Effectiveness of Available Wastewater Treatment Facilities in Rubber Production Industries in Sri Lanka

Disni Gamaralalage, Osamu Sawai, and Teppei Nunoura

***Abstract*—Rubber is a historical crop in Sri Lanka and now Sri Lanka is one of the leading rubber producers in the world. Even though rubber production is a well-established industry in the country, treatment of wastewater from rubber production plants is still an ongoing issue. Most of the industrial scale rubber production plants are equipped with wastewater treatment facilities. But small-scale rubber producers who cover 77% of country's rubber production have no available treatment facilities for wastewater from their rubber production. Also not enough research has been conducted for identifying effectiveness of currently applied treatment facilities to treat rubber wastewater in Sri Lanka. This study focuses on identifying the characteristics of Sri Lankan rubber wastewater and effectiveness of available wastewater treatment facilities in rubber production plants in Sri Lanka. Assessing efficiencies of applied wastewater treatments was performed by analyzing the characteristics of influents and effluents of treatment facilities. The characteristics of rubber wastewater and current situation of applied treatments were identified in the study including high inefficiencies in removing nitrogen in wastewater to required limit.**

***Index Terms*—Chemical oxygen demand, rubber wastewater, Sri Lanka, wastewater treatment.**

I. Introduction

Rubber is one of the main crop plantations in Sri Lanka and, Sir Hendry Wickham first introduced it in year 1876 to Sri Lanka [1]. Now Sri Lanka is among the world's top ten rubber producers with plantation area of 134 thousand hectares and with average annual yield of 1.25 tons per hectare [2]. Sri Lankan government targets to further increase rubber plantations in coming years including lands in Northern province which became available after tragic period due to war inside the country [1].

Research have been conducted for identifying suitability of non-traditional rubber plantation areas for introducing rubber plantation in Sri Lanka to cope up with the increasing demand of rubber in the world [3] and also for identifying socio-economic status of rubber farmers in the newly planted areas [4].

Rubber is a tropical crop; therefore, it needs plenty of rainfall, relatively stable high temperatures, deep soil and continuous moisture throughout the year [5]. Sri Lanka has 3 major climate zones as wet, intermediate and dry zones. Most of the rubber plantations are located in wet-zone (middle to south-west part of Sri Lanka), which has proper conditions for rubber plantation with average temperature of 24^{o}C and rainfall over 2500 mm. Rubber producers are classified into three categories by the ownership of rubber production land area as; large estates, medium estates and smallholder units [6]. 2014 progress report of Ministry of Plantation Industries-Sri Lanka [1] indicates that around 63.4% of rubber plantation areas (around 85,083 hectares) belong to smallholders and smallholders contribute to national rubber production by 77%. A smallholder is defined as an extent of 10 hectares or less, in the Rubber Control Act, No.11 of 1956 [1]. Sri Lanka produces four main types of rubber; Ribbed Smoked Sheets (RSS), Centrifuged Latex, Crepe rubber and Technically Specified Rubber (TSR).

Production of rubber results in generating large amount of wastewater. Natural rubber industry in Sri Lanka is considered as one of the most water polluting industries in the island [7]. Sri Lankan rubber wastewater has a strong odor and contains high volume of chemical oxygen demand (COD). The production processes of centrifuged latex, crepe rubber, RSS and TSR are shown in Fig. 1. In centrifuged latex production process, wastewater is mainly generated in centrifugation process, where a plenty of water is being used for washing the rotating blades. In crepe rubber and RSS productions, water is mostly used for wet-milling and coagulation process steps and majority of wastewater is generated in those two steps.

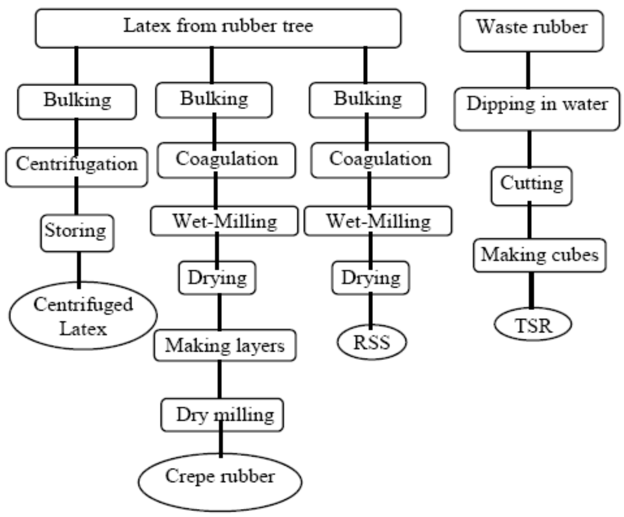

Fig. 1. Steps of rubber production processes.

In TSR production, dipping and cutting steps require large amount of water. Wastewater is generated mainly in dipping

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step in TSR production. Amount of water usage in each production industry is shown in Table I.

Even though rubber production is a well-established industry in Sri Lanka, treatment of rubber wastewater is an unsettled issue. Research have been performed for discussing the situation of rubber wastewater treatment in other countries; Malaysia and Vietnam [8], [9]. Most of the industrial scale rubber production plants are equipped with treatment facilities in Sri Lanka and it is very important to identify the efficacy of available treatments. But sufficient studies have not been conducted to identify the effectiveness of available treatment methods in Sri Lanka. Rubber smallholders have a high contribution to the country's rubber production, but there is no treatment available for the wastewater from smallholder units in Sri Lanka. Therefore, effective and economical treatment of rubber wastewater is a huge concern for the rubber industry in Sri Lanka.

TABLE I: DETAILS OF PRODUCTION FACILITIES

Production facility	No. of workers	Production capacity (kg/day)	Water usage (L/day)	Treatment facility available?
Centrifuged Latex	70	5400	20000	Yes
Crepe rubber 1	15	500	25000	Yes
Crepe rubber 2	30	1500	30000	Yes
TSR	40	5000	75000	Yes
Glove	62/shift	70000 glove pairs	2500000	Yes
RSS (large scale)	35	400	4000	No
Smallholder unit 1*	40 (38 - tapping)	180	600	No
Smallholder unit 2	2	8.5	45	No
Smallholder unit 3	7	75	500	No
Smallholder unit 4	7	18	80	No
Smallholder unit 5*	26 (25 - tapping)	105	480	No
Smallholder unit 6	7	32.5	200	No

* These smallholder units are small groups of individual smallholder units. Most of the group members do tapping in their rubber plantations and bring tapped latex for RSS production facility. Only few workers work in RSS production facility.

The objective of this study is to identify and validate the pollutants of Sri Lankan rubber wastewater and assess the effectiveness of available treatment facilities of industrial rubber wastewater. This study will provide important details on wastewater analysis and identifying suitable treatment methods.

II. METHODOLOGY

A. Field Survey

An extensive literature survey and a field survey to Sri Lankan rubber industries were carried out to identify the situation of different types of rubber production and wastewater treatment facilities in Sri Lanka. Field survey was conducted in the period of 23/4/2015-11/5/2015. Sri Lanka has a tropical climate and the period during survey from April to May was in the inter monsoon season [10] which has a mixed weather with majority of warm climate and less rainfalls. Selected rubber production facilities are located in Galle, Kaluthara, Colombo and Kegalle districts, within the wet-zone. Suitable rubber production facilities were selected with assistance from Rubber Research Institute of Sri Lanka. During the survey, visits to rubber production facilities (industrial scale and smallholder units) and rubber research institutes were conducted. Details of production processes, available wastewater treatment facilities and issues of different types of rubber (RRS, Crepe rubber, Centrifuged Latex and TSR) were gathered by interviews, questionnaires and field observations. As the quality of treated wastewater is a key parameter for identifying the effectiveness of treatment facility, treated and untreated water samples were collected from the visiting facilities.

The collected wastewater samples were analyzed on-site for pH, temperature and electrical conductivity (EC). The same samples were preserved for later analysis in laboratory for COD, total organic carbon (TOC), cations, anions and total phosphorous (TP). Effectiveness of available wastewater treatment methods in rubber production facilities was discussed from the results of water sample analysis. Available treatment facilities of each types of rubber are shown in Fig. 2.

For centrifuged latex production, considerable amounts of chemicals are added. Zinc oxide, tetramethylthiuram disulfide (TMTD), ammonia and diammonium hydrogen phosphate are added at the bulking tank and again ammonia and TMTD are added at the storage tank. Overall production process takes average one day in centrifuged latex industry. In crepe rubber industry, sodium bisulfate is added in the bulking tank, and formic acid and a bleaching agent (sodium salt of tolyl mercaptan) are added at the coagulation tank. Usual overall processing time is around four days from bulking to final dried crepe rubber sheets production. For RSS production, formic acid and sodium bisulfate are added at the coagulation tank and average processing time is three days for the total process. For TSR production, left over rubber particles from rubber field and waste rubber from other rubber industries are used. There is no chemical addition for the production and average 1.5 days processing time is required.

B. Sampling and Preservation

Wastewater was sampled from all the visited rubber production facilities. Treated water was collected from wastewater treatment facility at the rubber production factories. Collected water samples were analyzed on-site for some parameters and preserved for analyzing in the laboratory later on. Water samples were preserved by adding sulfuric acid to lower the pH to less than 2 and stored in the refrigerator at the temperature below $4^{o}C$ to analyze COD, ammonium ion, TP and TOC. For analyzing other selected parameters in the study, water samples were preserved by refrigerating below $4^{o}C$ [11].

C. Analysis of Water Samples

Water samples were analyzed on-site for temperature, pH (HORIBA Compact pH Meter, B-212) and EC (HORIBA Conductivity Meter, B-173). Preserved samples were analyzed at the laboratory for COD and TP by using portable total nitrogen and phosphorus meter (TOA-DKK). For analyzing TOC, total organic carbon analyzer (SHIMADZU) was used. Analysis of cations (NH_4^+) and anions ($H_2PO_4^-$, Cl^-, NO_2^-, Br^-, NO_3^-, SO_4^{2-}) were performed by ion chromatograph analysis (Jasco HPLC system composed with Shodex CD-5). For cation analysis, Universal Cation column (Alltech) and for anion analysis, IC I-524A column (Shodex) were used. From the characteristics of measured samples, efficiencies of the treatment facilities were discussed.

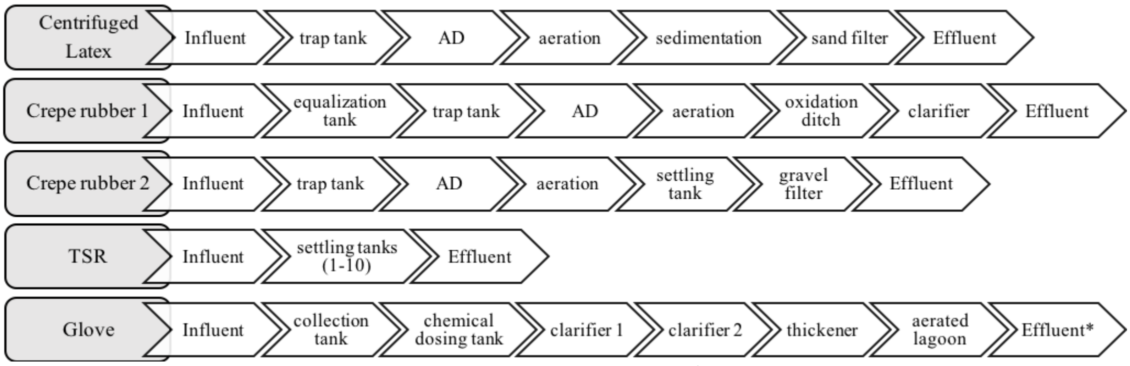

Fig. 2. Available wastewater treatment facilities.

* Effluent discharge to treatment facility in board of investment of Sri Lanka
AD - Anaerobic digestion

III. Results and Discussion

A. Rubber Wastewater Characteristics

The water samples collected from different types of rubber production facilities were analyzed for selected wastewater parameters to identify the characteristics of Sri Lankan rubber wastewater. The characteristics of Sri Lankan rubber wastewater are shown in Table II. Up to date there is no wastewater treatment available for small-scale rubber production facilities in Sri Lanka. Almost all the smallholder units produce RSS rubber sheets. Direct discharging of wastewaters from RSS rubber production to outside was clearly observed in the field survey. Similarly, overgrowing of plants near the discharging area due to eutrophication was a very common observation in most visited facilities.

From Table II, it is clearly seen that the wastewater from small-scale RSS production shows higher COD values than large-scale RSS production and it is nearly eight times higher COD values than the tolerance limit (400 mg/L) [12]. The usage of less amount of water for RSS production by small-scale producers compared to large-scale production (Table I) can be a possible reason for having high COD values. Also wastewater from small-scale RSS production has acidic pH and the total phosphorous values are in a high range compared to other rubber production industries (Table II). Therefore, wastewater from small-scale production needs to be treated before discharging to the environment.

TABLE II: Rubber Wastewater Characteristics

Type of rubber	pH	EC (mS/cm)	COD (mg/L)	TOC (mg/L)	TP(mg/L)
Centrifuged latex	6	8	4500	2500	173
Crepe rubber	5	3.3	2000-30000	410-4250	30-200
TSR	7.5	0.1	40	4	7
Glove	9.6	0.3	120	50	19
RSS (Large scale)	5	1.4	400	360	50
RSS (Small scale)	3.5-6	3.8	1000-3200	260-720	50-140

The odor from rubber wastewater was easily observable during the survey and neighborhoods around the rubber production facilities are facing much inconvenience. There is very low hygiene in the production facilities, as workers wear no gloves or shoes to cover their skin from contacting rubber and rubber wastewater. Therefore, peeling of skin occurs to most of the workers and the bad smell on their hands is not fading even after washing several times.

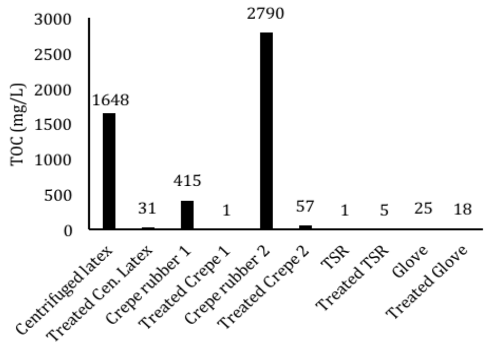

Fig. 3. TOC of treated and raw rubber wastewater.

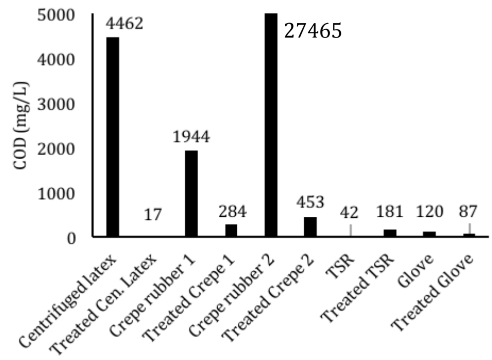

Fig. 4. COD of treated and raw wastewater samples.

Most of the visited factory environments consist of high ammonia smell, especially in centrifuged latex industry and some workers feel dizziness by being exposed to ammonia throughout the day. From COD and TOC analysis of rubber wastewater samples and treated water samples, it is very clear that the available treatment facilities can reduce COD and TOC values in a good extent (Fig. 3 and Fig. 4). But crepe rubber 2 industry seems unable to achieve the tolerance limit of 400 mg/L of COD for discharging to inland surface waters [12].

There is an increase in both COD and TOC values in TSR industry, but still those are below the tolerance limits. The raw materials for TSR industry are waste rubber particles from other rubber industries and left over rubber from rubber plantation. There are several washing cycles in TSR production and the washed water is not directed to settling tanks (Fig. 2), but is discharged to outside without any treatment. The washed water flows through small ditches inside the factory building, which can easily overflow and mix with treated water. The reason for having higher COD and TOC values (Fig. 3 and Fig. 4) for treated water from TSR industry can be the contamination due to mixing with washed water.

B. Ion Analysis

Ion analysis was conducted to recognize available ions in wastewater and treated water to identify the effectiveness of treatment facilities.

TABLE III: ION ANALYSIS IN RUBBER WASTEWATER

Type of rubber	Ion concentrations (mg/L)					
	[$H_2PO_4^-$]	[Cl^-]	[Br^-]	[NO_3^-]	[SO_4^{2-}]	[NH_4^+]
Centrifuged Latex	872	ND	72	28	ND	72
Treated Cen. Latex	120	ND	72	1188	ND	36
Crepe rubber 1	133	ND	ND	86	ND	3
Treated Crepe 1	ND	ND	ND	499	ND	21
Crepe rubber 2	415	ND	ND	107	ND	41
Treated Crepe 2	ND	ND	ND	496	ND	18
TSR	ND	ND	ND	ND	ND	14
Treated TSR	ND	ND	ND	603	ND	15
Glove	ND	ND	ND	47	ND	14
Treated Glove	ND	410	313	721	193	26

ND: Not detected

Anions were analyzed for nitrate, chloride, bromide, sulfate and dihydrogen phosphate ions, whereas cation analysis focused on ammonium ions in water samples. Chloride ions were detected only from treated water in glove industry (Table III). Considerable amount of chemicals including polyaluminum chloride, bromide and sulfate containing polymers were added during the treatment process in chemical dosing tank (Fig. 2) in glove industry and this added chlorides, bromides and sulfates could be the probable cause for detecting chloride, bromide and sulfate ions (Table III) in treated water from glove industry.

Fig. 5 indicates nitrogen concentrations as nitrate-nitrogen in treated and untreated wastewater from different types of rubber production facilities in Sri Lanka. It is clearly shown that nitrate-nitrogen concentrations in treated water are higher than that of untreated rubber wastewater (Fig. 5) for all types of rubber production.

One possible cause for having higher nitrate-nitrogen in effluent than influent can be due to nitrification of ammonium ion in influent. Fig. 6 indicates nitrogen concentrations as ammonium-nitrogen. Slightly higher ammonium-nitrogen concentrations in treated water than wastewater can be observed in crepe rubber 1, TSR and glove production industries. Even though there are increments in ammonium-nitrogen concentrations after treatment in crepe rubber 1, TSR and glove production facilities, ammonium-nitrate concentrations are still below the tolerance limit (40 mg/L) for discharging to Sri Lankan inland surface waters [12].

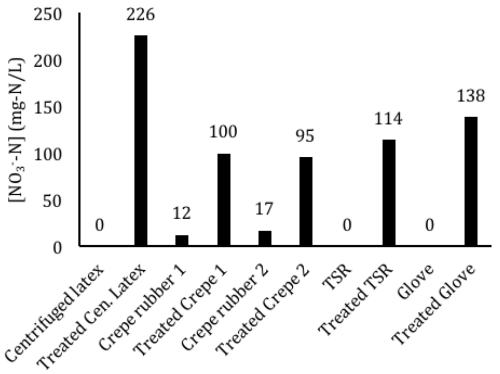

Fig. 5. Nitrate-nitrogen concentrations in rubber wastewater.

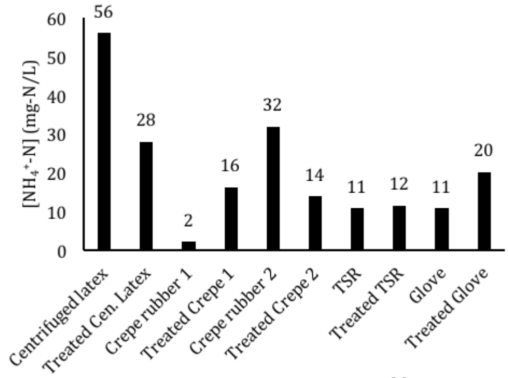

Fig. 6. Ammonium-nitrogen concentrations in rubber wastewater.

From the analysis of nitrogen ion in water, the applied treatment methods seem unable to remove nitrogen efficiently from rubber wastewater. Nitrate-nitrogen concentration figure (Fig. 5) is much significant and shows very high nitrogen concentration values in treated water. As tolerance limit for nitrate-nitrogen has not been defined yet in Sri Lanka, the rubber production facilities do not concern about evaluating nitrate-nitrogen in treated water.

The concentrations of nitrate ion in all the treated water outlets (Fig. 5) are over 45 mg/L, which is the drinking water standard in Sri Lanka [12]. Majority of Sri Lankans directly consume inland surface water due to lack of awareness on industrial polluted wastewater. High nitrogen content in discharging water can be harmful to the neighborhood community as high concentration of nitrate (Maximum limit: 10 mg/L of nitrate-nitrogen) in drinking water can cause blue baby syndrome (methemoglobinemia) in infants [13]. Currently, discharged waters have nitrate-nitrogen concentrations much above the safety level for drinking which leads to a necessity of denitrification process for Sri Lankan rubber wastewater.

Total phosphorous concentration values show a proper reduction after treatments, according to Fig. 7. Phosphate-phosphorous concentrations in wastewater and treated water are shown in Fig. 8. Lower phosphate-phosphorous concentrations are shown in treated water than wastewater, which agrees with the total phosphorous concentration figure (Fig. 7).

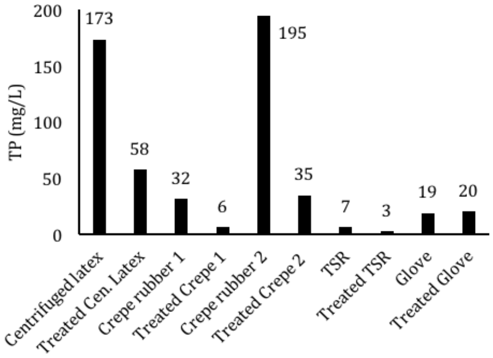

Fig. 7. Total phosphorous concentrations in rubber wastewater.

Therefore, available treatments in Sri Lankan rubber production facilities show effective results in removing phosphorous from wastewater, even though they show opposite outcomes for removing nitrogen in wastewater. Nevertheless, for treated water from the rubber production facilities, further reduction of phosphorous needs to be achieved to reach the discharge standards of Sri Lanka. The tolerance limit of phosphorous for discharging to inland surface waters is 5 mg/L in Sri Lanka [12].

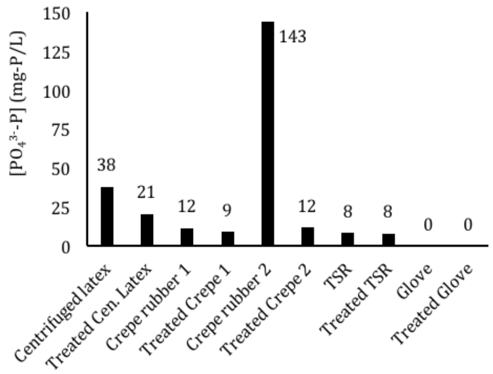

Fig. 8. Phosphorous concentrations in rubber wastewater.

IV. Conclusions

In this work effectiveness of available wastewater treatment facilities in Sri Lankan rubber industries were assessed. According to the characteristics of wastewater from smallholder units revealed in this study, wastewater needs to be treated before discharging to the environment. Because of high contribution to the rubber production (77%) by smallholder units, there is a high impact from wastewater from those smallholder units. Ion analyses have indicated the existence of unwanted ions that have contaminated the water during the treatment process. These ineffective performances of current wastewater treatments in large-scale rubber production facilities in Sri Lanka have contributed to an uncertain situation of available rubber wastewater treatment methods in Sri Lanka.

Therefore, cost effective and efficient treatments are needed for rubber wastewater in Sri Lanka. Currently applied wastewater treatment facilities seem unable to remove nitrogen efficiently in wastewater. Removing nitrogen from rubber wastewater needs to be considered as a new implication for available rubber production facilities. Therefore, a cost effective and efficient de-nitrification process to convert nitrate-nitrogen into nitrogen gas is desired.

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References

[1] Ministry of Plantation Industries, *Progress Report*, Government of Sri Lanka, 2014, pp. 1-95.

[2] Rubber Development Department of Sri Lanka. (2013). Rubber cultivation details. [Online]. Available: http://www.rubberdev.gov.lk/

[3] L. Samarapulli *et al.*, "Land suitability model for rubber in Monaragala district," *Journal of Environmental Professionals Sri Lanka*, vol. 3, no. 1, pp. 48-61, 2014.

[4] D. M. A. P. Dissanayake, W. Wijesuriya, H. M. L. K. Herath, and P. K. K. S. Gunaratne, "Socio-economic status of smallholder rubber farmers in the Monaragala District," *Journal of Food and Agriculture*, vol. 3, no. 1-2, pp. 41-49, 2010.

[5] P. S. Rao, C. K. Saraswathyamma, and M. R. Sethuraj, "Studies on the relationship between yield and meteorology parameters of para rubber tree (Hevea brasiliensis)," *Agricultural and Forest Meteorology*, vol. 90, pp. 235-245, 1998.

[6] W. Wijesuriya *et al.*, "Some issues related to sustainability in the smallholder rubber sector: A case study of three major rubber growing districts," *Journal of the Rubber Research Institute of Sri Lanka*, vol. 88, pp. 59-76, 2007.

[7] K. V. V. S. Kudaligama, W. M. Thurul, and P. A. J. Yapa, "Possibility of treating rubber factory wastewater in biological reactors using media with low specific surface area," *Journal of the Rubber Research Institute of Sri Lanka*, vol. 88, pp. 22-29, 2007.

[8] M. Mohammadi, H. C. Man, M. A. Hassan, and P. L. Yee, "Treatment of wastewater from rubber industry in Malaysia," *Afr. J. Biotechnol*, vol. 9, no. 38, pp. 6233-6243, Sep. 2010.

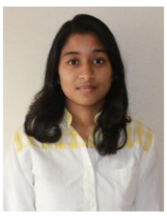
[9] N. H. Ngyuyen and T. T. Luong, "Situation of wastewater treatment of natural rubber latex processing in southeastern region, Vietnam," *J. Viet. Env*, vol. 2, no. 2, pp. 58-64, 2012.

[10] Department of Meteorology Sri Lanka. (2015). Climate in Sri Lanka, viewed on 15th December 2015. [Online]. Available: http://www.meteo.gov.lk/

[11] U.S. Environmental Protection Agency, *NPDES Compliance Inspection Manual*, Office of Enforcement and Compliance Assurance, 1200 Pennsylvania Avenue, N.W., 2004.

[12] BOI Sri Lanka, *Environmental Norms February*, Board of Investment of Sri Lanka, 2011.

[13] World Health Organization, *Nitrate and Nitrite in Drinking Water*, WHO Press, Geneva 27, Switzerland, 2011, pp. 1-23.



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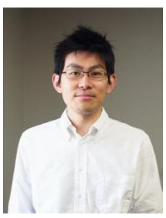

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