Applicability of semi quantitative approach to assess the potential environmental risks for sustainable implementation of water supply schemes: a case study of Sri Lanka

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ABSTRACT

Identification and quantification of environmental and socio-economic impact risks and effective monitoring of water projects are crucial for sustainable water resource management. Hence, the present study was conducted with the objectives of identifying potential environmental risks of different stages of the development of a new water supply scheme located in the wet zone of Sri Lanka, and categorizing identified impacts based on their significance. A rapid environmental assessment (REA) was followed to identify the upstream point source pollution and downstream water uses in the immediate catchment. Subsequently, a semi quantitative approach was conducted to screen the environmental, social, and economic risks concerning likelihood and sensitivity of the impact. Besides, an analysis of physico-chemical and biological parameters of water quality was conducted in the intake location. The semi quantitative method highlighted that low and medium risk with ecological impacts (50%), low risks towards sustainability of water source (75%), medium level constructional impacts (60%), and very high-level impacts at the operational stage were available (50%). A water quality monitoring program revealed that *Escherichia coli* count, total coliform bacterial count, and colour of the water were above the standard limits in the nearby freshwater source. In conclusion, a similar approach can be implemented worldwide as a reference to determine the potential socio-environmental consequences in water supply projects to minimize the adverse impacts. Through this study, sustainable mitigation measures were proposed accordingly to prevent the impacts and to strengthen the long-term viability of the new Rural Water Supply Scheme.

Key words | environmental impacts, environmental risk, mitigation measures, semi quantitative approach, sustainable use of water, water supply

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HIGHLIGHTS

- The safety of drinking water is an ongoing concern within the world.
- To reach the targets of safe drinking water, sanitation services should be strengthened.

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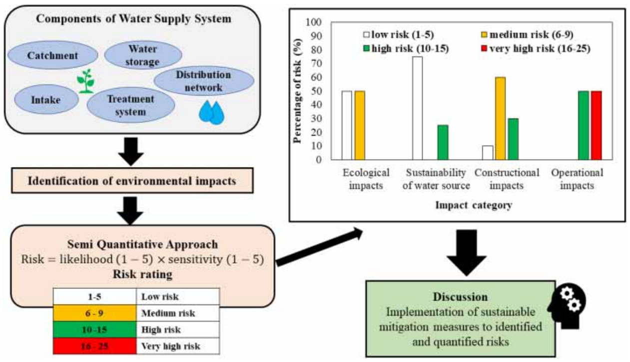
- Identifying potential environmental risks of new water supply projects is crucial for sustainable water resource management.
- Rapid environmental assessment and semi quantitative approaches can be applied to screen the socio-economic and environmental risks of water sanitization projects.
- Results revealed 50% of ecological, 60% constructional impacts, and 50% operational stage impacts.
- Implementing a sustainable environment plan is vital to control environmental impacts.

GRAPHICAL ABSTRACT



INTRODUCTION

The renewable freshwater ecosystems encompass a fraction of 0.3% of total global water resources, where people consume this for drinking, irrigation, agriculture, aquaculture, recreation, transportation, and so on (Arthington 2012). However, over the next century, climate change and the growing disparity between supply and demand of freshwater might dramatically change the hydrological cycle. Even now, many parts of the world are already limited by the quantity and quality of available water (Arthington 2012). It is estimated that more than 1.1 billion people suffer without having access to improved drinking-water facilities and, besides, 0.2 billion people exist without improved sanitation (World Health Organization 2015). More than 70% of the world's rural population in developing countries do not have access to adequate water supply and sanitation facilities (World Bank 2017). In special consideration, developing countries that are located in tropical regions are severely affected by these issues (World Health Organization 2015). The conditions are more critical in South Asian countries; it is stated that 40% of the population in East Asia suffer from improper sanitation and are affected by immobilizing the sanitation-related infirmities (United Nations 2018).

In catchments, even though monsoonal rain recharges the freshwater inputs, it is not surprising to find communities in tropical regions who do not have access to safe drinking water (Buytaert & De Bièvre 2012). The prime reasons are poverty, human-induced and natural stressors such as pollution, and ecosystem destruction (Cobbina et al. 2010). These activities increase the imbalance between the availability of safe drinking water and water consumption patterns within a catchment and may weaken the performance of the ecosystem services. For instance, human inputs and accelerated weathering cause an increase in the salinity of freshwater ecosystems. Higher salinity level causes a reduction in the quality of drinking water (Kaushal et al. 2013). Furthermore, impairment of water quality is responsible for the rapid distribution of waterborne diseases. For example, there exists a positive relationship between the quality of drinking water and chronic kidney disease in the North Central Province of Sri Lanka (Wanigasuriya 2012). Shreds of evidence show that many agrochemicals infiltrate through the soil and contaminate the surface and ground, which leads to widespread waterborne diseases (Wanigasuriya 2012). Thus, existing freshwater resources in tropical regions are under severe stress, which forces governments to find immediate solutions for the increasing demand for safe drinking water.

To reach the targets of safe drinking water for regional communities, effective monitoring of safe management of water and sanitation services should be strengthened throughout the catchment (World Health Organization & United Nations International Children's Emergency Fund 2013). One of the long-lasting remedies for shortage and unsafeness in drinking water is the consumption of groundwater sources, such as protected dug wells, tube wells, and boreholes (Shrestha *et al.* 2017). Water purification techniques and utilization of a water source at the household to meet domestic needs that complies with the World Health Organization (WHO) guideline is also recommended (World Health Organization & United Nations International Children's Emergency Fund 2013). At the national level, building of tanks, reservoirs, and the introduction of different rainwater harvesting systems (Thi Hoang Duong *et al.* 2011) are also better solutions for addressing drinking water scarcities and poor sanitation. Through these efforts, conservation goals of access to proper sanitation and safe drinking water can be accomplished.

The rural water supply schemes (RWSS) are one of the key solutions for providing safe drinking water for rural communities to develop human capital to support the growth potential of rural areas. These projects are usually proposed to be managed by community-based organizations (CBOs) (World Bank 2020). However, the challenge facing the sector today is how to scale up these experiences in order to meet the target of the Sustainable Development Goals (United Nations 2020). The sustainability of a water supply scheme is defined as the maintenance of an acceptable level of services throughout the design life of the water supply system (Mimrose *et al.* 2011). To gain the maximum benefits from RWSS and to continue to function over a prolonged period by providing quality, quantity, convenience, continuity, and health to the community, the water and sanitation service should be maintained in a sustainable manner. Sustainability of water supply and sanitation has mainly five dimensions: technical sustainability, financial sustainability, institutional sustainability, social sustainability and environmental sustainability (World Bank 2020). Further, a proper evaluation should be maintained from planning throughout the operational stage to maintain the above-mentioned sustainability criteria.

However, natural entities and anthropogenic derivates cannot be easily isolated. Therefore, when implementing remedies for improving drinking water and sanitation, a range of social (impacts on rural agricultural, flooding, safety hazards, social conflicts), environmental (siltation of water sources, over-extraction of water, ecosystem degradation, soil erosion), economical (damages to utilities) consequences may progress (Enéas da Silva *et al.* 2013). All these factors account for unsustainable standards in water supply and sanitation improvement projects, especially in rural communities (Behailu *et al.* 2017). Moreover, sustainable standards of drinking water supply in rural communities of developing countries are quite unsatisfactory (Akter *et al.* 2016). For instance, even though the environmental and social safeguards of these projects meet 25% of their standards in the beginning, most of the water supply systems in African and Asian countries fail before the second year after their inauguration (Taylor 2009). Therefore, identification of potential impacts on social, technical, and environmental aspects of drinking water projects within the catchment is critical to the success of the project. Hence, evaluation and recognition of possible risks and socio-environmental impacts on water supply projects should be incorporated through feasibility studies to ensure the sustainability of the project. Also, understanding the socio-economic and environmental conditions and the project impact on the catchment area is a must. In a feasibility analysis, along with the social and environmental risks and impacts, the demand for safe drinking water should be also assessed.

Risk assessment is a complex and systematic process to identify and compare threats and vulnerabilities that can occur in any scenario and can be determined quantitatively or qualitatively. However, when it comes to environmental risk assessment, the availability of relevant long-term data is limiting in most locations, especially in developing nations. Thus, semi quantitative approaches are always recommended. Semi quantitative methods are used to describe the relative risk scale, and different scales are used to characterize the likelihood of adverse events and their consequences. For example, the risk can be classified into categories like 'low', 'medium', 'high' or 'very high'

(Athearn 1971; Radu 2009; Tahar *et al.* 2017). There are few methods to quantify the potential environmental impacts. Among those methods, the semi quantitative method used by Petts (2009) can be employed to understand the likelihood and the sensitivity of the environmental impacts or risks that are associated with them to determine the sustainable mitigation measures. In addition, following water quality monitoring along with the semi quantitative assessment provides the platform to understand the variability of physical, chemical, and biological parameters of the source water at different times of the year. Thereby, it enables understanding of the receiving pollutant load and diversity of pollutant concentrations from the upstream areas of the water source. However, as catchments are subjected to various stresses, a systematic approach is essential to assess and monitor the resource usage options and environmental impacts in an integrative manner. This evaluation must reflect the representative dimensions including integrated issues and stakeholders, the role between the natural sciences, and anthropogenic aspects (Jakeman & Letcher 2003). In a scenario where the water intake is a river, the river banks should be protected to prevent contamination of the water. Presently, it is essential to design for water catchment protection planning for sustainable catchment management (Smith & Porter 2010) to ensure the safety of water for drinking and other ecological purposes. Therefore, having a semi quantitative approach to measure the risk and impacts of rural small-scale drinking water projects may facilitate researches to develop a similar framework to determine and carry out comprehensive sustainability studies before implementing similar types of small scale projects that lack long term socio-environmental data.

This study is based on Bulathkohupitiya Divisional Secretariat (DS) in Kegalle District, Sri Lanka (Figure 1). The area currently has a water supply scheme that is managed by the National Water Supply and Drainage Board (NWSDB), Sri Lanka. However, it has been unable to meet the demand for the pipe-borne water supply in that region. A total of 2012 households (24.2% of the total population) do not have access to the consumption of pipe-borne treated water in that region. Thus, a new Rural Water Supply Scheme (RWSS) was initiated to provide safe pipe-borne drinking water to the population in above Grama Niladhari Divisions (GNDs). It is expected to serve a projected population of 6,600 (1,600 households) in the year 2038. The total water demand in the area in 2038 is estimated at 1,000 m^3/day. It is expected that the provision of safe drinking water will contribute towards reducing the incidence of waterborne diseases and upgrade the livelihoods of the community. This project aims to contribute towards poverty reduction with improved health and time saved by the provision of improved access to safe drinking water at their doorsteps.

In the Sri Lanka context, Wijesinghe *et al.* (2019) has pointed out the importance of assessment of the sustainability of rural supply schemes and incorporation of community participation for sustainability. In addition, the integration of financial, socio-economic, managerial, institutional, and community has been heavily discussed for sustainable implementation of rural water supply schemes (Fernando & Morais 2019; Wijesinghe *et al.* 2019; Sinclair 2020). However, integration of environmental components and quantifying environmental and ecological impacts during the rural water supply projects has not been well addressed. Therefore, the present study thus attempts to identify the potential environmental risks and impacts of different stages of the development of a new rural water supply scheme and to categorize those impacts based on their significance. Hence, the present study was carried out with three key objectives: (1) to determine the applicability of rapid environmental assessment (REA) using the semi quantitative analysis method in characterizing the potential socio-environmental impacts of rural water supply schemes, (2) to determine the usability of raw water quality assessments to understand the baseline status of the water source, and (3) to identify the sustainable mitigatory measures to minimize the identified socio-environmental impacts of the selected rural water supply scheme.

MATERIAL AND METHODS

Study area

The study was carried out in Bulathkohupitiya (70°06′16″N and 80° 20′11″E), which is approximately 70 m above the mean sea level and located in the wet zone of Sri Lanka. The annual average rainfall varies between 2,500 mm and 3,000 mm and the annual average temperature varies between 18 °C and 35 °C (Department of Meteorology Sri

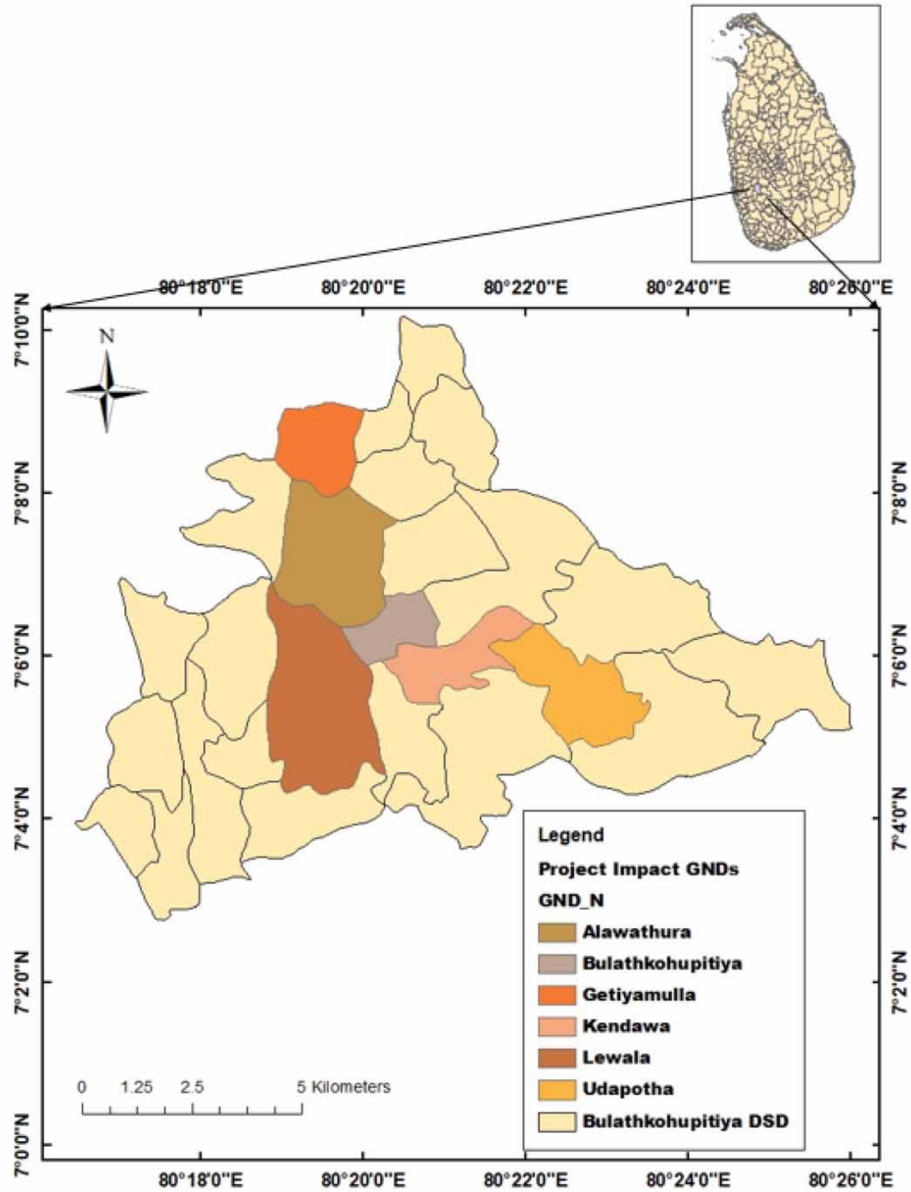


Figure 1 | Map of GNDs covered in Bulathkohupitiya DSD by the Bulathkohupitiya RWSS.

Lanka 2019). The Ritigaha Oya (river) is the water source where the proposed intake weir to be constructed.

The project site consists mainly of mountainous terrain. Geologically, this area consists of metamorphic hard rock. The surface water sources are intermittent streams, creeks, and canals associated with surface runoff. There are no adequate groundwater sources available within the selected GNDs due to the higher terrain of the area. In terms of land uses, the project area contains *Hevea brasiliensis* (15%) and *Camellia sinensis* (10%), home gardens (40%), and others (35%) including paddy cultivation. However, cultivation takes place in only one season (May to the end of August).

Sampling procedure

Rapid environmental assessment (REA) for environmental screening

REA was conducted to encounter pollution sources and downstream water users of Ritigaha Oya concerning the intake area of the water source (Kelly 2005). GIS mapping and direct visual analysis were used to identify the upstream point and non-point source pollution. A similar method was conducted to recognize the potential water users in the downstream. In terms of conservation and maintaining ecological balance, sampling was conducted to identify the native fish species in the intake location.

An environmental screening checklist is designed to help users decide whether environmental assessment (EA) is required based on the characteristics of a project and its environment (Kelly 2005; Petts 2009). Field observations for the REA were conducted by the group of experts (Figure 2). The impacts related to ecological components, design, constructions, social sector, community

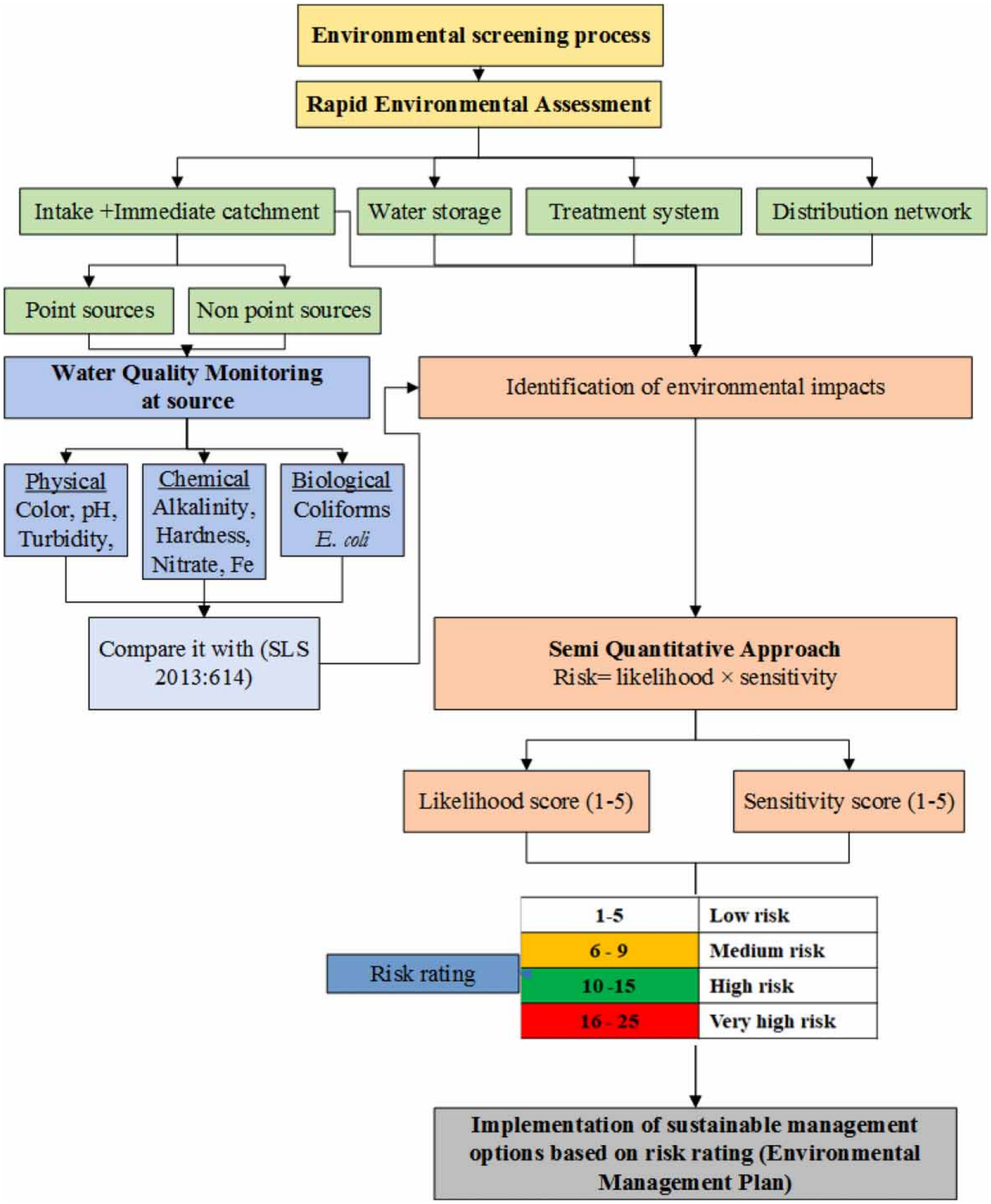


Figure 2 | Process flow diagram of the study design.

health, and the operational stage were screened through a checklist.

Risk quantification using semi quantitative risk assessment method

All potential biological, physical, and chemical hazards that could be associated with the water supply and all the risks were assessed using semi quantitative risk assessment (Petts 2009; Scottish Natural Heritage 2013). The descriptive information on risk level, semi quantitative risk matrix approach with likelihood and sensitivity analysis and summary of overall risk scoring and rating for evaluation are represented in Tables 1–3, respectively.

The risk score was generated as a multiplication of severity (sensitivity) and probable frequency of occurrence (likelihood) of a certain hazardous event (Equation (1)) (Petts 2009).

$$\text{Risk} = \text{likelihood score} \times \text{sensitivity score} \tag{1}$$

The risk score value is ranged from 1 to 25, whereas the risk rating is ranged from very high (25–16 score) to low (5–1 score). The significance level of a certain hazardous event was assigned based on the educational judgement for the impacts on human health, aesthetic value, operation and maintenance cost (Table 1).

The probable occurrence frequency of a certain hazardous event was categorized into five frequency levels, as daily, once a week, once a month, once a year, and more than once a year. The most suitable level for the respective hazard was selected based on educational judgement and experiences. Based on these details, risk scoring and rating were assigned (Table 3) and the sustainable mitigation measures were proposed through the Environmental Management Plan (EMP) to ensure the viability of RWSS.

Analysis of physical, chemical and biological parameters of water quality

Triplicated water samples were collected from the proposed intake location. Physical, chemical, and biological parameters such as colour (Hazen), turbidity (NTU), pH at 27 °C, total dissolved solids (mg/L), total alkalinity (as $CaCO_3$), total hardness (as $CaCO_3$), nitrate (as NO_3^-) mg/L, total iron (as Fe) (mg/L), total coliform bacteria colonies at 35 °C/100 mL, *Escherichia coli* (*E. coli*) bacteria colonies at 44.5 °C/100 mL and flow measurements were measured from March 2018 to June 2018. The observed results were compared with the Sri Lanka Water Quality guidelines (Sri Lankan Standard Institute 2013).

Table 1 | The descriptive information on risk level (Petts 2009)

Level	Descriptor	Description
1	Insignificant	No detectable, or insignificant health impact. No disruption to normal operation. Insignificant impact to normal operating costs.
2	Minor	Short term or localized aesthetic non-compliance, not related (e.g. Fe, Mn, H_2S, Zn, color, odor, taste, turbidity). Manageable disruption. Minor impact on normal operating costs.
3	Moderate	Widespread aesthetic issues or long-term non-compliance, not health related (for instance Fe, Mn, H_2S, Zn, color, odor, taste, turbidity). Significant impact to normal operation but manageable. Significant impact to normal operating costs.
4	Major	Potential long-term health effects or chronic toxicity (for example chemical organic constituents; for instance pesticides, trihalomethanes (THMs), or inorganic constituents including Hg, Cd, Pb). System significantly compromised; high level of monitoring is required. Disruption to consumers in the supply.
5	Catastrophic	Potential illness or acute toxicity (for instance microbial, chemical organic constituents; for example pesticide, or inorganic constituents; for example CN). Major impact for large population. Complete system failure.

RESULTS AND DISCUSSION

Upstream point source pollution and downstream water users in RWSS with reference to intake location

The produced immediate catchment map of Ritigaha Oya water source indicating the point sources pollution and

Table 2 | Semi quantitative risk matrix approach with likelihood and sensitivity analysis (Petts 2009)

		Severity or consequence				
		Rating 1: No impact or Insignificant	Rating 2: Minor impact	Rating 3: Moderate impact	Rating 4: Major impact	Rate 5: Catastrophic
Likelihood frequency	Rating: 1 (Rare or once in more than a year)	1	2	3	4	5
	Rating 2: (Unlikely once a year)	2	4	6	8	10
	Rating 3: Moderate (Once a month)	3	6	9	12	15
	Rating 4: (Likely once a week)	4	8	12	16	20
	Rating 5: (almost certain daily)	5	10	15	20	25

Risk score was calculated based on (Eq. 1); Risk = likelihood score × sensitivity score

Table 3 | Description of overall risk scoring and rating for evaluation (Petts 2009)

Risk score	Risk rating	Action
<6	Low	Documentation and keep under review
6-9	Medium	Documentation and keep under review
10-15	High	Priority actions required to mitigate hazard in short term
16-25	Very high	Urgent action required to mitigate and prevent hazard

Risk score was calculated based on (Eq. 1); Risk = likelihood score × sensitivity score

Risk score was calculated based on (Equation (1)); $Risk = likelihood\ score \times sensitivity\ score$.

downstream water users is shown in Figure 3. In terms of upstream point source pollution, two electricity generating powerhouses and two households were identified as the potential pollution sources. Residents used the river only for bathing purposes. Based on the questionnaire survey, it was identified that chemical fertilizer usage was minimal for those tea-cultivated lands.

The total catchment of a water source is a major component in an RWSS. However, the feasibility of monitoring all activities and scenarios taking place in a larger catchment is less effective when there are limited resources. Therefore, identification of anthropogenic and natural activities occurring in the immediate catchment of a water source or a water body is vital for the effectiveness and sustainability of RWSS (Najar & Khan 2012; WaSSIP 2017). The water extraction rate from the Ritigaha Oya for electricity generation is 1,500 L/s and in the dry period, the water extraction rate is reduced accordingly. In addition, all the extracted water is directed back to the Ritigaha Oya stream above. Therefore, flow alterations and volume reductions are at a minimal level.

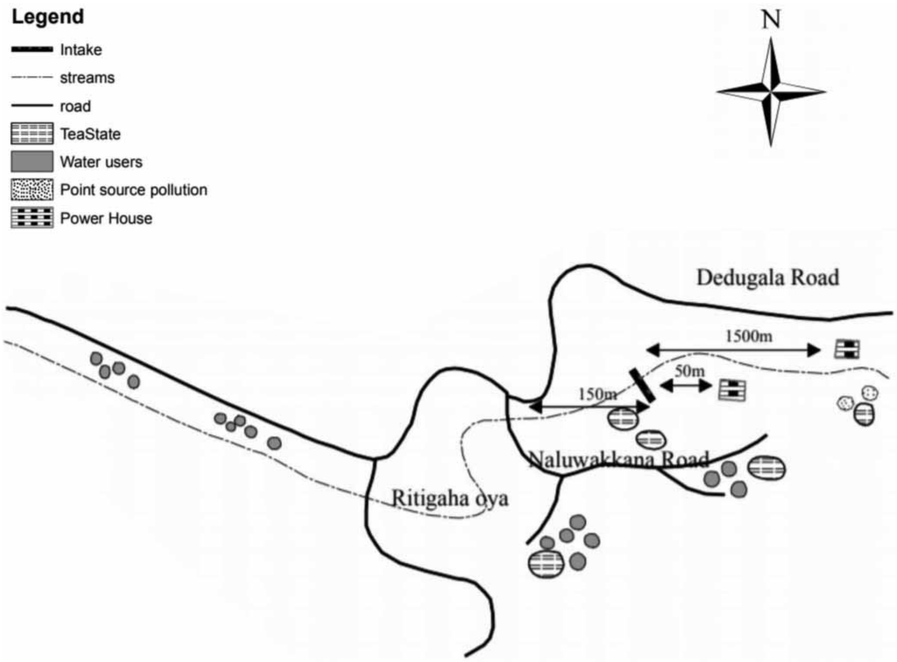


Figure 3 | Schematic map of immediate catchment area indicating potential upstream point source pollution and downstream water users.

Potential impacts in pre-construction, construction and operation stages using environmental screening and semi quantitative method

Ecological impacts

Significant ecological impacts were at low to medium level risks. However, it was proposed to remove some *Hevea brasiliensis* plants and it was considered as a medium significance environmental risk concerning the likelihood and the sensitivity as the tree compensation program is implemented to cover the tree loss at a ratio of 1:2 (number of cut-down trees: number of replanted trees from the same species) in a suitable area. This removal of trees take place only during the land clearance stage, once in the whole project life span. Hence, the likelihood reflects a very much lower score while sensitivity shows a medium level in terms of magnitude of removal of *Hevea brasiliensis* plants. Similar studies conducted in Sri Lanka have suggested the same principle to compensate for the tree cover loss in the development of RWSS project activities (WaSSIP 2016; WaSSIP 2018).

The impacts on fish and other biota due to changes in river hydrology were also considered as a medium level risk. Ritigaha Oya water source provides a range of habitats for fish species such as *Garra ceylonensis* (National conservation status: Vulnerable (VU), Ministry of Environment 2012), *Rasbora dandiya* (IUCN conservation status: Least Concern (LC) (Ministry of Environment 2012) and some two unidentified molluscan species. The occurrence status of those fish species is encountered as endemic and native respectively (Fernando 1974; Bambaradeniya 2006). Hence, the occurrence of those species exhibit conservation needs in the intake location of Ritigaha Oya water source. Even though construction of an intake weir is proposed, a medium level impact may be created. This is because the presence of the natural fish pathway facilitates the movement of fish by passing the proposed weir without any obstacle. Thereby, it ensures the migration of fish and sustains the viability of fish and other aquatic biodiversity in that area.

Sustainability of water source

Excessive algal growth in storage reservoirs and unsatisfactory condition of the microbiological quality of water was recorded as a high significance risk (Table 4). Possible

Table 4 | Summary of identified environmental impacts with risk score and risk rating

Identified Impacts	Likelihood	Sensitivity	Risk rating based on the risk score
Ecological impacts			
1. Impairment of historical/cultural monuments/areas and Loss/damage to these sites	1	3	low
2. Threat from land mines at the proposed site or access road to the site	2	2	low
3. Removal of trees occurring at the project site or during pipeline laying	2	3	medium
4. Changes to local hydrology such that conservation worthy or commercially significant fish stocks are affected	2	4	medium
Sustainability of water source			
1. Excessive algal growth in storage reservoirs	4	4	high
2. Unsatisfactory raw water quality (excessive pathogens or mineral constituents)	3	5	high
3. Siltation of downstream part of the stream due to intake development	3	3	low
4. Potential impacts of other downstream water use	1	4	low
5. Possible future contamination due to inadequate protection of intake wells and upstream pollution (wastewater discharge from communities, industries and agricultural activities)	2	4	low
6. Flooding due to water transmission lines blocking natural drainage paths	1	3	low
7. The satisfactory yield of the water source due to the extraction of water	5	1	low
8. Noticeable permanent or seasonal reduction in the volume of ground or surface water supply (consider cumulative impact)	2	2	low
Construction related impacts			
1. Impacts of mining and querying activities	2	4	medium
2. Noise and sound pollution	3	2	medium
3. Air pollution impacts	2	3	medium
4. Improper disposal of solid waste (from site clearance, trenching and construction)	4	3	medium
5. Contamination of downstream due to intake construction	1	5	low
6. Soil erosion	3	3	medium
7. Increased accidents and public safety issues due to construction work, material, and machinery	4	3	high
8. Impacts of occupational health and safety or workers	3	5	high
9. Dust generation due to the ground clearing, cutting trenches and material transportation and unloading in the vicinity of social sensitive areas	4	3	high
10. Damage due to the water transmission line on utilities such as roads, dams, telephone, electricity lines from construction activities	2	3	medium
operational impacts			
1. Waste disposal from the water treatment plant	3	4	high
2. Delivery of unsafe water due to poor operational and maintenance training, treatment and lack of water quality monitoring	4	5	Very high

Risk score is calculated using $Risk = livelihood\ score \times sensitivity\ score$. The risk rating is assigned based on the risk score (Table 2) future contamination due to inadequate protection of intake wells and upstream pollution (wastewater discharge from communities, industries, and agricultural activities), flooding due to water transmission lines blocking natural drainage paths, siltation of the downstream part of the stream due to intake development and impacts of other downstream water uses were identified as low significance risks concerning both livelihood and the sensitivity criteria (Table 4). Besides, impacts of the sustainability of Ritigaha Oya water source, permanent or seasonal reduction in volume of ground or surface water supply and the volume of yield for water users were recorded (minimum flow rate of the water source is 100 L/s) as the low level risks in the risk rating matrix. Water extraction was recorded as a low-level risk with regards to sustainable maintenance of the Ritigaha Oya water source. According to the river flow measurements, the safe yield required for the project for distribution to the identified beneficiaries was 12 L/s (total required demand is 100 m^3/day, or 12 L/s). Flow measurements of rainy and dry seasons were from 150 L/s to 100 L/s. The extraction of water from the intake location was grouped as a low-level risk in terms of sustainable maintenance of the Ritigaha Oya water source. Even though water extraction is followed throughout the year (high likelihood), the environmental flow is ensured to sustain the downstream biota. The water extraction during the dry season governed only 12% of the total flow and allowed 88% of the water flows to sustain as the environmental flow. Therefore, the extraction of water for the project will not adversely affect fish stocks, river ecosystems, as well as local hydrology. With streamflow estimates, it was revealed that sufficient and satisfactory yield would be available for reliable water service for the beneficiaries with a low degree of impact.

Obtained results of water quality showed that total coliform bacteria colonies and *E. coli* bacteria colonies were ranged from 55 to 64/100 mL (SLS 614:2013; 10 colonies/100 mL) and 19–22/100 mL (SLS 614:2013; 0 colonies/100 mL) respectively (Figure 4). Water extracted from the Ritigaha Oya was contaminated with total coliforms and *E. coli* (Table 4).

Bacterial quality parameters of Ritigaha Oya raw water showed that water quality was unsatisfactory in accordance with SLS standards, as there were excessive pathogens. The significant presence of *E. coli* strongly asserts the records of fecal contamination. This impact was considered as very high significance environmental risk as it creates a lot of waterborne diseases due to fecal contamination. Recent studies conducted in Sri Lanka surface water bodies such as the Rakwana river, Rathnapura and Walawe river (WaSSIP 2015a, 2017) and Ma Oya, Kegalle (WaSSIP 2015b) have identified the same issue of fecal contamination of surface water sources. A higher degree of fecal contamination is more abundant especially in the least developed nations in Asia and Africa (Bain *et al.* 2012). The main reason for the fecal contamination were observed as due to unavailability of access to proper sanitation. With regards to the health concerns, Shields *et al.* (2015) asserted that socially vulnerable groups such as children are facing health consequences due to the utilization of drinking water contaminated with fecal matter. Hence, a water quality monitoring program in the water source aligned with the impact identification highlights the importance of understanding the baseline condition of the existing water source and its quality. This approach supports the decision makers to consider aspects to install an effective water treatment facility.

The physico-chemical parameters of water quality in Ritigaha Oya water source near the intake location shows moderate pollution levels. The mean colour of the water (Hazen) was ranged from 7.20 to 10.00 (Sri Lankan Standard Institute 2013; 5.00 Hazen). Mean turbidity values were ranged from 0.6 to 0.7 (NTU), mean pH values were recorded within 6.9–7.4, mean total Dissolved Solids (TDS) measurements were ranged from 24–25.5 mg/L, mean alkalinity as ($CaCO_3$) of raw water was ranged from 22 to 24 mg/L, mean total hardness as ($CaCO_3$) of water was ranged from 26.0–27.6 mg/L, mean Nitrate (as NO_3^-) of water was ranged from 0.4 to 0.6 mg/L, and mean total Iron (as Fe) values were ranged from 0.02 to 0.03 mg/L (Figure 4).

Colour of water serves as an indication of dissolved humic substances in water sources (Hongve & Akesson 1996). Water quality monitoring throughout the study revealed that all the measured parameters except colour were recorded below the Sri Lanka Standards (Sri Lankan Standard Institute 2013) water quality guidelines. Colour

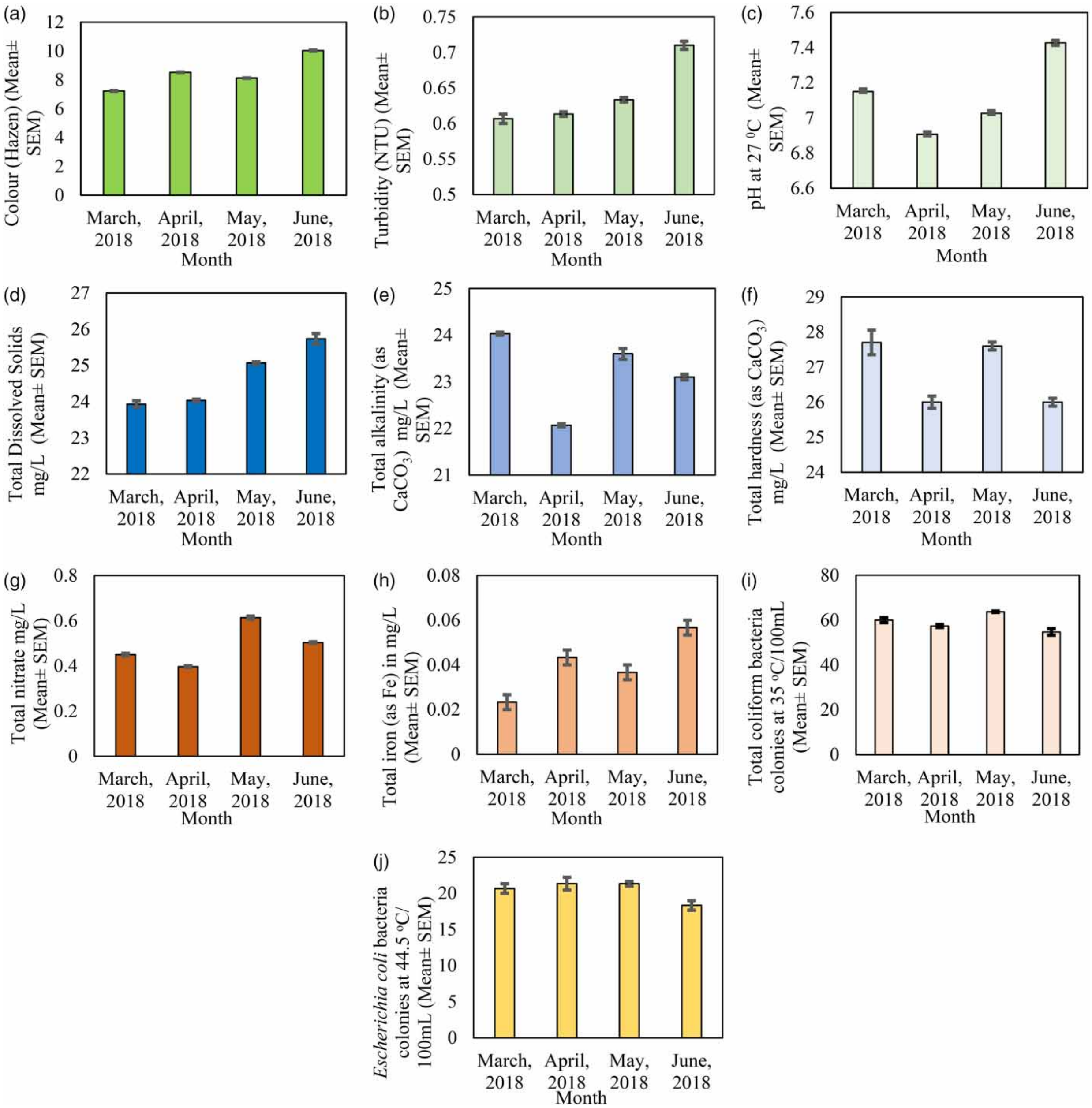


Figure 4 | Variation of (a) mean colour ± SEM (Hazen), (b) mean turbidity ± SEM (NTU), (c) mean pH at 27 °C ± SEM, (d) mean total dissolved solids ± SEM (mg/L), (e) mean total alkalinity (as $CaCO_3$) ± SEM in mg/L, (f) mean total hardness (as $CaCO_3$) ± SEM in mg/L, (g) mean total nitrate ± SEM in mg/ L, (h) mean total iron (as Fe) ± SEM in mg/ L, (i) mean total coliform bacteria colonies ± SEM at 35 °C/100 mL and, (j) mean *E. coli* bacteria colonies ± SEM at 44.5 °C/100 mL.

measurements were ranged from 7.20 to 10.00 Hazen (Figure 4) while the accepted limit was 5.00 Hazen (Sri Lankan Standard Institute 2013). Hongve & Akesson (1996) claimed that the presence of particulate matters (flocs of humus colloids and hydrous ferric oxides) in the waters affect the attenuation of light in the short-wave range. Also, particles cause turbidity because they cause little light scattering. This might be the reason for having exceeded colour measurement in Ritigaha Oya water source in accordance with Sri Lankan Standard Institute (2013).

Construction-related impacts

Increased accidents and public safety issues due to construction work, material, and machinery, occupational health and safety of workers and dust generation due to ground clearing, cutting trenches and material transportation, and unloading in the vicinity of social sensitive areas, were grouped under the high significant environmental risks during the construction phase (Table 4). Impacts from mining and querying, noise and sound pollution, air pollution from emissions, solid waste accumulation in construction sites, damage due to the water transmission line on utilities such as roads, dams, telephone, electricity lines from construction activities, and soil erosion in construction-related practices were listed as medium significant risks (Table 4). A low impact could be generated on agriculture or other cultivation from wastewater, moving soil, and loss of land.

During the construction phase of this RWSS, a medium level risk may be generated due to the intake development. Concrete, cement, sand, and other materials that are used for construction will wash downstream with water flow. While the construction takes place, it affects only a few time zones from the project time period. Hence, the likelihood remains at a lower level. Conversely, as pollution can be generated via intake development and imposes a threat on the biota, sensitivity of the risk has been assigned as a moderate level. Thus, management steps should be taken to avoid potentially adverse impacts on the surrounding aquatic ecosystems and aquatic life. A cofferdam including dewatering and removal after completion is proposed as a sustainable option to minimize the impacts created due to washing away of construction materials (WaSSIP 2017; WaSSIP 2018). It will facilitate workers to complete the intake weir in a dry environment, avoiding siltation and washing away of cement and concrete.

Impacts arise due to noises from machines and noise-generating activities, air emissions, and improper solid waste disposal when trenching and querying, soil excavations (Gangolells *et al.* 2009; Gangolells *et al.* 2011) and erosion were recorded as medium level risk considering likelihood and sensitivity (Table 4). Air pollution can take place when substances are emitted to the surrounding vicinity by construction activities that were recorded as a moderate level of environmental impact (Yoshino *et al.* 2019). Criterion air pollutants including dust, particulate matter, gases (SO_2, NO_2, and CO) are released to the environment from earth works and machinery used. Moreover, it is stated that ranges of air polluting stressors are generated due to construction works associated with the development of RWSS (Petts 2009; Yoshino *et al.* 2019).

Noise generation from construction activities was recorded in WaSSIP (2017) as a potential impact. As remedial actions, noise and vibration activities should be conducted not exceed 75 dB during the daytime and 55 dB during night-time, according to the Central Environmental Authority standards (Central Environmental Authority 2000). Noise and vibration activities occurring from 2200 hr to 0600 hr can be avoided. Servicing and maintenance of all construction vehicles and machinery should be done regularly and during routine servicing operations, the effectiveness of exhaust silencers shall be checked and if found defective shall be replaced (WaSSIP 2017; Yoshino *et al.* 2019).

For solid waste generated in trenching, querying and excavation activities, this can be conducted in accordance with EMP in relevant RWSS. In addition, workers and staff awareness can be made to overcome the unsafe waste disposal by construction activities (Harbin Water Project 2002; Petts 2009). Impacts on public and workers' health and safety were identified as a high-level environmental risk (Table 4). The reason is that until the construction is over, workers are functioning, and their lives will be at a risk. Hence, the sensitivity of the impact is at a higher level whereas the likelihood also plays a similar role to the sensitivity. A similar study conducted in the Galigamuwa, Sri Lanka, has considered the implication of health and safety perspectives as a higher significance in the construction phases of RWSS (WaSSIP 2017). Tadesse & Israel (2016) strongly claimed that there should be a huge consideration on public and workers' safety in every construction site in the world. Lack of standards, knowledge, and awareness on handling power tools and machinery and less regulation and enforcement are influential in poor health and safety among workers (Aderaw *et al.* 2011; Tadesse & Israel 2016). Further, inadequacy and lack of focus and awareness towards health and safety causes a lot of injuries to workers in construction sites (Adsul *et al.* 2011; Tadesse & Israel 2016). Utilization of Personal Protective Equipment (PPEs) such as safety helmets, gloves, boots, soundproof ear covers, and goggles is recommended worldwide to overcome most of the health and safety issues. Apart from that, the use of barricades and signboards is proposed to reduce unwanted accidents at sites (Barbeau *et al.* 2004; Asian Development Bank 2018). In addition, thorough monitoring and adherence to the quality assurance and quality control standards can be easily practiced, ensuring the health and safety of workers (Petts 2009; Scottish Natural Heritage 2013).

In terms of public health aspects, water stagnation resulting in pollution of water sources and increased risk of disease in project areas (e.g. filaria, malaria, hepatitis, gastrointestinal diseases) would be an impact. Therefore, RWSS should be designed to extract water responsibly, minimizing the pollution of the water source such that downstream users are also exposed to clean and safe river water. Additionally, improper siting of latrines near water sources, bad odour, and mosquito breeding in damaged latrine pits would have effects. Inappropriate sitting, unhygienic environment for workers and solid waste disposal within the camp sites would also be generated and should be minimized by implementing the proper EMP (WaSSIP 2017).

Operational impacts

Waste disposal from the water treatment plant would be a high-risk impact (Table 4). Long-term running of the water treatment plant causes aggregation of sludge and other wastes at the bottom of the drinking water treatment plant. Hence, it should be safely disposed of (Petts 2009). Sediment and sludge deposited within the treatment plant units will be disposed of in concurrence with the local authority.

Delivery of unsafe water due to poor operational and maintenance training of workers and treatment plant operators, treatment, and lack of water quality monitoring was identified as a very high significance risk, while waste (sludge) disposal from water treatment plants is a higher significance environmental risk in the operational stage (Table 4). The reason is that Bulathkohupitiya RWSS will be handed over to the relevant Community-Based Organization (CBO), which is driven by a group of villagers. Even though water quality monitoring facilities are given by the NWSDB, Sri Lanka, daily water purification (chlorination) and treatment plant monitoring activities will be carried out by CBO officials, who are unskilled. Therefore, proper operation and maintenance training programs should be given to operators of the water treatment plant to ensure the quality of drinking water and measurement of the water quality parameters on site (Petts 2009; WaSSIP 2017; Yoshino *et al.* 2019). Otherwise, it will lead to a distribution of partially treated or contaminated drinking water throughout the consumers. Currently, it is proposed that operators of CBOs be trained to carry out operation and maintenance of the RWSS scheme and a monitoring mechanism will be introduced within the institutional arrangements for sustainable service delivery with the Department of Community Water Supply, Sri Lanka. Thereby all the operational impacts can be minimized with respect to EMP. Hence, the semi quantitative approach provides an effective platform to understand the nature of the environmental impact associated in each phase of the RWSS project.

CONCLUSION

Water is a fundamental human right. The safety of drinking water is an ongoing concern within the world. More than two million of them die, mostly children under the age of five years, due to lack of safe drinking water. Most of them are poor and live in the developing world. Developing nations in tropical regions are critically suffering from lack of suitable drinking water sources as well as poor sanitation. Thus, the governments of these nations are overstretched to find immediate solutions for the increasing demand for safe drinking water while maintaining the WHO guidelines. This pressure on governments has led towards unsustainable standards in water supply and sanitation improvement projects. Conversely, there are many examples worldwide in developing nations where implementation of local water supply schemes deteriorates the environment, and many failures in sustainable operational practices. Furthermore, after a couple of years of implementation, many water supply schemes were not operating in a sustainable manner. Moreover, the governments of developing nations do not have adequate funding for high-tech water supply schemes. Thus, RWSS are a perfect solution for many developing nations to provide safe drinking water to communities, as the implementation and the maintenance cost is minimal.

However, many criticize these projects due to the high failure rates and environmental degradation. Therefore, identification of overarching socio-environmental and economical feature to maintain sustainable practices is essential. This study broadly analyses the social, environmental, economical, and technical aspects of a rural water supply project in the wet zone of Sri Lanka, while highlighting the importance of using Rapid Environmental Assessment and the semi quantitative method to identify the potential environmental impacts of different stages of a new Rural Water Supply Scheme. Identification of environmental impacts through the REA aids conservation of water resources as well as surrounding ecosystems while using the natural water resources in a sustainable manner. Further, this methodology can be used as a reference to identify potential socio-environmental issues for Rural Water Supply projects in developing nations in the tropics to minimize the possible impacts.

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CONFLICTS OF INTERESTS

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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CONSENT TO PARTICIPATE

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

Raw data availability can be checked with corresponding author.

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Not applicable.

AUTHOR CONTRIBUTION

B.K.A. Bellanthudawa – writing the draft of the manuscript (in collaboration), Conceptualization, and Data analysis, D. Halwatura – revise the manuscript, N.M.S.K. Nawalage – writing the draft of the manuscript (in collaboration), H.M.A.K. Handapangoda – Data collection and Preparation of GIS-based maps (in collaboration), S.R.Y.S.S.B. Sundarapperuma – Data collection and Conceptualization, D. Kudagama – Preparation of a GIS based maps (in collaboration), L. Wijesinghe – Data collection, Conceptualization and supervision, W.D. Darshana – Data collection, M.S.M. Sifan – Data collection, D.M.J.L. Dassanayake – Data collection, J.M.S.N. Jayasuriya – Supervision, P.L.A.D.C. Pinnagoda – Data analysis, R.M.C.Y. Rathnayaka – Data analysis.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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