Lankan well water ranged from 0 to 366 mg L^{-1} and the maximum nitrate value at 366 mg L^{-1} was from Puttalam district in the Northwestern coastal region [37] (Figure 4a). Leaching excess inorganic fertilizer of intensive agricultural lands with highly permeable sandy soil layers could be the major cause for the elevated level of nitrates in coastal regions such as Jaffna, Mannar, Batticaloa, and Hambantota [80]. Similarly, farm wells or agro-wells in Jaffna peninsula have shown an elevated nitrate level compared to domestic and public dug wells in the wet season which could be due to the thin soil layer above the underline sedimentary base. Seasonal variations of nitrates in shallow groundwater have been reported, and significant increase of nitrate level in wells located in the agricultural regions in Jaffna have been observed in the rainy season more than in the dry zone [31].

Table 4. Temporal variation of nitrate in groundwater of different agricultural regions in Sri Lanka, from 1985 to present.

District	1985 [59] (mg L^{-1})	2001, 2017—Recent (mg L^{-1}) *Min*	*Max*	*Average*	Literature
Jaffna	>20	0.7	51		[61]
			110	19	[37]
Puttalam	1–10		366	42	[37]
Hambantota	0–10		128	2	[37]
Anuradhapura	0–20		131	6	[37]
Mannar	20–40, >40		135	15	[37]
Batticaloa	0–20	48	171		[71]
		1.5	96.6		[79]

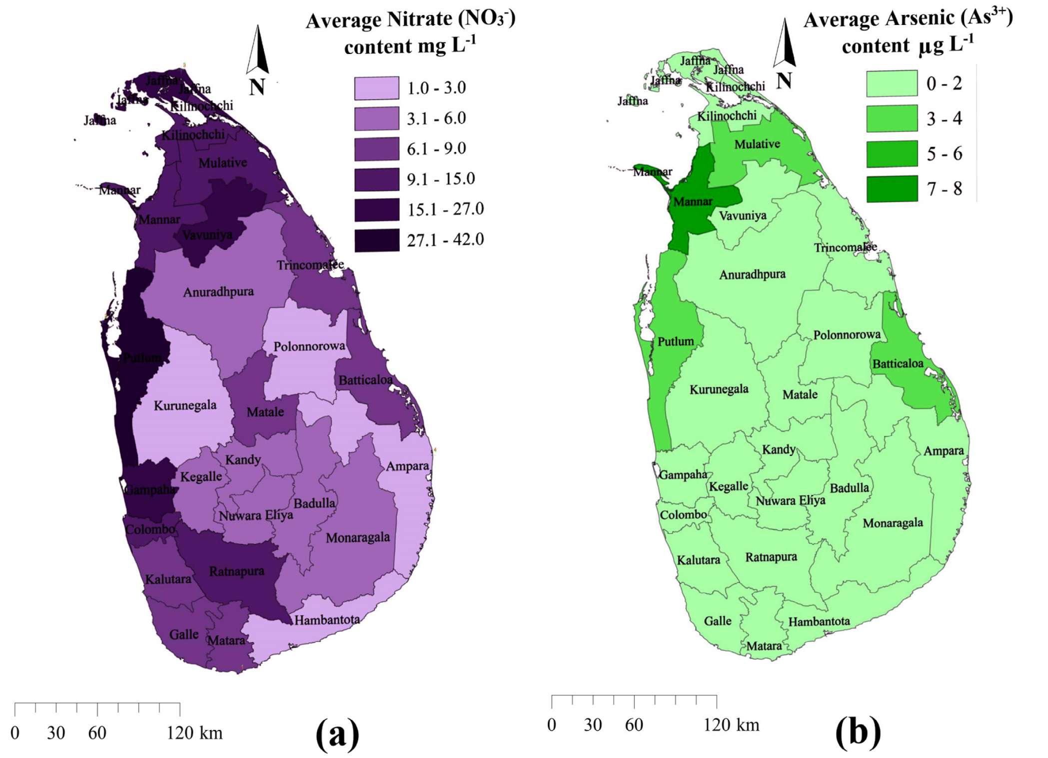

Figure 4. (**a**) Average Nitrate content, and (**b**) Average Arsenic content of the groundwater in each district in Sri Lanka; data extracted from [37].

Nitrate content of the groundwater in the urban and agricultural regions in Batticaloa ranged from 1.49 mg L^{-1} to 96.60 mg L^{-1} [79] while 15% of groundwater in the locations have exceeded the MAL of WHO and SLS 614–2013 (50 mg L^{-1}) for drinking purposes. Another groundwater quality assessment has been conducted to understand the mechanism of nitrate infiltration and contamination of shallow groundwater in the Batticaloa region using a modeling approach [81]. However, Ehanathan et al. [61] reported that maximum groundwater nitrate level which they have observed is 51 ppm, and the majority of locations had an acceptable level of nitrate in groundwater except one agro-well.

Improper sanitary practices are another causative factor for nitrate contamination which is observed in rural and semi-urban regions in Sri Lanka. The majority of the septic systems in these regions have not been located at an acceptable distance from the groundwater well. The average distance of toilet or soaking pits to groundwater well is around 6 m in the rural–urban community area. A clear relationship between the distance of toilet pit (<20 feet) and dug well with high contamination of nitrate was identified [35]. Higher permeability and lower thickness of the soil layer enhance the leaching of nutrients into the shallow groundwater.

Sugirtharan and Rajendran, 2015 [71], reported that the groundwater was contaminated by nutrients leached from the open dumping sites located in Thirupperumthurai, Batticaoloa district (Eastern Province). In that area, concentrations of phosphate and nitrate ranged from 0.24 to 1.63 mg L^{-1} and 48 to 171 mg L^{-1}, respectively. Even though phosphate level is acceptable, the nitrate level is totally above the MAL (<50 mg L^{-1}) for drinking water. Hence proper sanitary practices and reported maximum groundwater nitrate level which they have observed was 51 ppm, and the majority of locations had an acceptable level of nitrate in groundwater except one agro-well.

Hence proper sanitary practices and waste management should be implemented to protect groundwater resources and improve the drinking water quality, as well as the health in sensitive areas such as coastal regions, watersheds, and wetlands aquifers with this soil cover.

3.2.4. Trace/Heavy Metals

Trace/heavy metals are ubiquitous and chemically stable elements that can be observed in both biotic and abiotic natural environments. Their presence in the groundwater has drawn major attention over decades due to their toxicity tendency of bioaccumulation which may lead to carcinogenic health problems [82,83]. Major sources of heavy metals in Sri Lankan groundwater are the geology of the area by weathering rocks and minerals, municipal solid waste, and agrochemicals. However, the trace metal concentration of the groundwater in Sri Lanka is considerably low, sometimes negligible. However, some metals naturally in the rocks, minerals, and soils are available in a considerable amount in the groundwater. Mn, Cu, Ba, Sr, Co, Ni, Al, and Zn are the common metals in Sri Lankan groundwater, and As and Cd are the most controversial elements investigated in several studies to find out any relationship with CKDu issue in Sri Lanka [84,85]. However, a recent study that was conducted in the CKDu areas of Monaragala district in Uva Province showed that level of nephrotoxic trace elements such as, Cd, and Pb were well below the WHO permissible levels, thus negating their prime influence on the CKDu prevalence [44].

(a) Arsenic (As)

Arsenic is one of the major elements discussed over years related to the CKDu issue in Sri Lanka. Arsenic pollution of natural water sources by the anthropogenic influences such as industrial waste disposal and unsafe agricultural practices around the globe have been discussed in many studies [86–88]. Even though it has not been confirmed yet, agrochemicals have been considered as the source for the arsenic to the groundwater. Arsenic containing minerals is the major primary source which was confirmed for the groundwater contamination in certain areas in Sri Lanka [89]. The permissible limit for arsenic in drinking water of WHO and SLS 614–2013 standards is 10 µg L^{-1} [90,91]. Arsenic can be released from the base rocks in the aquifer in different ways with different geochemical conditions of the groundwater. Dissolution under reducing conditions from less soluble As(V) to more soluble As(III) is the common way to release arsenic from the rock minerals [92]. The presence of organic matter accelerates the process due to microbial activities [93]. Exposure of arsenic trapped in sulfide minerals to the oxygen leads to releasing more soluble arsenic into the groundwater. Dropping the water level or water table will trigger this process by exposing the minerals to the atmosphere [92,94]. Another way is where the pH is high, arsenic may be released from surface binding sites that lose their positive charge.

Even though arsenic in groundwater has not yet become a serious issue in Sri Lanka, comparatively higher arsenic levels were recorded in sedimentary terrains than aquifers in the metamorphic terrain [48]. Several studies reported that average arsenic content in the groundwater in Sri Lanka has not exceeded the MAL of SLS 614–2013, but its maximum level was reported from Mannar district (66 µg L^{-1}) followed by Puttalam, Batticaloa, and Mullaitivu located in Northern and belonging to the dry zone of Sri Lanka [36,37,95]

(Figure 4b). Groundwater in these regions stored in unconfined aquifers in the holocene sand dunes that are underlain by Miocene limestone, and more than 30% of the shallow dug wells in the Mannar Island exceeded the WHO permissible limit [36]. Amarathunga et al. [95] reported that high groundwater arsenic levels in the sandy aquifer system in the Mannar region located in the northwestern coastal belt in Sri Lanka, and total arsenic concentrations ranging from 6.5 μg L^{-1} up to 43.8 μg L^{-1} and all the wells with elevated As concentrations (>25 μg L^{-1}) showed near-neutral pH condition. The fined-grained sediments near the water table in this region have been identified as the arsenic source which has high arsenic content. With the precipitation, CO_2 dissolved slightly acidic rainwater which infiltrates the soil layer and enters the water table while lowering the pH level of the groundwater as well. Slightly acidic groundwater dissolves the carbonates in the bedrock material while maintaining pH at a near-neutral level. That condition is a driving force to the microbes present in water to oxidize the organic sediments while creating an anaerobic condition near the water table [93]. This condition is favorable for the dissolution of iron-rich coatings around sediment sand grains releasing arsenic into the solution, creating high arsenic content in groundwater. Similar findings of another study showed a high concentration of arsenic in the groundwater originated and mobilized through the reductive dissolution of Fe–Mn oxides and oxy-hydroxides coated on sandy aquifer materials [36].

The relationship between soil type and groundwater was reported in these regions of Mannar, Puttalam, Batticaloa, and Mullaitivu. All the locations with elevated arsenic levels in the groundwater have soil type of sandy regosols on the recent beach and dune sands, confirming the geological origin of arsenic in groundwater. Moreover, no relationship between groundwater nitrate and arsenic was found, confirming that arsenic has not been found with the nitrate-based inorganic fertilizers [37]. Similarly, another study has concluded that arsenic was not enriched in agricultural soil, non-agricultural soil, and groundwater in the wet, intermediate, and dry zones of Sri Lanka [52,96].

(b) Cadmium (Cd) and Lead (Pb)

Cadmium (Cd) and lead (Pb) are the most discussed elements present in the natural waters and soil in Sri Lanka due to the prevalence of CKDu issue throughout the agricultural community in the dry zone area. They are nephrotoxic, initially causing kidney tubular damage, and also cause bone damage, either via a direct effect on bone tissue or indirectly as a result of renal dysfunction [97]. WHO and SLS drinking water standards recommended 3 μg L^{-1} and 10 μg L^{-1} as MALs for cadmium (Cd) and lead (Pb), respectively [90]. Usually, the geogenic origin of these trace metals has been observed throughout the island, and anthropogenic activities such as overuse of inorganic fertilizers and other agrochemicals have also become controversial hypotheses for groundwater contamination in Sri Lanka.

However, unacceptable level of these two elements in the groundwater of Sri Lanka has not been reported up to now. Several studies conducted in CKDu prevailing regions reported that cadmium and lead in the groundwater in the dry zone were below the WHO and SLS standards for drinking [85,98,99]. Cd and Pb with a range of 0.01–0.15 μg L^{-1} and 1.76–8.85 μg L^{-1}, respectively, were reported in Ulagalla cascade, Anuradhapura district in North Central Province (NCP), less than the maximum permissible levels of SLS and WHO drinking water quality standards [100]. Besides, higher heavy metal levels such as Cd at 0.03–0.06 mg L^{-1} and Pb at 0.01–0.03 mg L^{-1} were reported in the surface water bodies in the same region, and were suspected to have originated from excess usage of inorganic fertilizers [101]. However, the mean cadmium level in surface water in the dry zone of Sri Lanka was at 0.3 μg L^{-1} below the MAL of WHO standards [97]. Most of the locations in underline karst limestone aquifer systems which existed in the Jaffna region (Northern Province) reported that dissolved Cd and Pb in groundwater were either at or below their analytical detection limit (0.1 μg L^{-1}) [102].

Usually, trace metals such as Cd and Pb present in the natural soils as a result of rock weathering but in quite lower levels. Some studies reported elevated levels of heavy metals in soils in some parts of intensive agricultural regions of upcountry and low country in wet zone regions [103]. Inorganic fertilizers used in different locations were found to have an unacceptable level of cadmium contents, such as fertilizer samples collected from Madirigiriya in NCP, and Girandurukotte in Uva Province were reported at 46.1 mg kg$-^{1}$, 39.8 mg kg^{-1} Cd content exceeding the acceptable limit of 10 mg kg^{-1} by SLS standards [104]. Thus, extensive agricultural regions can be recognized as highly vulnerable regions for heavy metal contamination of groundwater as well as surface runoff.

3.3. Organic and Microbial Contamination of Groundwater

3.3.1. Organic Pollutants

Organic pollutants such as pesticide residue, glyphosate, and antibiotics residue have been reported in significant amounts in natural waters in Sri Lanka [65,105]. Though WHO and SLS standards for drinking water have not defined limits for dissolved organic carbon (DOC), Chinese standards for drinking water quality (GB5749–2006) recommend COD_{Mn} at 5 mg L^{-1} as the maximum limit. The majority of the shallow groundwater sources in dry and semi-arid zones of Sri Lanka have shown higher levels of inorganic mineral content in the dry season due to the higher rates of evapotranspiration and lower precipitation. However, the natural organic matter dissolved in the groundwater has increased in the wet season due to the enhanced microbial activities on the organic matter in the moist environment and dissolution of aquifer materials as a result of slightly acidic rainwater [10,106]. In the NCP, the average DOC content in the groundwater was reported in dry and wet periods at 5.9 mg L^{-1} and 5.3 mg L^{-1}, respectively [10]. In namely High Risk, Low Risk, and No Risk of CKDu zones in the NCP, the DOC concentration varied between 1.35 and 2.08 mg L$-$1 showing a monotonous behavior. Another recent study confirmed that more than 51.5% of the groundwater samples from NCP exceeded the Chinese water quality guideline for TOC [45]. However, the mean DOC content in the Control Zone (Kandy) varied within a narrow interval between 1.37 and 1.62 mg L^{-1} [106]. Source of DOC in the groundwater in the dry zone was reported to have an autochthonous origin, and DOC in the groundwater in the NCP was mainly composed of the organic fractions, in order, as fulvic acids > humic acids > aromatic protein II > soluble microbial by-products, and the molecular weights (MW) of these fractions ranged from 100–3000 Da [10]. The three groups were Fraction-I (MW < 900 Da), Fraction-II (900–1800 Da), and Fraction-III (1800–4000 Da) while Fraction-II was highlighted as the most common faction in the groundwater of high CKDu prevalence zone [106]. Another study has shown that higher molecular weight, stronger exogenous feature, and greater degree of humification and unsaturation than from non-CKDu groundwater were the characteristics of DOM in the CKDu groundwater [107]. However, higher levels of DOC in groundwater could lead to higher cost of operations and lower efficiency of existing drinking water stations equipped with reverse osmosis (RO) membrane technology in the CKDu areas due to the rapid fouling effect [10]. It was reported that DOC plays a huge role in membrane fouling in RO units while acting as a co-constituent for organic, inorganic, biological, and interactive membrane fouling [108,109].

A study conducted in the NCP reported that glyphosate (270–690 µg kg^{-1}) and aminomethylphosphonic acid (AMPA) (2–8 µg kg^{-1}) were detected in all soil samples [100,105]. Their significantly higher levels were observed in surface water, but trace level of glyphosate at 1–4 µg L-1 was detected in all groundwater samples, and AMPA at 2–11 µg L^{-1} was detected in only a few groundwater samples. Information about groundwater pollution due to veterinary antibiotics is lacking in Sri Lanka, but some studies were conducted to investigate surface water pollution by antibiotic-related chemicals from pharmaceutical wastes in Sri Lanka [110–112]. However, recent study showed that in central dry zone of Sri Lanka, at least one organic compound (agrochemical residue) from Diazinon, p,p′-DDE, Propanil, Endosulfan II, o,p′-DDT, Pretilachlor, Propachlor, Lindane, and Clomazon was detected from 68% of shallow wells at higher levels exceeding the EPA and WHO drinking water guidelines [113].

3.3.2. Microbial Contamination

There are few studies related to the microbial pollution analysis of the groundwater in Sri Lanka. Several rural and highly populated regions reported drinking water health issues related to biological contaminants such as E Coli, total coliform, Salmonellas spp. and Shigella spp. In Sri Lanka, the highest incidences of typhoid fever were recorded from the Jaffna peninsula from 2005 to 2013. A study reported that more than 90% of the public water sources were microbially unsatisfactory in the Jaffna peninsula, and the entire Jaffna peninsula was contaminated with total coliform (85% locations exceeded the 200 CFU limit), E. coli (23% locations exceeded the 200 CFU limit), and 38% sampling locations were positive for Salmonella spp. [35]. The distance between toilet pits and drinking water sources is again inferred as the possible reason. Coastal regions of the dry zone are also vulnerable to groundwater contamination by microbial pathogens. Fecal contamination was reported in the Kalpitiya peninsula in Puttalam district of the northwestern coast due to the typically used human excreta disposal method of pit latrines [114]. The level of the water table and the higher permeability of the soil in the coastal areas are the major reasons for microbial contamination of groundwater in this region because of not following the recommended distances from the water source to the latrine pit. In a water quality assessment conducted covering semi-urban and rural areas of five major districts (Kandy, Nuwaraeliya, Anuradhapura, Kurunegala, and Rathnepura), 100% of the locations were contaminated with total coliforms and fecal coliforms [115], indicating the potential of health risks of consuming well water without any disinfection process.

A recent study comprehensively investigated the microbial community in the groundwater of the CKDu regions in Sri Lanka (Anuradhapura and Monaragala), which showed CKDu prevalence significantly influenced the distribution of antibiotic resistome and microbial community composition [116]. In the groundwater in all the regions, the dominant antibiotic resistance gene (ARG) was mexF and considered as an intrinsic ARG. The acinetobacter was a potential human pathogen common in the groundwater of CKDu-affected regions, while CKDu prevalence specially enriched the Aeromonas.

4. Performance of Existing Drinking Water Treatment Technologies in Sri Lanka

Groundwater-based drinking water supply in hard metamorphic and sedimentary terrain (dry zone) usually relies on membrane-based water treatment methods such as RO technology [117]. Currently, more than 2000 RO stations have been already established in these regions to mitigate the drinking water quality issues [118]. RO technology has an excellent capability to remove hardness minerals in the groundwater; 98–100% removal of total hardness by the RO technology has been reported from decentralized drinking water stations in the NCP [119]. A recent study has been reported that the average hardness rejection was around 95.8% in the CBO-established RO stations in NCP [118]. Compared to the monovalent cation rejections (~92%), RO technology shows excellent rejection for divalent hardness cation rejection (99%). However, RO product water showed quite lower Ca (<2.8 mg L^{-1}) and Mg (<1.4 mg L^{-1}) levels which are essential for the human body [118,119]. It has been suggested that reduced cardiovascular mortality and other health benefits would be associated with minimum levels of approximately 20 to 30 mg L^{-1} calcium and 10 mg L^{-1} magnesium in drinking water [120,121]. Thus, existing RO stations seem to show that they have a lack of remineralization processes to enhance the essential mineral content in the product water. A proper mineral addition step to the RO-permeated water such as a simple mixing process with sediment and pathogen-free raw groundwater or filtration through calcite contactors should be applied for the existing RO stations [118]. Nanofiltration has also been implemented in the CKDu-affected regions in the dry zone, but insufficient level of hardness minerals in the product water has been observed [117]. Electrodialysis reverse (EDR) technology is one of the future hopes for the Sri Lankan water sector to enhance drinking water quality [122]. It can retain essential minerals in the product water by controlling the operating parameters such as filtration time [123]. However, membranes of EDR systems are also under development to overcome the fouling issues with DOC or humic substances (humic acid and fulvic acid) in rural groundwaters [124].

Elevated level of fluoride was another major concern when drinking water is produced using groundwater especially in the dry zone of Sri Lanka [48,117]. Generally, conventional coagulation-flocculation water treatment technologies used for the purification of soft surface water is not effective for removing fluoride from the groundwater to produce safe drinking water. Advanced membrane technologies such as RO, NF, and EDR should be used for the removal of dissolved constituents. Excellent removal of fluoride (74%) has been observed in existing RO stations [119]. As a result of that, a significantly lower level of fluoride (~0.07 mg L^{-1}) in the RO product water has been observed from many RO stations in different studies [117,118]. Similarly, one nanofiltration station recently established also showed lower levels of fluorides (0.01–0.2 mg L^{-1}) in the product drinking water [117]. Thus pressure-driven membrane filtration technologies produce low fluoride drinking water which may be adjusted by external mineral additions such as calcite contactors. EDR groundwater treatment has achieved better treatment for fluorides (>80%) due to its capability to adjust the permeate ion concentrations by changing the filtration time [123]. Thus, it can be used to retain an essential amount of fluoride in treated product drinking water from the groundwater in the dry zone.

Agricultural runoff, improper sanitary practices, and open solid waste dumping sites are identified as the major causes of the elevated nitrates level in a certain region in Sri Lanka. Existing RO drinking water stations have the capability of removing nitrate by 70% and retain below 5 mg L^{-1} level in the produced drinking water [118,119]. Similarly, existing NF stations could have reached lower than 2.6 mg L^{-1} of nitrates in their permeates [117]. Thus, compared to the conventional surface water treatment strategies, these membrane technologies such as RO, NF, and EDR show much better removal of dissolved nitrates.

Heavy metal removal can be successfully achieved by membrane technologies established in the dry zone, because conventional coagulation-flocculation technologies are not effective for removing dissolved inorganic metal ions in water. Even though many types of heavy metals in groundwater are reported at acceptable levels in groundwater in Sri Lanka, for special cases such as arsenic contamination in the Mannar region, these membrane technologies such as RO, NF, and EDR can be effectively used for the production of safe drinking water [125]. Our recent study found that the arsenic content of produced RO drinking water (<2.4 μg L^{-1}) was well below the MAL (10 μg L^{-1}) established by WHO [118]. Commercial NF membranes exhibited a rejection between 86% and 99% towards arsenate As (V) while it reached 99.8% for synthesized NF membranes [126]. Thus, nanofiltration can be recommended as an energy-efficient way to remove the excess trace metals from the groundwater.

Removal of DOC could be achieved effectively by membrane-based technologies. Existing RO stations reported 55% of average DOC removal efficiencies while producing product drinking water with DOC at lower than 3.6 mg L^{-1} [119], which was well below the safe limit given by Chinese drinking water standards (5 mg L^{-1}). Excellent removal of DOC by RO and NF drinking treatment stations has also been reported in another study, i.e., retaining DOC in the product water at 0.01–2.2 mg L-1 by RO and 0.9 mg L^{-1} by the NF station [117]. Another study showed that a >99% rejection rate for both protein and humic acid on a synthetic groundwater solution similar to the groundwater in dry zone Sri Lanka, could be achieved by small-scale tubular RO module [127]. Removal of DOC is an essential factor to mitigate the carcinogenic disinfection by-product (DBP) formation in disinfection, and it also can be achieved by ultrafiltration (UF) membrane methods [128,129].

Conventional disinfection technologies of drinking water such as chlorination have been identified causing indirect health effects for humans. Carcinogenic disinfection by-product formation during the chlorination process is a critical issue [128]. High chlorine dosage, natural organic matter content, retention time, and temperature enhance the formation of DBPs such as trihalomethanes and halogenic acetic acids [130]. Thus, the removal efficiency of DOC is a major consideration for the selection of a disinfection technology.

Conventional surface water treatment plants in Sri Lanka still use the chlorination process as the major disinfection process [131,132]. Several studies reported that main water supply schemes have the risk of high DBP in the drinking water [133]. However, advanced technologies such as RO and NF stations in the dry zone of Sri Lanka use ultraviolet (UV) radiation units for sterilization of product drinking water [117,119,134]. UV sterilization is a better disinfection method for drinking water which could mitigate the DBP formation.

5. Challenges of Drinking Water Produced from Groundwater in Sri Lanka

"Water for All" is a flagship pledge made to the people by the National Policy Framework of Sri Lanka "Vistas of Prosperity and Splendor", which expects to provide clean drinking water to all households by the end of 2025 [135]. Though pipe-borne water supply coverage was up to 51.5% of the population and safe water access population reached 91.6% in 2019, there are still big gaps and challenges in terms of safe drinking water supply for all, especially in rural communities to reach the UN SDG 6th goal, e.g., the capacity to regularly monitor and assess water quality of groundwater, R & D and application of cost-effective water treatment technologies for groundwater, source water protection, and management of groundwater. The quality of water sources plays a key role in expanding the clean water supply throughout the country, and the selection of cost-effective drinking water treatment technologies for a certain area depends on the quality of water sources. As an initial step, water quality survey is the critical factor, and implementing active water quality management strategies such as developing local water quality monitoring guidelines, source water protection, educational and awareness programs for stakeholders, and integrated health monitoring programs, are essential for the development of the water sector [136]. In Sri Lanka, monitoring and assessment of water quality of source water are not continuous and regular, especially in rural regions, e.g., water supply schemes by CBOs (dug well and tube wells) commonly available in the dry zone of Sri Lanka have not continually and regularly monitored water quality to check the feasibility for drinking purposes. Such a current situation with a lack of available water resources quality data will not only slow down the process of expanding the water supply, but also directly affect the overall health and the livelihood of the community [137]. For example, the prevalence of CKDu created hardships including financial burden for families of the patients. Water quality surveys and mapping for the rural regions should be initiated immediately and carried out widely in Sri Lanka [136,138]. Ministry of Urban Development, Water Supply and Housing Facilities (MUDWSHF), Sri Lanka initiated a program to assess the water quality of CBO-established water supply schemes at the end of 2019. This program will be initiated with seven districts covered by the Water Supply and Sanitation Improvement Project (WaSSIP), in which NWSDB, Department of National Community Water Supply (DNCWS), and China–Sri Lanka Research Grant Project are the major stakeholders of the program. The WaSSIP, funded jointly by the Government of Sri Lanka (GOSL) and the World Bank (WB), aspires to increase access to piped water services and improved sanitation in Badulla, Monaragala, Nuwaraeliya, Kegalle and Ratnapura, Kilinochchi, and Mullaitivu districts. Cabinet Memorandum on 16th of December 2019 issued by the MUDWSHF explained the importance of identifying the vulnerable areas and mapping them for each area by quality analysis of groundwater, and educating the people and stake- holders. For example, the China–Sri Lanka Research Grant Project carried out water quality investigation and assessment of groundwater in the CKDu prevailing areas and rural regions in the dry zone of Sri Lanka [10,106,116,117,139,140]. It is the first time in Sri Lanka that the geochemical characteristics of groundwater were assessed in different CKDu prevailing areas with the association of water quality index (WQI) with respect to drinking water sources and an appropriate treatment method, and the majority of the water sources in the areas do not qualify for drinking purposes without treatment [117]. As an example of a high risk CKDu region, NCP reported 9.4% of the groundwater was poor in quality with respect to WQI [45]. Similarly, Monaragala region reported over 50% of groundwater samples of the study area are poor in quality based on the WQI calculation [141]. As suggested in many studies done in Sri Lanka, integrated groundwater quality management strategies should be implemented to improve water supply for community well-being [136–138]; such coordination and cooperativeness among different major national agencies and sub-national agencies involved in the supply of drinking water and drainage facilities should be enhanced for the overall effectiveness and the efficiency of the future programs and plans [14].

As previously discussed, elevated concentrations of hardness, fluoride, salinity, DOC, alkalinity, and coliforms of water were the main issues in the groundwater of the CKDu-affected areas [117,119,141], and suitable water treatment technologies are the necessary barriers to provide a safe drinking supply for community well-being [117,119]. At present, almost all communities of the CKDu-affected areas rely on small-scale reverse osmosis (RO) treatment plants for drinking water supply. All RO plants achieved high removal rates (>95%) for excessive chemical constituents in groundwater, but the recovery rates were fairly low (~46%) and the current disinfection practices in RO plants were insufficient to ensure the microbial safety of the product water. Low demand for product water, scarcity of groundwater, lack of technical capacity of the local communities, poor maintenance practices, and unplanned brine removal were the key issues related to RO plant O&M [119]. In China–Sri Lanka Research Grant Project, advanced drinking water treatment technologies such as nanofiltration (NF) and electrodialysis reversal (EDR) method, and evaluation of the performances of existing water treatment with reverse osmosis (RO) are implemented to improve the quality of drinking water supply of the rural community [117,118].

However, advanced and expensive methods of drinking water production could be replaced by non-frugal treatment technologies according to novel studies [142]. Except for membrane-based drinking water treatment technologies, new studies show that use of rainwater to produce drinking water is more economical, and systematic rainwater harvesting and development of partial infiltration strategies would give different benefits such as the reduction of the detrimental effects of flooding, improvement in groundwater recharge, and protection of the conventional water sources as well [143]. Similarly, dilution of high salinity groundwater with rainwater to make drinking water with moderate salinity can be suggested as a simple and inexpensive technology with lower energy footprint.

Regular water quality monitoring and surveying revealed the exact sources of the groundwater pollution in each area which should be addressed immediately, such as extensive agricultural practices, overuse of agrochemicals, and improper waste disposal methods, to control and prevent groundwater pollution. Government policies should be developed to screen, select, and develop environmentally friendly agrochemicals, fertilizers, and environmental resist species (seeds) for farming through expanding the R&D capability. Meanwhile, it is very important to educate farmers about reasonably using agrochemicals, organic farming, and the selection of high resistance seeds to reduce the impacts of agriculture activities on groundwater. Strategies, facilities, and technologies for waste management and sanitation should be established, implemented, and developed especially for rural areas, e.g., open dumping sites should be removed and recycled, new solid waste treatment technologies should be developed and implemented. Rural communities should be educated and sanitary facilities should be improved to avoid health issues related to contamination of the drinking water sources.

6. Conclusions and Outlook

Drinking purpose is the major usage apart from agricultural usage of groundwater throughout Sri Lanka, especially in rural communities of the dry zone areas. Usually, the wet zone of Sri Lanka is dominated by HCO_3 type groundwater and the metamorphic terrain dry zone is composed of Ca–Mg type groundwater due to the mineral weathering. The dominant groundwater type of sedimentary terrain is usually Na–SO_4–Cl type governed by the ion exchange processes with seawater intrusion.

Groundwater quality in Sri Lanka usually has a quite higher variation in the region by region. Comparably better groundwater quality has been reported from the wet zone compared to the dry zone. Higher mineral content has been reported from the dry zone and semi-arid regions in Sri Lanka due to the geochemical interaction, higher evaporation, and lower precipitation. Elevated levels of total hardness, fluoride, DOC, and alkalinity, and salinity are reported as the major issues in the groundwater of the dry zone areas. Trace metals such as arsenic, cadmium, and lead in groundwater reported comparatively higher levels in only a few locations, but the majority of the regions have acceptable levels for drinking purposes. The elevated level of geogenic fluoride is significant in the groundwater in the dry zone because of the dissolution of minerals such as amphiboles, biotite, and apatite in high-grade metamorphic terrains. Primary sources of nitrate in groundwater are inorganic fertilizers, septic systems, and manure storage and spreading operations. Compared to the conventional coagulation-flocculation strategies, existing membrane-based drinking water stations such as RO drinking water plants in the dry zone supply safe and clean water with acceptable levels of dissolved constituents to the community.

Under the UN SDG 6th goal, Sri Lanka has made significant progress in clean water supply improvement, such as accessibility to safe drinking water supply for up to 91% of the population, there are still big gaps and challenges in terms of safe drinking water supply for all, especially in rural communities. Thus, the integrated groundwater quality management becomes essential and should be carried out to improve the capacity of monitoring and assessment of groundwater quality, research & development, and to apply for cost-effective water treatment technologies, protect source groundwater, make educational and awareness programs for stakeholders, as well as strategies and facilities for the usage of agrochemicals and inorganic fertilizers, waste management, and sanitation. For improvement of community well-being, novel advanced and efficient drinking water treatment technologies such as membrane technologies including RO, NF, and EDR for the centralized and decentralized drinking water supply systems, respectively, should be further implemented in the CKDu-affected regions in Sri Lanka. Thus, this study will help to guide the groundwater-based drinking water supply strategies which will be implemented in the future in Sri Lanka as well as around the globe.

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References

1. National Water Supply and Drainage Board, Annual Report. 2017. Available online: http://ebis.waterboard.lk/documentation/it/Annual_Report_2017/Annual_Report_2017_English.pdf (accessed on 14 June 2020).
2. NWSDB. Corporate Planning Division: National Water Supply & Drainage Board, Sri Lanka. December 2020. Available online: http://www.waterboard.lk/web/index.php?option=com_content&view=article&id=78&Itemid=425&lang=en (accessed on 26 December 2020).

3. Senarathne, S.; Jayawardana, J.M.C.K.; Edirisinghe, E.A.N.V.; Chandrajith, R. Influence of regional climatic on the hydrogeochemistry of a tropical river basin—A study from the Walawe river basin of Sri Lanka. *Environ. Sci. Pollut. Res.* **2020**, *28*, 15701–15715. [CrossRef] [PubMed]
4. Geekiyanage, N.; Pushpakumara, D.K.N.G. Ecology of ancient Tank Cascade Systems in island Sri Lanka. *J. Mar. Isl. Cult.* **2013**, *2*, 93–101. [CrossRef]
5. Zubair, L. Modernisation of Sri Lanka's Traditional Irrigation Systems and Sustainability. *Sci. Technol. Soc.* **2005**, *10*, 161–195. [CrossRef]
6. Bebermeier, W.; Meister, J.; Withanachchi, C.R.; Middelhaufe, I.; Schütt, B. Tank Cascade Systems as a Sustainable Measure of Watershed Management in South Asia. *Water* **2017**, *9*, 231. [CrossRef]
7. Nianthi, K.W.G.R.; Jayakumara, M.A.S. Progress of research on cascade irrigation systems in the dry zones of Sri Lanka. *Community Environ. Disaster Risk Manag.* **2010**, *2*, 109–137. [CrossRef]
8. Panabokke, C.R.; Perera, A. *Groundwater Resources of Sri Lanka*; Water Resource Board: Colombo, Sri Lanka, 2005.
9. Balasooriya, S.; Munasinghe, H.; Herath, A.T.; Diyabalanage, S.; Ileperuma, O.A.; Manthrithilake, H.; Daniel, C.; Amann, K.; Zwiener, C.; Barth, J.A.C.; et al. Possible links between groundwater geochemistry and chronic kidney disease of unknown etiology (CKDu): An investigation from the Ginnoruwa region in Sri Lanka. *Expo. Health* **2019**, *12*, 823–834. [CrossRef]
10. Cooray, T.; Wei, Y.; Zhong, H.; Zheng, L.; Weragoda, S.; Weerasooriya, R. Assessment of Groundwater Quality in CKDu Affected Areas of Sri Lanka: Implications for Drinking Water Treatment. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1698. [CrossRef]
11. Dharma-Wardana, M.W.C.; Amarasiri, S.L.; Dharmawardene, N.; Panabokke, C.R. Chronic kidney disease of unknown aetiology and ground-water ionicity: Study based on Sri Lanka. *Environ. Geochem. Health* **2015**, *37*, 221–231. [CrossRef]
12. Alexakis, D. Linking DPSIR Model and Water Quality Indices to Achieve Sustainable Development Goals in Groundwater Resources. *Hydrology* **2021**, *8*, 90. [CrossRef]
13. Ho, L.T.; Goethals, P.L.M. Opportunities and Challenges for the Sustainability of Lakes and Reservoirs in Relation to the Sustainable Development Goals (SDGs). *Water* **2019**, *11*, 1462. [CrossRef]
14. Government of the DemocraticSocialist Republic of Sri Lanka. *Voluntary National Review (VNR) of Sri Lanka*; Government of the DemocraticSocialist Republic of Sri Lanka: Sri Jayawardenepura Kotte, Sri Lanka, 2018.
15. Ministry of Mahaweli Development and Environment. *National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016–2025*; Ministry of Mahaweli Development and Environment: Ethul Kotte, Sri Lanka, 2016.
16. Nianthi, K.W.G.R. *Nationally Determined Contributions (NDCs) Sri Lanka*; Ministry of Mahaweli Development and Environment: Ethul Kotte, Sri Lanka, 2016.
17. Cooray, P.G. The Precambrian of Sri Lanka: A historical review. *Precambrian Res.* **1994**, *66*, 3–18. [CrossRef]
18. Cooray, P.G. *An Introduction to the Geology of Sri Lanka (Ceylon)*; National museums of Sri Lanka publication: Colombo, Sri Lanka, 1984; Volume 38.
19. Dharmapriya, P.L.; Malaviarachchi, S.P.K.; Santosh, M.; Tang, L.; Sajeev, K. Late-Neoproterozoic ultrahigh-temperature metamorphism in the Highland Complex, Sri Lanka. *Precambrian Res.* **2015**, *271*, 311–333. [CrossRef]
20. Nakagawa, M.; Kehelpannala, K.; Manabe, T.; Ranaweera, L.; Nasu, A. Kaolin deposit at Meetiyagoda, southwestern Sri Lanka. *Clay Sci.* **2017**, *21*, 29–34. [CrossRef]
21. Edirisinghe, E.; Karunarathne, G.; Tilakarathna, I.; Gunasekara, J.; Priyadarshanee, K. Isotope and chemical assessment of natural water in the Jaffna Peninsula in northern Sri Lanka for groundwater development aspects. *Isot. Environ. Health Stud.* **2020**, *56*, 205–219. [CrossRef] [PubMed]
22. Joshua, W.; Thushyanthy, M.; Nanthagoban, N. Seasonal variation of water table and groundwater quality of the karst aquifer of the Jaffna Peninsula-Sri Lanka. *J. Natl. Sci. Found. Sri Lanka* **2013**, *41*, 3. [CrossRef]
23. Panabokke, C.R.; Ariyaratne, B.R.; Seneviratne, A.; Wijekoon, D.; Molle, F. *Characterization and Monitoring of the Regolith Aquifer within Four Selected Cascades (Sub-Watersheds) of the Malala Oya Basin*; International Water Management Institute: Colombo, Sri Lanka, 2007.
24. Wijesekara, R.S.; Kudahetty, C. Preliminary groundwater assessment and water quality study in the shallow aquifer system in the Attanagalu Oya Basin. In *Proceedings of the National Conference on Water, Food Security and Climate Change in Sri Lanka: Water Quality, Environment and Climate Change*; International Water Management Institute: Colombo, Sri Lanka, 2010; Volume 2, pp. 77–87.
25. Chandrajith, R.; Chaturangani, D.; Abeykoon, S.; Barth, J.A.C.; van Geldern, R.; Edirisinghe, E.A.N.V.; Dissanayake, C.B. Quantification of groundwater-seawater interaction in a coastal sandy aquifer system: A study from Panama, Sri Lanka. *Environ. Earth Sci.* **2014**, *72*, 867–877. [CrossRef]
26. Jayasingha, P.; Pitawala, A.; Dharmagunawardhane, H.A. Vulnerability of Coastal Aquifers Due to Nutrient Pollution from Agriculture: Kalpitiya, Sri Lanka. *Water Air Soil Pollut.* **2011**, *219*, 563–577. [CrossRef]
27. Dissanayake, C.B.; Weerasooriya, S.V.R. A geochemical classification of groundwater of Sri Lanka. *J. Natl. Sci. Con. Sri Lanka* **1985**, *13*, 147–186. [CrossRef]
28. Thilakerathne, A.; Schüth, C.; Chandrajith, R. The impact of hydrogeological settings on geochemical evolution of groundwater in karstified limestone aquifer basin in northwest Sri Lanka. *Environ. Earth Sci.* **2015**, *73*, 8061–8073. [CrossRef]
29. Rubasinghe, R.; Gunatilake, S.K.; Chandrajith, R. Geochemical characteristics of groundwater in different climatic zones of Sri Lanka. *Environ. Earth Sci.* **2015**, *74*, 3067–3076. [CrossRef]

30. Senarathne, S.; Jayawardana, J.M.C.K.; Edirisinghe, E.A.N.V.; Chandrajith, R. Characterization of groundwater in Malala Oya river basin, Sri Lanka using geochemical and isotope signatures. *Groundw. Sustain. Dev.* **2019**, *9*, 100225. [CrossRef]
31. Mikunthan, T.; Vithanage, M.; Pathmarajah, S.; Ariyaratne, M.R.; Manthrithilake, H. *Hydrogeochemical Characterization of Jaffna's Aquifer Systems in Sri Lanka*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2013. [CrossRef]
32. Puvaneswaran, P. Geomorphology of the Valukkai aru drainage basin. *Sri Lankan J. S. Asian Stud.* **1986**, *1*, 43–58.
33. Rajasooriyar, L.; Mathavan, V.; A Dharmagunawardhane, H.; Nandakumar, V. Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. *Geol. Soc. Lond. Spec. Publ.* **2002**, *193*, 181–197. [CrossRef]
34. Nagarajah, S.; Abeykoon, V.; Emerson, B.N.; Yogalingam, S. Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution [Sri Lanka]. *Trop. Agric.* **1988**, *144*, 61–78.
35. Mahagamage, M.G.Y.L.; Manage, P.S.; Manage, P.M. Water quality and microbial contamination status of groundwater in Jaffna Peninsula, Sri Lanka. *J. Water Land Dev.* **2019**, *40*, 3–12. [CrossRef]
36. Bandara, U.; Diyabalanage, S.; Hanke, C.; van Geldern, R.; Barth, J.A.; Chandrajith, R. Arsenic-rich shallow groundwater in sandy aquifer systems buffered by rising carbonate waters: A geochemical case study from Mannar Island, Sri Lanka. *Sci. Total Environ.* **2018**, *633*, 1352–1359. [CrossRef]
37. Herath, H.M.A.S.; Kubota, K.; Kawakami, T.; Nagasawa, S.; Motoyama, A.; Weragoda, S.K.; Chaminda, G.G.T.; Yatigammana, S.K. Potential risk of drinking water to human health in Sri Lanka. *Environ. Forensics* **2017**, *18*, 241–250. [CrossRef]
38. Jayawardana, D.T.; Pitawala, H.; Ishiga, H. Groundwater Quality in Different Climatic Zones of Sri Lanka: Focus on the Occurrence of Fluoride. *Int. J. Environ. Sci. Dev.* **2010**, *1*, 244–250. [CrossRef]
39. Song, X.; Kayane, I.; Tanaka, T.; Shimada, J. Conceptual model of the evolution of groundwater quality at the wet zone in Sri Lanka. *Environ. Geol.* **1999**, *39*, 149–164. [CrossRef]
40. Balasooriya, B.M.J.K.; Chaminda, G.G.T.; Ellawala, K.C.; Kawakami, T. Comparison of Groundwater Quality in Southern Province. 2017. Available online: http://www.dcee.ruh.ac.lk/images/donaimage/ACEPPProceeding2017/Environment_Engineering_and_Management/Comparison_of_Groundwater.pdf (accessed on 1 April 2022).
41. World Health Organization. *Hardness in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality*; World Health Organization: Geneva, Switzerland, 2010.
42. Ras, H.S.; Ghizellaoui, S. Determination of anti-scale effect of hard water by test of electrodeposition. *Procedia Eng.* **2012**, *33*, 357–365. [CrossRef]
43. *SLS 614*; Specification for Potable Water (First Revision). Sri Lanka Standards Institution: Colombo, Sri Lanka, 2013.
44. Liyanage, D.N.D.; Diyabalanage, S.; Dunuweera, S.P.; Rajapakse, S.; Rajapakse, R.M.G.; Chandrajith, R. Significance of Mg-hardness and fluoride in drinking water on chronic kidney disease of unknown etiology in Monaragala, Sri Lanka. *Environ. Res.* **2022**, *203*, 111779. [CrossRef] [PubMed]
45. Indika, S. Evaluation of Groundwater Quality and its Treatment by Reverse Osmosis Membrane Technology in CKDu Prevailing Regions of Sri Lanka. Master's Thesis, University of Chinese Academy of Sciences, Beijing, China, 2021.
46. Chandrajith, R.; Padmasiri, J.P.; Dissanayake, C.B.; Prematilaka, K.M. Spatial distribution of fluoride in groundwater of Sri Lanka. *J. Natl. Sci. Found. Sri Lanka* **2012**, *40*, 303. [CrossRef]
47. Wijeyaratne, W.M.; Subanky, S. Assessment of the Efficacy of Home Remedial Methods to Improve Drinking Water Quality in Two Major Aquifer Systems in Jaffna Peninsula, Sri Lanka. *Scientifica* **2017**, *2017*, 9478589. [CrossRef] [PubMed]
48. Chandrajith, R.; Diyabalanage, S.; Dissanayake, C. Geogenic fluoride and arsenic in groundwater of Sri Lanka and its implications to community health. *Groundw. Sustain. Dev.* **2020**, *10*, 100359. [CrossRef]
49. Nanayakkara, S.; Senevirathna, L.; Harada, K.H.; Chandrajith, R.; Nanayakkara, N.; Koizumi, A. The Influence of fluoride on chronic kidney disease of uncertain aetiology (CKDu) in Sri Lanka. *Chemosphere* **2020**, *257*, 127186. [CrossRef]
50. Wickramarathna, S.; Balasooriya, S.; Diyabalanage, S.; Chandrajith, R. Tracing environmental aetiological factors of chronic kidney diseases in the dry zone of Sri Lanka—A hydrogeochemical and isotope approach. *J. Trace Elem. Med. Biol.* **2017**, *44*, 298–306. [CrossRef]
51. Weragoda, S.K.; Kawakami, T. Evaluation of groundwater quality in 14 districts in Sri Lanka: A collaboration research between Sri Lanka and Japan. In *Trends in Asian Water Environmental Science and Technology*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 151–155.
52. Jayawardana, D.T.; Pitawala, H.; Ishiga, H. Geochemical assessment of arsenic and selected trace elements in agricultural and non-agricultural soil in Sri Lanka. *Trop. Agric.* **2012**, *160*, 1–19.
53. Rajasooriyar, L.D.; Boelee, E.; Prado, M.C.C.M.; Hiscock, K.M. Mapping the potential human health implications of groundwater pollution in southern Sri Lanka. *Water Resour. Rural Dev.* **2013**, *1*, 27–42. [CrossRef]
54. Dissanayake, C.B.; Chandrajith, R. Medical geochemistry of tropical environments. *Earth-Sci. Rev.* **1999**, *47*, 219–258. [CrossRef]
55. Tennakoon, T. Dental fluorosis in anuradhapura district, Sri Lanka. In Proceedings of the 4th International Workshop on Fluorosis Prevention and Defluoridation of Water, Colombo, Sri Lanka, 2–6 March 2004; pp. 19–22.
56. 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 J. Agric. Res.* **2014**, *3*, 110–124. Available online: https://www.researchgate.net/profile/Sunil_Wimalawansa/publication/284804894_Impact_of_changing_agricultural_practices_on_human_health_Chronic_kidney_disease_of_multi-factorial_origin_in_Sri_Lanka/links/565b252508aeafc2aac60ba4.pdf (accessed on 28 December 2020).

57. Weerahewa, J.; Gedara, P.K.; Kanthilanka, H. The Evolution of Food Policy in Sri Lanka: 1948–2017. In *Reference Module in Food Science*; Elsevier: Amsterdam, The Netherlands, 2017.
58. Weerahewa, J.; Kodithuwakku, S.; Ariyawardana, A. *Fertilizer Subsidy Programme in Sri Lanka*; CUL Initiatives in Publishing: Cornell, NY, USA, 2010.
59. Weerasooriya, S.; Dissanayake, C. *The Hydrogeochemical Atlas of Sri Lanka*; Natural Resources, Energy & Science Authority of Sri Lanka: Colombo, Sri Lanka, 1985.
60. Priyadarshanee, K.; Pang, Z.; Edirisinghe, E.; Dharmagunawardhane, H.; Pitawala, H.; Gunasekara, J.; Tilakarathna, I. Deep groundwater recharge mechanism in the sedimentary and crystalline terrains of Sri Lanka: A study based on environmental isotope and chemical signatures. *Appl. Geochem.* **2022**, *136*, 105174. [CrossRef]
61. Ehanathan, S.; Raagulan, K.; Rajapakse, R.M.G.; Velauthamurty, K. Groundwater quality in the Jaffna peninsula of Sri Lanka and a qualitative study of BTEX removal by greenly synthesized iron nanoparticles-electro-catalyst system. *Groundw. Sustain. Dev.* **2020**, *11*, 100362. [CrossRef]
62. Atapattu, S.S.; Kodituwakku, D.C. Agriculture in South Asia and its implications on downstream health and sustainability: A review. *Agric. Water Manag.* **2009**, *96*, 361–373. [CrossRef]
63. Mujeri, M.K.; Shahana, S.; Chowdhury, T.T.; Haider, K.T. *Improving the Effectiveness, Efficiency and Sustainability of Fertilizer Use in South Asia*; South Asia Global Development Network: New Delhi, India, 2012; Available online: http://www.gdn.int/admin/uploads/editor/files/SA_3_ResearchPaper_Fertilizer_Efficiency.pdf (accessed on 12 February 2021).
64. Gopalakrishnan, T.; Kumar, L.; Mikunthan, T. Assessment of Spatial and Temporal Trend of Groundwater Salinity in Jaffna Peninsula and Its Link to Paddy Land Abandonment. *Sustainability* **2020**, *12*, 3681. [CrossRef]
65. Divisekara, T.; Navaratne, A.; Abeysekara, A. Impact of a commercial glyphosate formulation on adsorption of Cd(II) and Pb(II) ions on paddy soil. *Chemosphere* **2018**, *198*, 334–341. [CrossRef]
66. Geiger, F.; Bengtsson, J.; Berendse, F.; Weisser, W.W.; Emmerson, M.; Morales, M.B.; Ceryngier, P.; Liira, J.; Tscharntke, T.; Winqvist, C.; et al. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl. Ecol.* **2010**, *11*, 97–105. [CrossRef]
67. Mandal, A.; Sarkar, B.; Mandal, S.; Vithanage, M.; Patra, A.K.; Manna, M.C. Impact of agrochemicals on soil health. In *Agrochemicals Detection, Treatment and Remediation*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 161–187.
68. Villeneuve, A.; Montuelle, B.; Bouchez, A. Effects of flow regime and pesticides on periphytic communities: Evolution and role of biodiversity. *Aquat. Toxicol.* **2011**, *102*, 123–133. [CrossRef]
69. Balasubramanya, S.; Stifel, D.; Horbulyk, T.; Kafle, K. Chronic kidney disease and household behaviors in Sri Lanka: Historical choices of drinking water and agrochemical use. *Econ. Hum. Biol.* **2020**, *37*, 100862. [CrossRef]
70. Jayasumana, C. Chronic Interstitial Nephritis in Agricultural Communities (CINAC) in Sri Lanka. *Semin. Nephrol.* **2019**, *39*, 278–283. [CrossRef]
71. Sugirtharan, M.; Rajendran, M. Ground water quality near municipal solid waste dumping site at Thirupperumthurai, Batticaloa. *J. Agric. Sci.* **2015**, *10*, 21. [CrossRef]
72. Fernando, R.L.S. Solid waste management of local governments in the Western Province of Sri Lanka: An implementation analysis. *Waste Manag.* **2019**, *84*, 194–203. [CrossRef] [PubMed]
73. Jayaweera, M.; Gunawardana, B.; Gunawardana, M.; Karunawardena, A.; Dias, V.; Premasiri, S.; Dissanayake, J.; Manatunge, J.; Wijeratne, N.; Karunarathne, D.; et al. Management of municipal solid waste open dumps immediately after the collapse: An integrated approach from Meethotamulla open dump, Sri Lanka. *Waste Manag.* **2019**, *95*, 227–240. [CrossRef] [PubMed]
74. Balasooriya, B.M.R.S.; Vithanage, M.; Nawarathna, N.J.; Zhang, M.; Herath, G.B.B.; Mowjood, M.I.M. Solid waste disposal site selection for Kandy District, Sri Lanka integrating GIS and risk assessment. *Int. J. Sci. Res. Publ.* **2014**, *4*.
75. Dharmarathne, N.; Gunatilake, J. Leachate characterization and surface groundwater pollution at municipal solid waste landfill of Gohagoda, Sri Lanka. *Int. J. Sci. Res. Publ.* **2013**, *3*, 1–7.
76. Maheshi, D. Environmental and economic assessment of 'open waste dump' mining in Sri Lanka. *Resour. Conserv. Recycl.* **2015**, *102*, 67–79. [CrossRef]
77. Mondal, P.; Nandan, A.; Siddiqui, N.A.; Yadav, B.P. Impact of Soak Pit on Groundwater Table. *Environ. Pollut. Control J.* **2014**, *18*, 12–17.
78. Okotto, L.; Okotto-Okotto, J.; Price, H.; Pedley, S.; Wright, J. Socio-economic aspects of domestic groundwater consumption, vending and use in Kisumu, Kenya. *Appl. Geogr.* **2015**, *58*, 189–197. [CrossRef]
79. Vaheesar, K. Nitrate and fluoride content in ground water in the Batticaloa district. *JSc-EUSL* **2001**, *2*, 9–15.
80. Jayasingha, P.; Pitawala, A.; Dharmagunawardhana, H. Fate of urea fertilizers in sandy aquifers: Laboratory and field case study from Kalpitiya, Sri Lanka. *J. Natl. Sci. Found. Sri Lanka* **2013**, *41*, 121. [CrossRef]
81. Bawatharani, R.; Mowjood, M.I.M.; Dayawansa, N.D.K.; Kumaragamage, D. Simulation of nitrate leaching in Yala season in Batticaloa-A modeling approach. *J. Sci. Univ. Kelaniya* **2010**, *5*, 33–45. [CrossRef]
82. Khan, M.I.; Khisroon, M.; Khan, A.; Gulfam, N.; Siraj, M.; Zaidi, F.; Fatima, S.H.; Noreen, S.; Shah, Z.A.; Qadir, F.; et al. Bioaccumulation of heavy metals in water, sediments, and tissues and their histopathological effects on *Anodonta cygnea* (Linea, 1876) in Kabul River, Khyber Pakhtunkhwa, Pakistan. *Biomed. Res. Int.* **2018**, *2018*, 1910274. [CrossRef] [PubMed]
83. Vetrimurugan, E.; Brindha, K.; Elango, L.; Ndwandwe, O.M. Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta. *Appl. Water Sci.* **2017**, *7*, 3267–3280. [CrossRef]

84. Bandara, J.; Wijewardena, H.; Liyanege, J.; Upul, M. Chronic renal failure in Sri Lanka caused by elevated dietary cadmium: Trojan horse of the green revolution. *Toxicol. Lett.* **2010**, *198*, 33–39. [CrossRef] [PubMed]
85. Wimalawansa, S.J. The role of ions, heavy metals, fluoride, and agrochemicals: Critical evaluation of potential aetiological factors of chronic kidney disease of multifactorial origin (CKDmfo/CKDu) and recommendations for its eradication. *Environ. Geochem. Health* **2016**, *38*, 639–678. [CrossRef] [PubMed]
86. Shaji, E.; Santosh, M.; Sarath, K.; Prakash, P.; Deepchand, V.; Divya, B. Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. *Geosci. Front.* **2021**, *12*, 101079. [CrossRef]
87. Kumar, M.; Patel, A.K.; Singh, A. Anthropogenic dominance on geogenic arsenic problem of the groundwater in the Ganga-Brahmaputra floodplain: A paradox of origin and mobilization. *Sci. Total Environ.* **2022**, *807*, 151461. [CrossRef] [PubMed]
88. Golfinopoulos, S.K.; Varnavas, S.P.; Alexakis, D.E. The Status of Arsenic Pollution in the Greek and Cyprus Environment: An Overview. *Water* **2021**, *13*, 224. [CrossRef]
89. Singh, R.; Singh, S.; Parihar, P.; Singh, V.P.; Prasad, S.M. Arsenic contamination, consequences and remediation techniques: A review. *Ecotoxicol. Environ. Saf.* **2015**, *112*, 247–270. [CrossRef]
90. World Health Organization. *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum*; World Health Organization: Geneva, Switzerland, 2017.
91. World Health Organization. *Arsenic in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality*; World Health Organization: Geneva, Switzerland, 2003.
92. Bondu, R.; Cloutier, V.; Benzaazoua, M.; Rosa, E.; Bouzahzah, H. The role of sulfide minerals in the genesis of groundwater with elevated geogenic arsenic in bedrock aquifers from western Quebec, Canada. *Chem. Geol.* **2017**, *474*, 33–44. [CrossRef]
93. Drewniak, L.; Rajpert, L.; Aleksandra, M.; Sklodowska, A. Dissolution of Arsenic Minerals Mediated by Dissimilatory Arsenate Reducing Bacteria: Estimation of the Physiological Potential for Arsenic Mobilization. *BioMed Res. Int.* **2014**, *2014*, 841892. [CrossRef]
94. Pi, K.; Wang, Y.; Xie, X.; Ma, T.; Liu, Y.; Su, C.; Zhu, Y.; Wang, Z. Remediation of arsenic-contaminated groundwater by in-situ stimulating biogenic precipitation of iron sulfides. *Water Res.* **2017**, *109*, 337–346. [CrossRef] [PubMed]
95. Amarathunga, U.; Diyabalanage, S.; Bandara, U.G.C.; Chandrajith, R. Environmental factors controlling arsenic mobilization from sandy shallow coastal aquifer sediments in the Mannar Island, Sri Lanka. *Appl. Geochem.* **2019**, *100*, 152–159. [CrossRef]
96. Jayawardana, D.T.; Pitawala, H.M.T.G.A.; Ishiga, H. Assessment of soil geochemistry around some selected agricultural sites of Sri Lanka. *Environ. Earth Sci.* **2014**, *71*, 4097–4106. [CrossRef]
97. Chandrajith, R.; Ariyaratna, T.; Dissanayake, C.B. The Status of Cadmium in the Geo-environment of Sri Lanka. *Ceylon J. Sci.* **2012**, *16*, 47–53.
98. Jayasiri, M.; Yadav, S.; Dayawansa, N.; Propper, C.R.; Kumar, V.; Singleton, G.R. Spatio-temporal analysis of water quality for pesticides and other agricultural pollutants in Deduru Oya river basin of Sri Lanka. *J. Clean. Prod.* **2022**, *330*, 129897. [CrossRef]
99. Wasana, H.M.; Aluthpatabendi, D.; Bandara, J. Drinking water quality assessment towards chronic kidney disease of uncertain aetiology (CKDu) in North Central Province of Sri Lanka. In Proceedings of the International Symposium on Water Quality and Human Health, Peradeniya, Sri Lanka, 22–23 March 2012; p. 67. Available online: https://www.researchgate.net/publication/275349429_Drinking_water_quality_assessment_towards_Chronic_Kidney_disease_of_uncertain_aetiology_CKDu_in_North_Central_Province_of_Sri_Lanka (accessed on 23 December 2020).
100. Wanasinghe, W.C.S.; Gunarathna, M.H.J.P.; Herath, H.M.P.I.K.; Jayasinghe, G.Y. Drinking Water Quality on Chronic Kidney Disease of Unknown Aetiology (CKDu) in Ulagalla Cascade, Sri Lanka. *Sabaragamuwa Univ. J.* **2018**, *16*, 17. [CrossRef]
101. Bandara, J.M.R.S.; Senevirathna, D.M.A.N.; Dasanayake, D.M.R.S.B.; Herath, V.; Abeysekara, T.; Rajapaksha, K.H. Chronic renal failure among farm families in cascade irrigation systems in Sri Lanka associated with elevated dietary cadmium levels in rice and freshwater fish (Tilapia). *Environ. Geochem. Health* **2008**, *30*, 465–478. [CrossRef]
102. Chandrajith, R.; Diyabalanage, S.; Premathilake, K.; Hanke, C.; van Geldern, R.; Barth, J. Controls of evaporative irrigation return flows in comparison to seawater intrusion in coastal karstic aquifers in northern Sri Lanka: Evidence from solutes and stable isotopes. *Sci. Total Environ.* **2016**, *548*, 421–428. [CrossRef]
103. Premarathna, H.L.; Hettiarachchi, G.; Indraratne, S. Trace Metal Concentration in Crops and Soils Collected from Intensively Cultivated Areas of Sri Lanka. *Pedologist* **2011**, *54*, 230–240. Available online: http://ci.nii.ac.jp/naid/110008896944/en/ (accessed on 30 March 2016).
104. Chandrajith, R.; Seneviratna, S.; Wickramaarachchi, K.; Attanayake, T.; Aturaliya, T.N.C.; Dissanayake, C.B. Natural radionuclides and trace elements in rice field soils in relation to fertilizer application: Study of a chronic kidney disease area in Sri Lanka. *Environ. Earth Sci.* **2010**, *60*, 193–201. [CrossRef]
105. Gunarathna, S.; Gunawardana, B.; Jayaweera, M.; Manatunge, J.; Zoysa, K. Glyphosate and AMPA of agricultural soil, surface water, groundwater and sediments in areas prevalent with chronic kidney disease of unknown etiology, Sri Lanka. *J. Environ. Sci. Health Part B* **2018**, *53*, 729–737. [CrossRef] [PubMed]
106. Makehelwala, M.; Wei, Y.; Weragoda, S.K.; Weerasooriya, R.; Zheng, L. Characterization of dissolved organic carbon in shallow groundwater of chronic kidney disease affected regions in Sri Lanka. *Sci. Total Environ.* **2019**, *660*, 865–875. [CrossRef] [PubMed]
107. Zeng, X.; He, W.; Guo, H.; Shi, Q.; Zheng, Y.; Vithanage, M.; Hur, J. Recognizing the groundwater related to chronic kidney disease of unknown etiology by humic-like organic matter. *NPJ Clean Water* **2022**, *5*, 8. [CrossRef]

108. Lin, W.; Li, M.; Wang, Y.; Wang, X.; Xue, K.; Xiao, K.; Huang, X. Quantifying the dynamic evolution of organic, inorganic and biological synergistic fouling during nanofiltration using statistical approaches. *Environ. Int.* **2019**, *133*, 105201. [CrossRef] [PubMed]
109. Lin, W.; Li, M.; Xiao, K.; Huang, X. The role shifting of organic, inorganic and biological foulants along different positions of a two-stage nanofiltration process. *J. Membr. Sci.* **2020**, *602*, 117979. [CrossRef]
110. Kumar, M.; Sulfikar; Chaminda, T.; Patel, A.K.; Sewwandi, H.; Mazumder, P.; Joshi, M.; Honda, R. Prevalence of antibiotic resistance in the tropical rivers of Sri Lanka and India. *Environ. Res.* **2020**, *188*, 109765. [CrossRef]
111. Manage, P.M. Heavy Use of Antibiotics in Aquaculture; Emerging Human and Animal Health Problems—A review. *Sri Lanka J. Aquat. Sci.* **2018**, *23*, 13–27. [CrossRef]
112. Pathirana, B.M.; Thilakaratna, W.S.; Pathirana, E. *Antibiotic Resistance of Bacteria: Natural Water Bodies vs. Commercial Aquaria*; National Aquatic Resources Research and Development Agency: Tangalle, Sri Lanka, 2016.
113. Shipley, E.R.; Vlahos, P.; Chandrajith, R.; Wijerathna, P. Agrochemical exposure in Sri Lankan inland water systems. *Environ. Adv.* **2022**, *7*, 100150. [CrossRef]
114. Piyadasa, R.U.K. Ground water fecal contamination in Kalpitiya Peninsula of Sri Lanka. *Int. J. Multidiscip. Res. Dev.* **2020**, *7*, 109–114.
115. Mannapperuma, W.M.G.C.K.; Abayasekara, C.L.; Herath, G.B.B.; Werellagama, D.R.I.B. Potentially pathogenic bacteria isolated from different tropical waters in Sri Lanka. *Water Supply* **2013**, *13*, 1463–1469. [CrossRef]
116. Cooray, T.; Zhang, J.; Zhong, H.; Zheng, L.; Wei, Y.; Weragoda, S.K.; Jinadasa, K.; Weerasooriya, R. Profiles of antibiotic resistome and microbial community in groundwater of CKDu prevalence zones in Sri Lanka. *J. Hazard. Mater.* **2021**, *403*, 123816. [CrossRef] [PubMed]
117. Cooray, T.; Wei, Y.; Zhang, J.; Zheng, L.; Zhong, H.; Weragoda, S.K.; Weerasooriya, R. Drinking-Water Supply for CKDu Affected Areas of Sri Lanka, Using Nanofiltration Membrane Technology: From Laboratory to Practice. *Water* **2019**, *11*, 2512. [CrossRef]
118. Indika, S.; Wei, Y.; Hu, D.; Ketharani, J.; Ritigala, T.; Cooray, T.; Hansima, M.; Makehelwala, M.; Jinadasa, K.; Weragoda, S.; et al. Evaluation of Performance of Existing RO Drinking Water Stations in the North Central Province, Sri Lanka. *Membranes* **2021**, *11*, 383. [CrossRef] [PubMed]
119. Imbulana, S.; Oguma, K.; Takizawa, S. Evaluation of groundwater quality and reverse osmosis water treatment plants in the endemic areas of Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka. *Sci. Total Environ.* **2020**, *745*, 140716. [CrossRef]
120. Kozisek, F. Health Risk from Drinking Demineralized Water. In *Rolling Revision of the WHO Guidelines for Drinking Water Quality*; National Institute of Public Health: Prague, Czech Republic, 2004.
121. World Health Organization. *Nutrients in Drinking Water*; World Health Organization: Geneva, Switzerland, 2005.
122. Hansima, M.; Makehelwala, M.; Jinadasa, K.; Wei, Y.; Nanayakkara, K.; Herath, A.C.; Weerasooriya, R. Fouling of ion exchange membranes used in the electrodialysis reversal advanced water treatment: A review. *Chemosphere* **2021**, *263*, 127951. [CrossRef] [PubMed]
123. Patrocínio, D.C.; Kunrath, C.C.N.; Rodrigues, M.A.S.; Benvenuti, T.; Amado, F.D.R. Concentration effect and operational parameters on electrodialysis reversal efficiency applied for fluoride removal in groundwater. *J. Environ. Chem. Eng.* **2019**, *7*, 103491. [CrossRef]
124. Hansima, M.; Jayaweera, A.; Ketharani, J.; Ritigala, T.; Zheng, L.; Samarajeewa, D.; Nanayakkara, K.; Herath, A.C.; Makehelwala, M.; Jinadasa, K.; et al. Characterization of humic substances isolated from a tropical zone and their role in membrane fouling. *J. Environ. Chem. Eng.* **2022**, *10*, 107456. [CrossRef]
125. Dutta, T.; Bhattacherjee, C.; Bhattacherjee, S. Removal of Arsenic Using Membrane Technology—A Review. *Int. J. Eng. Res. Technol.* **2012**, *1*, 1–23. Available online: www.ijert.org (accessed on 3 May 2021).
126. Worou, C.N.; Chen, Z.-L.; Bacharou, T. Arsenic removal from water by nanofiltration membrane: Potentials and limitations. *Water Pract. Technol.* **2021**, *16*, 291–319. [CrossRef]
127. Li, Q.; Zhang, H.; Tan, C.; Lian, B.; García-Pacheco, R.; Taylor, R.A.; Fletcher, J.; Le-Clech, P.; Ranasinghe, B.; Senevirathna, T.; et al. Numerical and experimental investigation of a DC-powered RO system for Sri-Lankan villages. *Renew. Energy* **2021**, *182*, 772–786. [CrossRef]
128. Li, X.-F.; Mitch, W.A. Drinking Water Disinfection Byproducts (DBPs) and Human Health Effects: Multidisciplinary Challenges and Opportunities. *Environ. Sci. Technol.* **2018**, *52*, 1681–1689. [CrossRef] [PubMed]
129. Zazouli, M.A.; Kalankesh, L.R. Removal of precursors and disinfection by-products (DBPs) by membrane filtration from water: A review. *J. Environ. Health Sci. Eng.* **2017**, *15*. [CrossRef] [PubMed]
130. Kali, S.; Khan, M.; Ghaffar, M.S.; Rasheed, S.; Waseem, A.; Iqbal, M.M.; Niazi, M.B.K.; Zafar, M.I. Occurrence, influencing factors, toxicity, regulations, and abatement approaches for disinfection by-products in chlorinated drinking water: A comprehensive review. *Environ. Pollut.* **2021**, *281*, 116950. [CrossRef] [PubMed]
131. Sumanaweera, S. Kelani Right Bank Water Treatment Plant Sri Lanka. August 2015. Available online: http://www.jwrc-net.or.jp/aswin/en/newtap/report/NewTap_012.pdf (accessed on 4 May 2021).
132. Weragoda, S.K. Kandy South Water Treatment Plant Sri Lanka. June 2015. Available online: http://www.jwrc-net.or.jp/aswin/en/newtap/report/NewTap_005.pdf (accessed on 4 May 2021).

133. Amarasooriya, A.A.G.; Weragoda, S. Survey of Disinfection by-products in drinking water in Greater Kandy Water supply scheme. In Proceedings of the 5th International Conference on Sustainable Built Environment, Kandy, Sri Lanka, 12–15 December 2014.
134. Sri Lanka Navy. Navy Built RO Plants in Ampara Vested with the Public. February 2021. Available online: https://news.navy.lk/eventnews/2021/02/06/202102061300/ (accessed on 22 April 2021).
135. Presidential Secretariat. 'Will Ensure Clean Drinking Water Supply for Every Household Across Country before 2025' ... —Presidential Secretariat of Sri Lanka. 2021. Available online: https://www.presidentsoffice.gov.lk/index.php/2020/09/03/will-ensure-clean-drinking-water-supply-for-every-household-across-country-before-2025/ (accessed on 21 February 2021).
136. Pinto, U.; Thoradeniya, B.; Maheshwari, B. Water quality and chronic kidney disease of unknown aetiology (CKDu) in the dry zone region of Sri Lanka: Impacts on well-being of village communities and the way forward. *Environ. Sci. Pollut. Res.* **2020**, *27*, 3892–3907. [CrossRef] [PubMed]
137. Thoradeniya, B.; Pinto, U.; Maheshwari, B. Perspectives on impacts of water quality on agriculture and community well-being—A key informant study from Sri Lanka. *Environ. Sci. Pollut. Res.* **2019**, *26*, 2047–2061. [CrossRef] [PubMed]
138. Kumari, M.K.N.; Sakai, K.; Kimura, S.; Yuge, K.; Gunarathna, M.H.J.P. Classification of Groundwater Suitability for Irrigation in the Ulagalla Tank Cascade Landscape by GIS and the Analytic Hierarchy Process. *Agronomy* **2019**, *9*, 351. [CrossRef]
139. Makehelwala, M.; Wei, Y.; Weragoda, S.K.; Weerasooriya, R. Ca^{2+} and ${SO_4}^{2-}$ interactions with dissolved organic matter: Implications of groundwater quality for CKDu incidence in Sri Lanka. *J. Environ. Sci.* **2020**, *88*, 326–337. [CrossRef] [PubMed]
140. Zheng, L.; Cooray, T.; Zhong, H.; Weragoda, S.; Weerasooriyae, R.; Makehelwala, M.; Wei, Y. Critical challenges and solutions on ground drinking water in chronic kidney disease of unknown etiology (CKDu) affected regions in Sri Lanka. *Chin. J. Environ. Eng.* **2020**, *14*, 2100–2111. [CrossRef]
141. Udeshani, W.; Dissanayake, H.; Gunatilake, S.; Chandrajith, R. Assessment of groundwater quality using water quality index (WQI): A case study of a hard rock terrain in Sri Lanka. *Groundw. Sustain. Dev.* **2020**, *11*, 100421. [CrossRef]
142. Huang, Z.; Nya, E.L.; Cao, V.; Gwenzi, W.; Rahman, M.A.; Noubactep, C. Universal Access to Safe Drinking Water: Escaping the Traps of Non-Frugal Technologies. *Sustainability* **2021**, *13*, 9645. [CrossRef]
143. Huang, Z.; Nya, E.L.; Rahman, M.A.; Mwamila, T.B.; Cao, V.; Gwenzi, W.; Noubactep, C. Integrated Water Resource Management: Rethinking the Contribution of Rainwater Harvesting. *Sustainability* **2021**, *13*, 8338. [CrossRef]