Title	Seasonal efficiency of a hybrid sub-surface flow constructed wetland system in treating milking parlor wastewater at northern Hokkaido
Author(s)	Sharma, Pradeep Kumar; Takashi, Inoue; Kato, Kunihiko; Ietsugu, Hidehiro; Tomita, Kunihiko; Nagasawa, Tetsuaki
Citation	ECOLOGICAL ENGINEERING, 53, 257-266 https://doi.org/10.1016/j.ecoleng.2012.12.054
Issue Date	2013-04
Doc URL	http://hdl.handle.net/2115/53736
Type	article (author version)
File Information	seasonal variation_Preadeep etal.2013.pdf

Seasonal Efficiency of a Hybrid Sub-surface Flow Constructed Wetland System in treating Milking Parlor Wastewater at Northern Hokkaido

Pradeep Kumar Sharma[1,2], Inoue Takashi[1], Kunihiko Kato[3], Hidehiro Ietsugu[4], Kunihiko Tomita[5], Tetsuaki Nagasawa[1]

Pradeep Kumar Sharma[1,2]

(Affiliation address): [1]Graduate School of Agriculture, Hokkaido University,
N9 W9, Kita-ku, Sapporo, 060-8589, Japan.

(Present address): [2]Department of Environment Science, Graphic Era
University, 566/6, Bell Road, Clement Town,
Dehradun, India, 248002.
Email: pradeep2910@gmail.com

Inoue Takashi[1]: Graduate School of Agriculture, Hokkaido University,
N9 W9, Kita-ku, Sapporo, 060-8589, Japan.
Email: tino@env.agr.hokudai.ac.jp

Tetsuaki Nagasawa[1]: Graduate School of Agriculture, Hokkaido University,
N9 W9, Kita-ku, Sapporo, 060-8589, Japan.
Email: ngsw@env.agr.hokudai.ac.jp

Kunihiko Kato[3] : National Agricultural Research Centre for Hokkaido
Region,Hitsujigaoka-1,Toyohira-ku,Sapporo,
062-8555, Japan
Email: katokuni@affrc.go.jp

Hidehiro Ietsugu[4]: TUSK Co. Ltd. Hokkaido, Japan

Kunihiko Tomita[5]: Town Office, Embetsu, Hokkaido, Japan

Corresponding Author:

Dr. Pradeep Kumar Sharma (Assistant Professor)

Department of Environment Science, Graphic Era University, 566/6, Bell Road,

Clement Town, Dehradun, Uttarakhand, India , 248002

Email: pradeep2910@gmail.com

Talex: +91-9720625982, Fax: +91-135-2644025

Abstract

This paper presents the effects of seasonal variations on the purification and removal efficiencies of a hybrid sub-surface CW system (VF-VF-HF) treating milking parlor wastewater at northern Hokkaido, Japan. VF(a) and VF(b) are gravel beds, each 160 m^2 in size whereas HF is sand bed and 336 m^2 in size. Daily mean air temperature at site showed a difference of 16 ^oC between warm (May-October) and cold (November-April) periods. Average influent concentrations for cold and warm periods were: COD_{Cr}: 3,749 and 4,988 mg

L^{-1}; BOD_5 : 1,637 and 1,395 mg L^{-1}; TSS : 661 and 862 mg L^{-1}; TN : 161 and 194 mg L^{-1}; TP : 23.9 and 31.9 mg L^{-1} and total carbon : 1,212 and 1,715 mg L^{-1}. Average purification rates of BOD_5, TSS, TP, PO_4-P and total carbon fluctuated < 2.5% between both periods. However purification rates of NH_4-N and Organic-P decreased by 9.5 and 12% respectively during warm period. Average removal rates of TSS and BOD_5 were unaffected between both periods, while that of COD_{Cr}, TN, total carbon increased by 3-4% during warm period. Hybrid sub-surface CW system achieved purification and removal rates of >95% for TSS and total coliform; >89% for COD_{Cr} and BOD_5; >76% for TN and >72% for TP during both cold and warm periods.

Keywords : Hybrid sub-surface CWs; cold climate; seasonal variation; milking parlor wastewater

1. INTRODUCTION

Constructed wetlands (CWs) have shown their ability to remove large amounts of organic material, nitrogen and phosphorus from wastewater of various origins (Tanner et al., 1995; Tunçsiper, 2009; Justin, et al., 2009; Hilley et al., 2003). They are considered to be cost-effective and simple in design and operation (Hunt et al., 2009). Based on their designs, CWs can be categorized as surface flow (SF) and sub-surface flow (SSF) CWs. SF CWs require relatively large area and associated with odor problem during the course of water treatment. However SSF CWs which were developed few decades back are well known for their smaller footprints and efficient treatment ability. Considering the flow of wastewater in the CW unit during treatment, SSF CWs can be differentiated as Horizontal sub-surface flow (HF) or Vertical sub-surface (VF) CWs. HF CWs are good for removal of organics and suspended solids (Vymazal, 2005), but are unable to achieve full nitrification (Cooper, 1999). HF CWs have been successfully tested for milking parlor/dairy waste water treatment in different parts of world (Kern and Bretter, 2002; Montavi, et al., 2002, 2003; Hill, et al., 2003). VF CWs posses aerobic environment which provide nitrates (Molle et al., 2008) and also have advantage of reduced footprints. They have also been tested for variety of wastewaters including milking parlor/dairy wastewater (Veenstra, 1998; Kern and

Idler, 1999). The recent developments in CW technology showed the way to exploit the individual characteristics of VF and HF CWs together in one system in the form of hybrid CWs. Hybrid CWs has gained popularity all over the world and been operated for the treatment of various kinds of waste waters. (Burka and Lawrence, 1990; Kantawanichkul and Neamkam, 2003; Brix et al., 2003; Bulc, 2006; Öövel, 2007; Tuszyñska, 2008; Justin, 2009; Singh et al., 2009; Vymazal, 2011; Serrano et al., 2011), however limited studies are available reflecting the treatment potential of hybrid CWs for high strength dairy/milking parlor wastewater under extremely cold climates (Reeb and Werckmann, 2005; Abe et al., 2010, Sharma et al., 2011).

Live stock wastewater treatment became rigorous in Japan after the enforcement of new law on ‘Livestock excreta management and recycling’ in 2004 (Abe et al., 2010). However strict legal regulations on milking parlor waste water are not imposed due to its low nutrient composition compared to livestock slurry. Presently in Japan, dairy waste water of <50 m^3 d^{-1} per establishment has no treatment obligations, therefore it is either infiltrating underground or flowing into nearby river/pond without any prior treatment, causing ground and surface water pollutions.

Hokkaido is the largest milk producing region of Japan. In 2009, there were 7,809 dairy farms, (34% of the total number of dairy farms in Japan) and 1374 milking parlors in Hokkaido. These milking parlors discharge large volumes of waste water every day. A real-scale hybrid SSF CWs system was constructed and operated at Embetsu (Northern Hokkaido) with an objective to assess the potential of hybrid SSF CWs for the treatment of milking parlor waste water under extremely cold climates of Hokkaido. Present paper describes the seasonal variations in the treatment efficiency of this hybrid CWs.

2. MATERIALS AND METHODS

2.1 Details of Hybrid Sub-surface flow CW system

2.1.1 Location and configuration of system

A hybrid sub-surface flow CW was designed and constructed by our research group in November 2006 at Embetsu (44° 45' N, 141° 48' E) in Northern Hokkaido. It consists of three beds (VF-VF-HF) constructed in series (Fig. 1). VF beds were designed as per the design recommendations of Paul Cooper. The areas of VF beds were calculated using following equations (Cooper, 1997; 2005).

$$\mathrm{OTR} = Q \times \left\{ \left(\mathrm{BOD_{In}} - \mathrm{BOD_{Out}} \right) + 4.3 \times \left(\mathrm{NH_4{-}N_{In}} - \mathrm{NH_4{-}N_{Out}} \right) \right\} \Big/ \mathrm{Area} \;\text{.........}(1)$$

OTR: Oxygen transfer rate (g O_2 m^{-2} day^{-1}); Q: Influent Flow Rate: m^3 day^{-1}; A: Total area (m^2); BOD (mg L^{-1}); NH_4 –N (mg L^{-1}).

OTR for all beds was considered as follows:

VF beds= 28 g O_2 m^{-2} day^{-1}

Limit loading rate (LLR) was calculated using following equation.

$$\mathrm{LLR} = \left[\left(\text{Flow Rate } (\mathrm{Q}) \times \mathrm{BOD_{In}} \right) \Big/ \text{Total area} \right] \times 100 \;\text{.....................}(2)$$

LLR=25(g BOD_5 m^{-2} day^{-1}) or 50 (g COD_{Cr} m^{-2} day^{-1})

Area of HF bed was kept nearly equal to areas of both VF beds together so that both beds (VF &HF) could equally contribute in treatment of wastewater.

2.1.2 Filter material, bed depth, surface vegetation

The first, VF(a) and second,VF(b) beds are vertical sub-surface flow beds, each160 m^2 whereas third (HF) bed is horizontal sub-surface bed, 336 m^2 in area. Details of filter material and surface vegetation of all beds can be found in Sharma, et al., (2011).

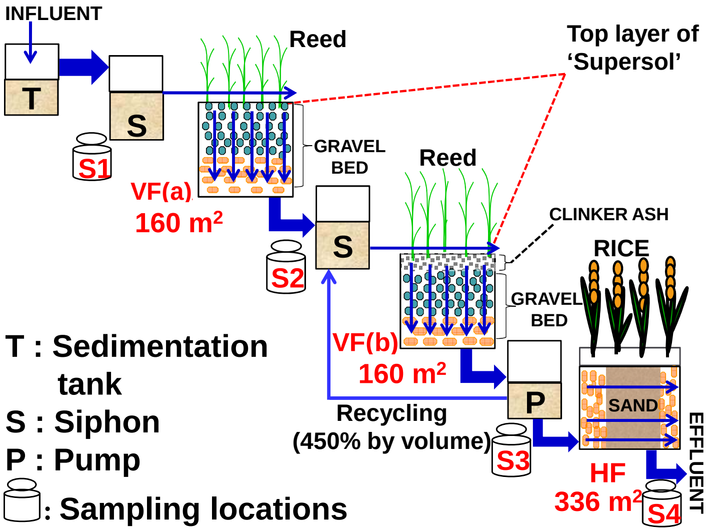


Fig.1: Schematic layout of Hybrid Sub-surface flow CW system at Embetsu, Hokkaido

Siphons were used for dosing wastewater at VF beds. For HF bed, an electric pump was used for dosing wastewater instead of siphon because of hydraulic limitations. Waste water was pretreated in a sedimentation tank (5.4 m^3) for settling suspended solids.

2.2 Sampling measurement and analysis

Sampling was carried out from November 2006 to October 2010 at sampling locations S1, S2, S3 and S4 (Fig.1). The waste water flow and temperature monitoring equipments were installed at all sampling locations. Pressure type water sensors were used for measuring water flow. At S4 location, water flow was measured using a triangular weir. Air temperature sensor, rainfall and snow measurement instruments were installed near S2 location. We used tipping bucket type rain gauge for measuring rainfall.

Samples were collected once in a month, preserved and analyzed for TSS, COD_{Cr}, BOD_5, TN, NH_4-N, NO_3-N, TP, PO_4-P, organic-P, TC and total coliform. DO, pH, ORP and EC were measured at field during sampling time.TSS was measured by suction filtration method (filtration at 45 μm and drying at 105 ^{o}C). TN, and TC were measured using Vario max instrument. NH_4-N, TP and PO_4-P were measured by Spectrophotometric method. NO_3-N was measured by Ion Cromatograph. Total coliform was measured using Petrifilm plate count method. BOD_5 was measured by ‘JIS K 0121’ method of Japanese

Industrial standards. COD_{Cr} was measured using 'HACH DR2800' portable spectrophotometer.

Seasonal variations in the purification and removal rates of COD_{Cr}, BOD_5, TN, NH_4-N, TP, PO_4-P, Organic-P, TSS, TC and total coliform were assessed for cold and warm periods. Cold period represents sampling period from November to April months and warm period represents sampling period from May to October months from 2007 to 2010.

The statistical analysis of the data was performed using the programme Analyse-it 2.22. Spearman Rank Correlation analysis was used to analyse the relationship between the water quality parameters and environmental indicators for cold and warm periods. The level of significance (p) <0.05 was accepted in all cases.

2.3 System efficiency for pollutant removal

Besides monitoring the changes in concentration and load, the efficiency of hybrid sub-surface CWs was calculated in terms of purification and removal rates of all selected parameters of wastewater during both warm and cold periods.

3.0 RESULTS

3.1 Meteorology

The daily mean air temperature showed a difference of 16.3 ^{o}C between the warm and cold periods during entire study period. In the warm period, daily mean air temperature ranged between -0.8 ^{o}C and 26.3 ^{o}C, with an average of 14.7 ^{o}C. In the cold period, when the bed surfaces were covered with snow, daily mean air temperature varied from -17.4 ^{o}C to 15.5 ^{o}C with an average of -1.6 ^{o}C. Precipitation was higher during warm period compared to cold period. Monthly precipitation during cold period ranged between 14.5 to 135.5 mm with an average of 69.4 mm. Whereas, during warm period it varied from 8.0 to 354.5 mm with an average of 113.9 mm.

3.2 Composition, HLRs, dosing pattern, temperature of influent and effluent

Influent was discharged from a milking parlor located adjacent to the hybrid sub-surface CWs. The influent was a mixture of wastewaters originated from various operations of milking parlor, such as: floor washings after milking; disinfectant and detergent washings from equipments; spilled milk during milking along with cow dung and urine. In 2007, from February to December, large quantity of rejected milk was also mixed with influent every day. Nearly all times, Influent was yellowish in color with str

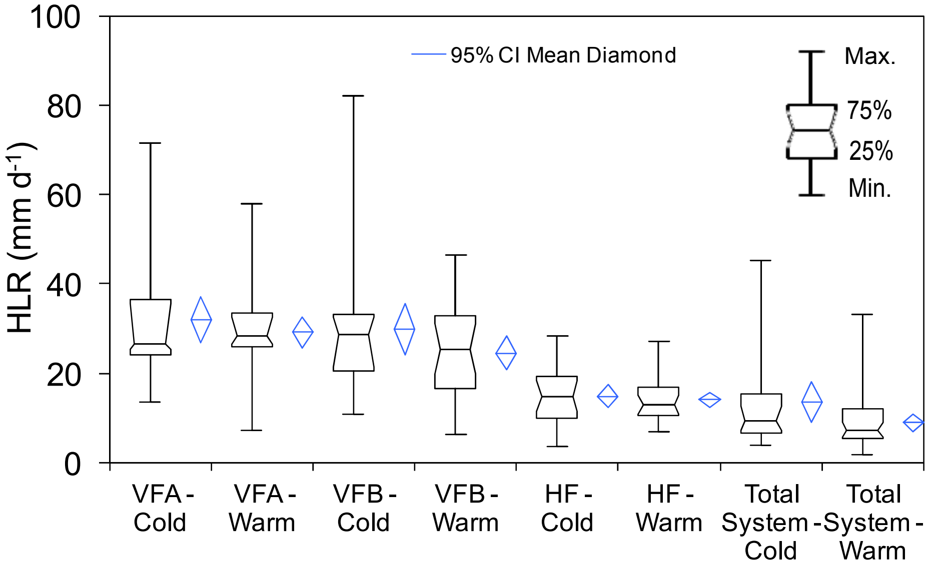
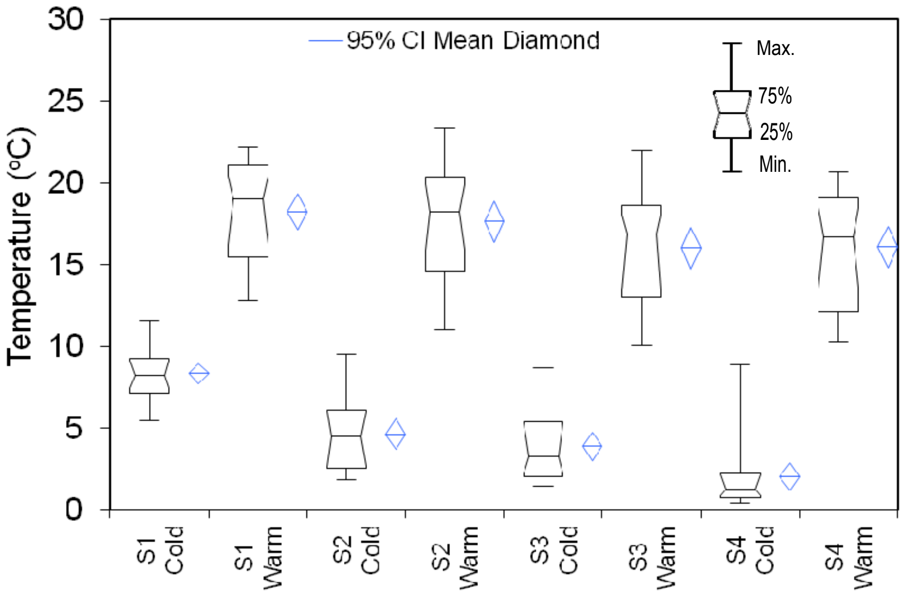


Fig. 2: Average hydraulic loading rates at VFA, VFB, HF beds and total system during cold and warm periods at hybrid sub-surface CWs in Embetsu

Average hydraulic loading rates (HLRs) of 7.9 and 7.3 mm d^{-1} were observed during cold and warm periods. It fluctuated from 4.7 to 17.4 mm d^{-1} during cold period and 1.8 to 14.2 mm d^{-1} during warm period (Fig.2). In cold period, higher HLR was recorded during snow melting period, while in warm period high HLR was received during spring season.

Wastewater was dosed twice every day with an interval of 8 hours to VF(a) bed in both periods. Dosing was carried out using siphon located before VF(a) bed.

Daily mean influent and effluent temperatures during cold period were recorded as 8.4 and 2.1 °C (Fig.3). Daily mean influent and effluent temperatures during warm period were 18.2 and 16.1 °C respectively.



Daily mean air temperature was constantly below zero during January and February months of cold period. Although temperature showed a significant drop from influent to effluent during cold period however wastewater did not freeze and treatment continued underneath the bed surfaces throughout the study period.

3.3 Seasonal variations in Influent and effluent concentrations

Fig. 3: Daily mean water temperature at S1, S2, S3 and S4 sampling locations during cold and warm periods in hybrid CWs at Embetsu

3.3.1

Mean influent pH during cold period was 7.0±0.5 and it showed a slight decrease in the effluent with an average value of 6.6±0.9. However, during warm period mean pH of 6.2±0.7 in influent increased to 6.9±0.4 at effluent. EC concentrations of influent and effluent showed similarity for both periods. Average EC decrease from influent to effluent during cold and warm periods was found as 0.4 and 0.5 mS cm^{-1}. Average ORP in the influent during cold and warm periods was observed as 227±59 and 204±51 mV whereas in the effluent, average ORP concentrations were increased to 292±99 and 250±80 mV during cold and warm periods respectively.

3.3.2 Organic matter, total suspended solids and nutrients

The waste water from the milking parlor had a high organic load with average COD_{Cr} concentrations of 3,749±2,054 mg L^{-1} during cold and 4,988±3,301 mg L^{-1} during warm period (Table 1). Compared with cold periods, average influent concentration during warm period was higher for TP, PO_4-P, organic-P, TN, NH_4-N, COD_{Cr}, BOD_5, TSS and TC.

Table 1: Average concentrations of water quality parameters in the influent and effluent during cold and warm periods at hybrid sub-surface CWs in Embetsu

		pH	**EC mS cm^{-1}**	**DO mg L^{-1}**	**ORP mV**	**TP mg L^{-1}**
Cold period	Influent	7.0 ± 0.5	1.2 ± 0.3	2.7 ± 1.5	227 ± 59	23.9 ± 10.5
	Effluent	6.6 ± 0.9	0.8 ± 0.4	3.0 ± 1.9	292 ± 99	3.9 ± 2.6
Warm period	Influent	6.2 ± 0.7	1.4 ± 0.4	0.8 ± 0.8	204 ± 51	31.9 ± 16.6
	Effluent	6.9 ± 0.4	0.9 ± 0.2	1.4 ± 0.8	250 ± 80	6.0 ± 3.6

		PO_4-P mg L^{-1}	**Org. P mg L^{-1}**	**TN mg L^{-1}**	**NH_4-N mg L^{-1}**	**NO_3-N mg L^{-1}**
Cold period	Influent	19.8 ± 10.3	4.1 ± 1.5	161 ± 59	73.9 ± 37.6	0.5 ± 0.8
	Effluent	3.0 ± 2.3	0.9 ± 0.7	28.3 ± 4.2	19.3 ± 16.7	0.7 ± 1.1
Warm period	Influent	27.2 ± 10.3	4.7 ± 2.6	194 ± 15.7	75.8 ± 40.5	0.2 ± 0.4
	Effluent	4.8 ± 3.0	1.2 ± 0.9	30.3 ± 21.2	19.5 ± 13.4	1.5 ± 3.9

		COD_{Cr} mg L^{-1}	**BOD_5 mg L^{-1}**	**TSS mg L^{-1}**	**Total C mg L^{-1}**	**T.Coliform* no. ml^{-1}**
Cold period	Influent	3,749 ± 2,054	1,637 ± 677	661 ± 526	1,212 ± 596	230 ± 953
	Effluent	308 ± 333	130 ± 85	15 ± 22	158 ± 119	0.8 ± 2.8
Warm period	Influent	4,988 ± 3,301	1,395 ± 397	862 ± 794	1,715 ± 955	184 ± 267
	Effluent	287 ± 382	114 ± 73	14 ± 28	181 ± 102	1.4 ± 2.1

*Total Coliform values are in thousands

However concentration of total coliform was higher during cold period.

Average influent NO_3-N concentration was more or less similar for both periods. Similar to influent concentrations, effluent concentrations were higher in warm period compared to cold period for TP, PO_4-P, organic-P, NO_3-N and TC, but COD_{Cr} and BOD_5 in contrast, showed higher concentrations during cold period. Furthermore, TSS, TN and NH_4-N concentrations in the effluent were nearly similar during both periods. NH_4-N dominated in the influent TN concentrations and accounted for 46% of TN in cold and 39% in warm period. In the effluent, average NH_4-N concentrations accounted for 68% of TN in cold and 64% in warm period. For phosphorus, 83% of TP in the cold period and 85% in the warm period derived from PO_4-P in the influent. However in the effluent, 77% of TP in cold period and 80% in warm period accounted for PO_4-P. Average NO_3-N concentrations showed a marginal increase from 0.5 to 0.7 mg L^{-1} during cold periods, whereas during warm period average NO_3-N concentrations in the effluent were higher than what were observed in cold periods. Average concentrations of TP, PO_4-P, TN, NH_4-N and TSS in the effluent were below discharge limit during both cold and warm periods, however average BOD_5 concentrations during cold period and COD_{Cr} concentrations for both periods could not meet the discharge limit value. Although influent was was pre-treated in a sedimentation tank located before VF(a) bed, however it contained high load of TSS, reaching values of 4.9±2.6 g m^{-2} d^{-1} during cold and 6.1±5.0 g m^{-2} d^{-1} during warm period (Table 2). Average TSS and COD_{Cr} loads in influent were higher in warm period compared to cold period. However effluent showed nearly similar loads for COD_{Cr} and TSS for both periods.

Average Influent and effluent BOD_5 loads in contrast, were higher during cold period compared to warm period. Influent and effluent loads of TN, NH_4-N, TP and PO_4-P showed a strong similarity between cold and warm periods.

3.4 Seasonal variations in purification and removal rates

Figure 4 shows the purification rates of VF and HF beds for both periods. During cold period, average purification rates in VF(a), VF(b) & HF beds were observed as: TSS (72, 73 & 70%), COD_{Cr} (60, 51 & 58%), BOD_5 (45, 61& 63%), TN (42, 40 & 50%), NH_4-N (36, 34 & 39%), TC (54, 42 & 51%), TP (38, 35 & 60%) and PO_4-P(39, 40 & 57%)

Table 2: Average load of water quality parameters in the influent and effluent during cold and warm periods at hybrid sub-surface CWs at Embetsu

		TSS	**COD_{Cr}**	**BOD_5**	**TN**
Cold period	Influent	4.9 ± 2.6	27.5 ± 14.0	12.4 ± 4.7	1.21 ± 0.45
	Effluent	0.1 ± 0.2	2.8 ± 2.7	1.32 ± 0.7	0.26 ± 0.17
Warm period	Influent	6.1 ± 5.0	32.9 ± 24.1	9.6 ± 3.7	1.22 ± 0.62
	Effluent	0.1 ± 0.2	2.3 ± 2.1	1.0 ± 0.8	0.23 ± 0.15

		NH_4-N	**TP**	**PO_4-P**	**Total C**
Cold period	Influent	0.58 ± 0.22	0.18 ± 0.08	0.15 ± 0.07	9.0 ± 4.3
	Effluent	0.16 ± 0.13	0.04 ± 0.02	0.03 ± 0.02	1.5 ± 0.9
Warm period	Influent	0.58 ± 0.26	0.20 ± 0.10	0.17 ± 0.10	10.7 ± 6.3
	Effluent	0..16 ± 0.10	0.05 ± 0.03	0.04 ± 0.03	1.37 ± 0.8

All values are in g m^{-2} d^{-1}

respectively. Average purification rates in VF(a), VF(b) & HF beds during warm period were recorded as: TSS (79, 72 & 73%), COD_{Cr} (70, 60 & 52%), BOD_5 (40, 62 & 64%), TN (56, 47 & 33%), NH_4-N (40, 34 & 35%), TC (60, 52 & 45%), TP(35, 34 & 56%) and PO_4-P(33, 32 & 61%) respectively.

In VF beds, higher purification rates were observed for COD_{Cr}, TN, NH_4-N and TC during warm period compared to cold period. Whereas

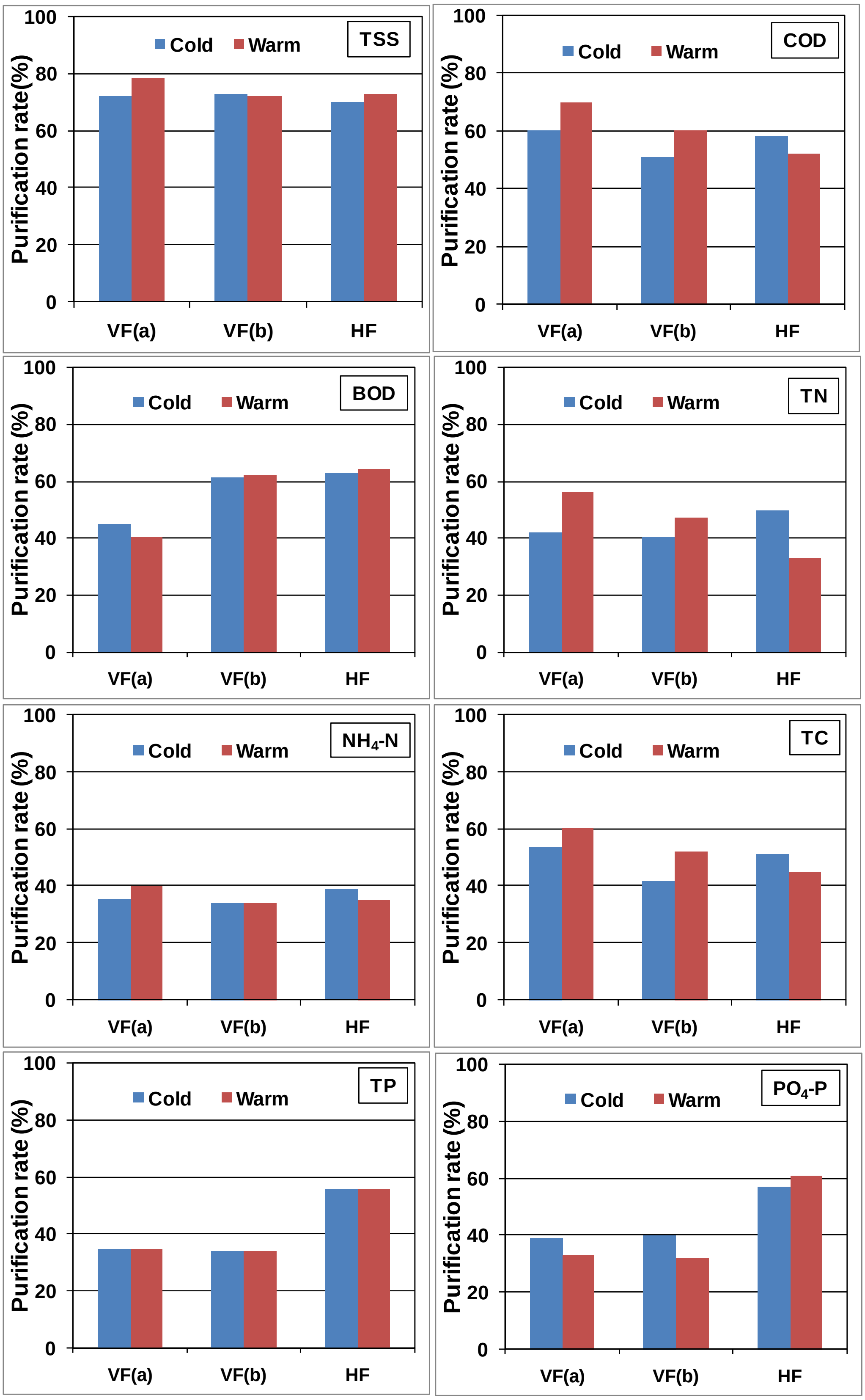


Fig. 4: Purification rates of TSS, COD_{Cr}, BOD, TN, NH_4-N, TC, TP, PO_4-P in VF and HF beds during cold and warm periods in hybrid CWs at Embetsu

HF bed showed higher purification rate for COD_{Cr}, TN, NH_4-N, TC & TP during cold period.

Figures 5 to 8 represent purification and removal rates of total system for TSS, COD_{Cr}, BOD_5, TN, NH_4-N, TC,TP, PO_4-P, Organic-P, and

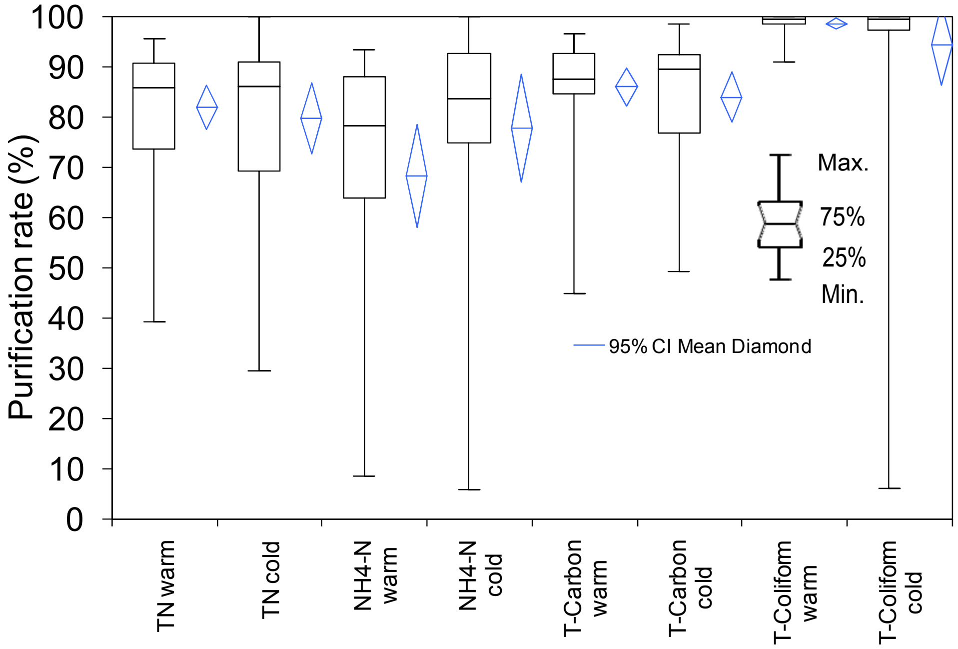


Fig. 5: Purification rates of TN, NH_4-N, total Carbon and Total Coliform during cold and warm periods in hybrid CWs at Embetsu

total coliform for cold and warm periods. Marginal increase in purification rates of COD_{Cr}, TSS, TN and total carbon was observed in warm period compared to cold period.

However total coliform showed an increase of 4.2% in purification rate during warm period than cold period. BOD_5, TP, PO_4-P showed a slight decrease in their purification rates during warm period. However, a significant decrease of 9.5% in NH_4-N and 12% in organic-P purification rate was recorded during warm period compared to cold period.

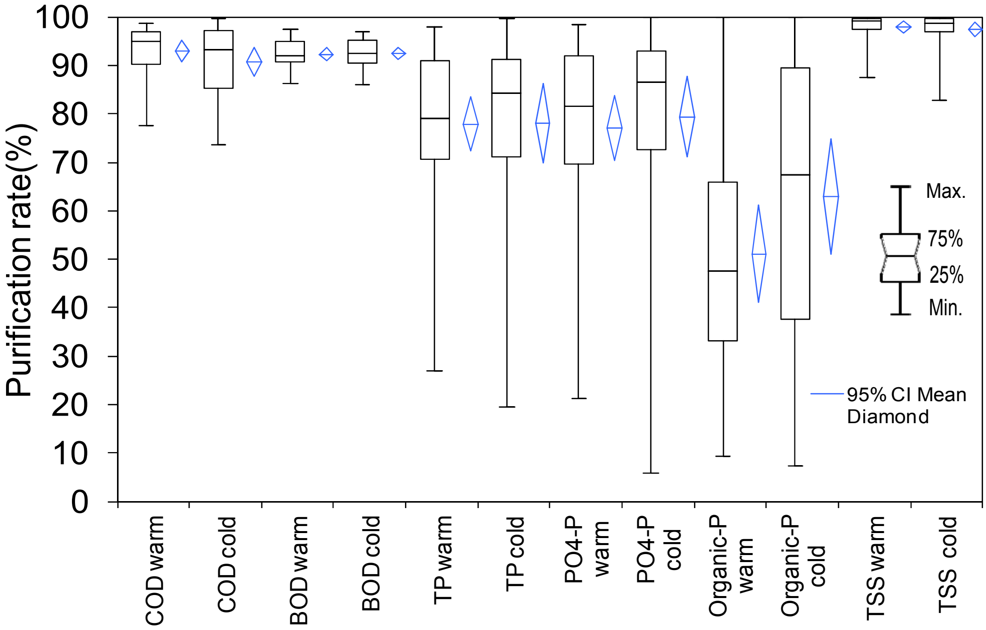


Fig. 6: Purification rates of COD, BOD, TP, PO_4-P, Organic P and TSS during cold and warm periods in hybrid CWs at Embetsu

Removal rates of TSS and BOD_5 showed a minor increase during warm period, however COD_{Cr}, TN and TC achieved an increase of 3-4% in removal rates during warm period. NH_4-N and organic P removal rates, in contrast to their purification rates showed a very little decrease of <1% during warm period. TP and PO_4-P showed a decrease of 3.4 and

8.0% in their removal rates during warm period compared to cold period respectively.

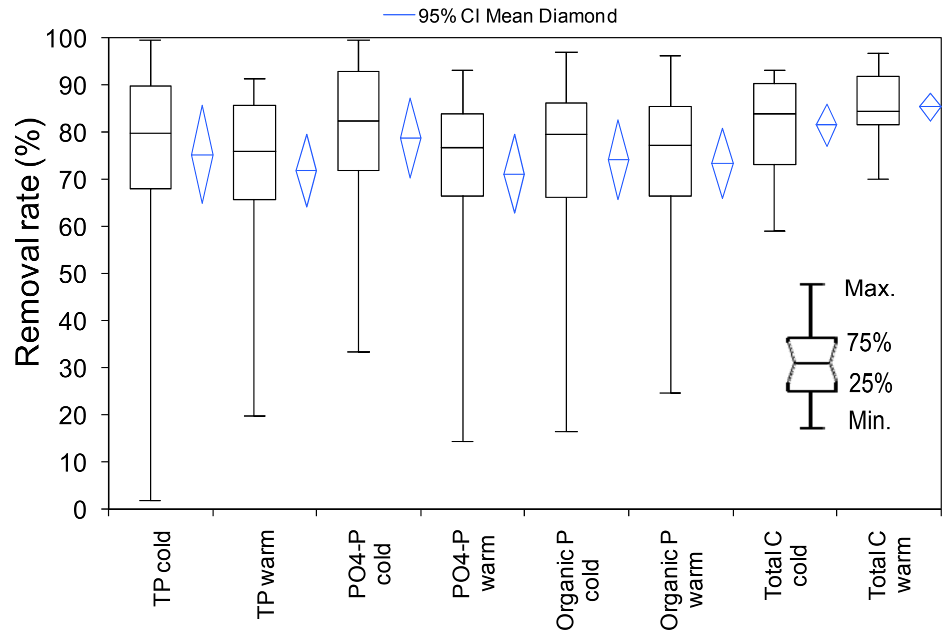


Fig. 7: Removal rates of TP, PO_4-P, Organic P and total Carbon during cold and warm periods in hybrid CWs at Embetsu

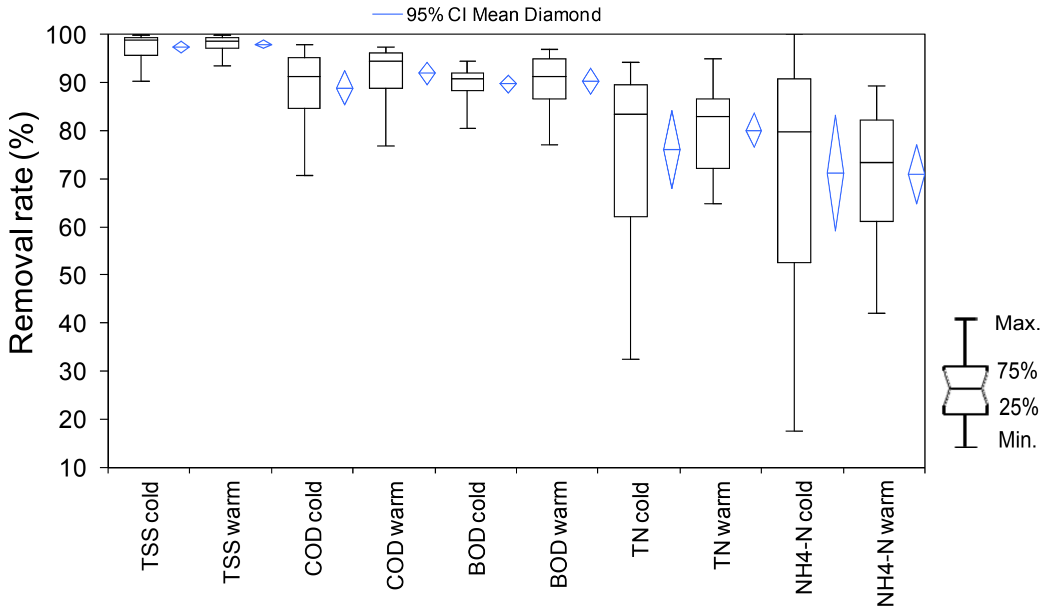


Fig. 8: Removal rates of TSS, COD, BOD, TN and NH_4-N during cold and warm periods in hybrid CWs at Embetsu

4. DISCUSSION

4.1 Seasonal effect on purification and removal rates of water quality indicators

During warm period, the effluent pH was slightly elevated to influent pH. In HF bed, during warm period wastewater level was kept approximately 10 cm above the bed surface for promoting the growth of rice (*Oriza sativa*) grown in this bed. This resulted more anaerobic conditions in HF bed favouring denitrification process. Water logged conditions in HF bed also resulted growth of algal blooms on the HF bed surface during warm period. In this period, partially nitrified effluent from VF beds, under optimal temperature conditions might have denitrified in the HF bed resulting to release of CO_2 and alkalinity in the wastewater. CO_2 is responsible for lowering of pH by formation weak carbonic acid in the wastewater while alkalinity increases the pH. Along with this, algal growth on HF bed surface might have consumed the CO_2 from the waste water as a result of photosynthesis. Finally the released alkalinity had most probably increased the pH in the final effluent. Hill et al., (2003) also reported an increase in effluent pH during warm period. EC concentrations in effluent were always lower than influent concentrations during both periods reflecting treatment of dissolved ions in the wetland system during whole period. EC concentrations were positively correlated with concentrations of COD_{Cr}, TN, and TP in influent for both cold and warm periods (Spearman R value varied from 0.55 to 0.72) (Table 3 and 4). High influent concentrations derived mainly from organic particulate matter which is confirmed by a significant positive relationship of TSS with COD_{Cr}, BOD_5, TN and TP during cold and warm periods. (Spearman R value varied from 0.63 to 0.87) (Table 3 and 4). Kern (2003) also found similar relationship during treatment of dairy wastewater in HF CWs in Germany. The major source of TSS was excreta of cows which mixed with the influent during floor washing operations at milking parlor. NH_4-N fraction in TN showed an increase in effluent compared to influent during both cold and warm periods. This indicates that removal of particulate organic nitrogen was more significant during both periods.

Table 3: Spearman Rank Correlation values between air temperature and water quality parameters in the influent (I) and effluent (O) of Hybrid Sub-surface flow constructed wetland system during cold period at Embetsu

	HLR (I)	Temp. °C (I)	Air temp. °C (I)	DO (I)	pH (I)	EC (I)	TSS (I)	COD$_{Cr}$ (I)	BOD$_5$ (I)	TN (I)	TP (I)	HLR (O)	Temp. °C(O)	Air temp. °C	DO (O)	pH (O)	EC (O)	TSS (O)	COD$_{Cr}$ (O)	BOD$_5$ (O)	TN (O)	TP (O)
HLR(I)	1.00																					
Temp.°C (I)	-0.19	1.00																				
Air temp.°C	0.11	**0.46**	1.00																			
DO (I)	0.18	-0.12	-0.25	1.00																		
pH(I)	0.26	-0.12	**-0.39**	0.32	1.00																	
EC(I)	-0.29	0.00	-0.07	**-0.41**	**-0.40**	1.00																
TSS (I)	-0.17	0.08	0.34	-0.22	**-0.56**	0.35	1.00															
COD$_{Cr}$ (I)	-0.26	0.11	-0.03	-0.25	**-0.70**	**0.55**	**0.82**	1.00														
BOD$_5$ (I)	-0.22	0.20	-0.25	-0.26	-0.22	0.08	0.23	0.36	1.00													
TN (I)	-0.26	-0.03	-0.03	-0.23	**-0.57**	**0.67**	**0.79**	**0.93**	0.27	1.00												
TP (I)	-0.34	0.21	-0.04	-0.23	**-0.72**	**0.60**	**0.78**	**0.97**	**0.46**	**0.93**	1.00											
HLR (O)	0.23	**0.49**	0.34	0.18	-0.01	-0.41	0.28	0.04	-0.15	0.04	0.03	1.00										
Temp.°C(O)	**-0.58**	**0.55**	0.32	**-0.52**	-0.26	0.29	0.10	0.11	0.23	0.18	0.25	-0.16	1.00									
Air temp.°C	0.11	**0.46**	1.00	-0.25	**-0.39**	-0.07	0.07	-0.03	0.23	-0.03	-0.04	0.34	0.32	1.00								
DO (O)	-0.13	0.14	0.14	0.33	-0.08	-0.08	0.01	0.08	-0.16	0.09	0.10	-0.13	-0.14	0.14	1.00							
pH(O)	0.34	-0.01	0.05	0.41	**0.56**	-0.11	**-0.46**	**-0.43**	**-0.49**	-0.24	**-0.45**	-0.09	-0.11	0.05	0.12	1.00						
EC(O)	0.00	-0.15	**-0.55**	0.10	0.15	0.33	-0.02	0.24	-0.10	0.33	0.20	-0.24	-0.18	**-0.55**	-0.21	0.16	1.00					
TSS (O)	-0.19	**0.48**	-0.24	-0.29	-0.06	-0.05	0.20	0.32	**0.57**	0.22	0.34	0.06	**0.44**	-0.24	-0.11	-0.11	0.18	1.00				
COD$_{Cr}$ (O)	**-0.50**	0.29	**-0.45**	-0.24	-0.06	0.10	0.09	0.32	**0.56**	0.21	0.35	-0.11	0.34	**-0.45**	-0.24	**-0.40**	0.31	**0.74**	1.00			
BOD$_5$ (O)	-0.19	0.22	-0.36	-0.32	0.01	0.15	0.14	0.17	**0.75**	0.15	0.29	-0.09	0.33	-0.36	-0.41	-0.40	0.03	**0.65**	**0.58**	1.00		
TN (O)	0.11	0.21	-0.46	0.09	0.37	-0.08	-0.08	0.07	0.26	0.10	0.04	0.09	-0.19	**-0.46**	-0.13	0.13	**0.65**	**0.46**	**0.51**	0.24	1.00	
TP (O)	0.27	0.08	**-0.40**	0.29	**0.43**	-0.03	-0.17	-0.04	-0.14	0.01	-0.08	0.15	-0.30	**-0.40**	-0.03	0.38	**0.73**	0.34	0.23	0.12	**0.76**	1.00

DO: dissolved oxygen; EC: electrical conductivity. Bold values with underline are statistically significant at $p<0.0001$; without underline are significant at $p<0.05$.

Table 4: Spearman Rank Correlation values between air temperature and water quality parameters in the influent (I) and Effluent (O) of Hybrid Sub-surface flow constructed wetland system during warm period at Embetsu

	HLR (I)	Temp °C (I)	Air temp °C	DO (I)	pH (I)	EC (I)	ORP (I)	TSS (I)	COD (I)	BOD (I)	TN (I)	TP (I)	HLR (O)	Temp °C(O)	Air temp °C	DO (O)	pH (O)	EC (O)	ORP (O)	TSS (O)	COD (O)	BOD (O)	TN (O)	TP (O)
HLR (I)	1.00																							
Temp.°C (I)	0.28	1.00																						
Air temp°C	0.30	**0.93**	1.00																					
DO (I)	0.23	-0.03	-0.03	1.00																				
Ph (I)	-0.23	-0.27	-0.28	0.11	1.00																			
EC (I)	-0.07	0.29	0.35	-0.11	-0.38	1.00																		
ORP (I)	0.06	-0.36	-0.37	0.06	-0.12	-0.35	1.00																	
TSS (I)	-0.21	0.13	0.12	-0.27	**-0.72**	**0.52**	-0.08	1.00																
COD (I)	0.10	0.18	0.22	-0.21	**-0.79**	**0.64**	0.04	**0.87**	1.00															
BOD (I)	0.07	0.07	-0.07	-0.09	**-0.71**	0.31	0.32	**0.63**	**0.72**	1.00														
TN (I)	0.02	0.04	0.07	-0.23	**-0.73**	**0.72**	0.05	**0.83**	**0.97**	**0.70**	1.00													
TP (I)	0.06	0.14	0.16	-0.19	**-0.44**	**0.71**	0.02	**0.85**	**0.97**	**0.77**	**0.96**	1.00												
HLR (O)	**0.44**	-0.01	0.01	0.03	0.07	-0.03	-0.06	-0.38	-0.08	-0.19	0.02	-0.14	1.00											
Temp°C (O)	0.31	**0.90**	**0.87**	-0.05	-0.38	0.28	-0.31	0.16	0.19	0.12	0.04	0.15	0.11	1.00										
Air temp °C	0.30	**0.93**	1.00	-0.03	-0.28	0.35	-0.37	0.12	0.22	-0.07	0.07	0.16	0.01	**0.87**	1.00									
DO (O)	-0.15	-0.21	-0.23	0.13	0.26	-0.04	0.17	-0.09	-0.19	-0.30	-0.17	-0.20	-0.15	-0.21	-0.23	1.00								
pH (O)	-0.21	-0.18	-0.03	-0.05	0.33	-0.09	-0.07	-0.30	-0.39	**-0.46**	-0.33	**-0.41**	0.07	0.12	-0.03	0.23	1.00							
EC (O)	-0.10	0.21	0.25	-0.28	-0.34	**0.43**	-0.03	0.29	0.37	0.28	**0.40**	**0.36**	-0.18	0.14	0.25	-0.18	-0.27	1.00						
ORP (O)	-0.29	-0.29	-0.25	0.12	-0.15	-0.04	0.19	0.20	0.25	0.22	0.21	0.17	-0.22	-0.35	-0.25	-0.24	-0.25	0.19	1.00					
TSS (O)	-0.05	-0.05	-0.08	-0.31	**-0.72**	0.10	0.25	0.29	0.23	0.22	0.20	0.18	-0.03	-0.04	-0.08	0.16	-0.13	0.39	0.06	1.00				
COD (O)	-0.29	-0.29	-0.32	-0.19	**-0.40**	0.08	**0.55**	**0.41**	**0.49**	**0.79**	**0.50**	**0.47**	-0.12	-0.21	-0.32	-0.20	-0.33	0.33	0.29	**0.52**	1.00			
BOD (O)	-0.05	-0.05	-0.12	-0.55	**-0.52**	0.28	0.37	**0.49**	**0.48**	**0.61**	**0.52**	**0.56**	0.05	-0.05	-0.12	0.22	-0.12	0.34	-0.08	**0.45**	**0.57**	1.00		
TN (O)	-0.26	-0.26	-0.27	-0.28	-0.27	**0.30**	0.33	0.38	**0.46**	**0.50**	**0.55**	**0.48**	0.02	-0.05	-0.27	0.15	-0.04	**0.44**	0.03	**0.56**	**0.71**	**0.61**	1.00	
TP (O)	**0.41**	**0.41**	**0.46**	-0.02	**-0.44**	0.19	0.05	0.14	**0.41**	**0.46**	0.34	**0.36**	0.06	**0.51**	**0.46**	**-0.57**	-0.10	0.32	-0.01	0.07	**0.43**	-0.04	**0.43**	1.00

DO: dissolved oxygen; EC: electrical conductivity. Bold values with underline are statistically significant at p<0.0001 ; without underline are significant at p<0.05.

Furthermore, positive correlation of TSS and TN in influent and higher removal rates of TSS during both periods gives a confirmation of it (Table 3 and 4). Average NO_3-N concentrations were higher in warm period compared to cold period. This might be because nitrification rate increases at higher temperatures. We observed high NO_3-N concentrations at VF(a) bed outlet (12-95 mg L^{-1}) during warm period in 2008 and 2009. These high NO_3-N concentrations were most probably decreased in HF bed through denitrification process therefore high NO_3-N concentrations could not be observed at HF outlet, which is the final outlet also.TSS purification and removal rates were consistent during both cold and warm periods because TSS is removed by filtration and sedimentation processes which are not temperature dependent. Kadlec et al.,(2003) also found in his study that seasonal variations does not affect TSS removal rate. The correlation values between TSS and air temperature during both periods also gives a confirmation of it (Table 3 and 4). COD_{Cr} showed a slight increase in purification and removal rates during warm period compared to cold period. This probably was because of higher average COD_{Cr} load in the influent during warm period compared to the cold period. (Table 2). Generally high influent concentrations correspond with high reductions, reflecting a high buffer capacity of the constructed wetlands. Kern, (2003) also observed an increase in the COD removal rate with increase in influent concentrations. BOD_5 removal and purification rates were almost unchanged during both periods. As BOD_5 was in the form of particulate suspended soilds (TSS in this case; $R=0.63$, $p<0.05$) which has no seasonal effect, therefore, purification and removal rates of BOD_5 showed no variation between cold and warm periods. Previous studies such as; Bavor, et al., 1989; Bahlo and Wach, 1990 and Vymazal, 2011 also reported that BOD_5 removal rate is independent of temperature variations. TP purification rate was nearly similar for both cold and warm periods, however removal rate was decreased by 3.4% during warm period compared to cold period. During warm period average TP concentration in the influent was 33% higher than average TP concentrations during cold period. Furthermore, a positive correlation between influent and effluent TP concentrations (Spearman correlation R value: 0.36, $p<0.05$) (Table 4) indicate that higher influent TP concentrations during warm period might be a reason for lower removal rates during this period. Similar reason can be explained for lower removal rates of PO_4-P during warm period. Besides this, higher TP and PO_4-P concentrations were observed in the effluent during snow melting season in cold period and rainy season in warm period due to high HLRs in the beds. Hill et al.,(2003) also observed lower TP removal rates during these periods. In this study, temperature change between cold and warm period showed no effect on TP purification rate. Several other researchers such as; Jessen et al.,(1993); Maehlum and Stalnacke (1999); Züst and Schönborn (2003) and Yalcuk and Ugurlu, (2009) also reported in their studies that temperature had no effect on the TP removal from wastewater.

NH_4-N purification is temperature dependent and generally purification rate increases with increasing temperature. But in this study we observed a slight decrease in NH_4-N purification rate in warm period compared to cold period. This was due to very low NH_4-N purification rates of 9% during May, 2007, which affected the average NH_4-N purification rate for whole warm period also. During this period wastewater dosing siphon at S2 sampling location stopped working due to some mechanical problem leading to continuous flow of waste water in VF(b) bed. This caused more anaerobic conditions on the VF(b) bed and resulted lower NH_4-N purification rate during this period. However removal rate of NH_4-N was not affected due to seasonal variation and showed more or less similar rates for both seasons. TN purification and removal rates showed an increase during warm period. This was because of higher nitrification in VF beds and denitrification in HF bed during warm period compared to cold period. Higher NH_4-N purification in VF & HF beds during warm period gives a confirmation of it. Although DO concentrations were higher in cold period but average water temperature was below 5^{o} C which restricted good nitrification in VF beds during this period. Kadlec, (2003) and Öövel et al., (2007) also reported similar trend in their studies. Average Influent concentration for

TC was observed 40% higher during warm period compared to influent concentration during cold period. This did not show any negative effect on purification and removal rates of total carbon during warm period. Infact the purification and removal rates were increased by 2 and 4% respectively during warm period compared to cold period. High decomposition rate during warm period and buffering characteristics of CWs might be the possible reasons for increased purification and removal rates during warm periods. Total coliform showed a 4% higher purification rate during warm period compared to cold period, however average purification rates were above 90% in both periods. Principle mechanism in removal of total coliform from wastewater seemed to be filtration of total coliform at filter media of beds followed by natural die-off and predation. Higher purification rate during warm period was in accordance with the results of Kern (2000) who observed 99.3 and 95.8% purification of coliform during warm and cold period.

5. CONCLUSIONS

The hybrid sub-surface flow CWs may be considered efficient for treating milking parlor waste water during warm and extremely cold periods. It is remarkable that besides extremely low air and water temperatures along with heavy snow cover over the beds during winter months, treatment continued without affecting the purification and removal efficiency of system except in snow melting and rainy seasons, which showed low TP purification rates. Therefore, analysis of Phosphorus mass flux before and after these seasons are recommended in future studies for understanding the exact cause of low TP removal efficiencies in snow melting and rainy seasons. It was demonstrated that COD, TN and TP mainly derived from particulate organic matter. High organic load although limited the good nitrification at VF beds however TN removal rates were quite satisfactory. The final effluent met discharge limit for TN, TP, NH_4-N, BOD_5 and total coliform, however COD_{Cr} could not meet the discharge limit value of 120 mg L^{-1} at final outlet. As COD_{Cr} mainly derived from suspended particulate matter, a better arrangement for separation of TSS at sedimentation tank would therefore help in achieving discharge targets for COD_{Cr} in final effluent. Purification and removal rates increased slightly during warm period for TSS, COD_{Cr}, TN, TC and total coliform, however performance of system was quite good for both warm and cold periods. Furthermore, Regardless of extremely adverse climatic conditions and high nutrient loads, hybrid sub-surface CWs can efficiently achieve higher purification and removal rates of >95% for TSS and total coliform, >89% for COD_{Cr} and BOD_5, >76% for TN and >72% for TP during both cold and warm periods.

6. ACKNOWLEDGEMENT

The authors wish to thank Research Council of Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan, for their support by granting funds for the project.

7. REFERENCES

Abe, K., Kato, K., Ozaki, Y., 2010. Vegetation-based Wastewater Treatment Technologies for Rural areas in Japan. JARQ. 44(3), 231-242.

Bahlo, K.E., and Wach, F.G., 1990. Purification of Domestic Sewage

With and Without Faeces by Vertical Intermittent Filtration in Reed and Rush Beds. In: Constructed Wetlands in Pollution Control. P.F., Cooper and B.C. Findlater, eds., Pergmon Press, Oxford, U.K., 215.

Bavor, H.J., Roser, D.J. and Smalls, I.C., 1989. Performance of Solid matrix Wetland Systems Viewed as Fixed Film Reactors. In: Constructed Wetland for Wastewater Treatment. D.A., Hammer, ed., Lewis Publishers, Chelsea, Mich., pp. 646.

Brix, H., Arias, C.A. and Johansen, N.H., 2003. Experiments in a two-stage constructed wetland system: nitrification capacity and effects of recycling on nitrogen removal. In: Wetlands: Nutrients, Metals and mass cycling, J. Vymazal, eds., Backhuys Publishers, Leiden, The Netherlands, pp. 237-258.

Bulc, T.G., 2006. Long term performance of a constructed wetland for landfill leachate treatment. Ecol. Eng. 26, 365-374.

Burka, U. and Lawrence, P., 1990. A new community approach to waste treatment with higher water plants. In: Constructed wetlands in water pollution control, P.F. Cooper, and B.C. Findlater, eds.,Pergamon Press, Oxford, U.K.,pp. 359-371.

Cooper, P., Smith, M., Maynard, H., 1997. The design and performance of a nitrifying vertical–flow reed bed treatment system. Wat. Sci. Technol. 35, 5, 215-221.

Cooper, P., 1999. A Review of the design and performance of vertical-flow and hybrid reed bed treatment systems. Wat. Sci. Technol. 40, 3, 1-9.

Cooper, P., 2005. The performance of vertical flow constructed wetland systems with special reference to the significance of oxygen transfer and hydraulic loading rates. Wat. Sci. Technol. 51, 9, 81-90.

Hiley, P., 2003. Performance of wastewater treatment and nutrient removal wetlands (reedbeds) in cold temperate climates, In: Mander, Ü., Jenssen, P. (Eds.), Constructed Wetlands for wastewater treatment in cold climates. WIT Press, Southampton, UK, pp. 1-18.

Hill, C.M., Duxbury, J.M., Geohring, L.D., Peck, T., 2003. Designing constructed wetlands to remove phosphorus from barnyard run-off: Seasonal variability in loads and treatment, In: Mander, Ü., Jenssen, P.

(Eds.), Constructed Wetlands for wastewater treatment in cold climates. WIT Press, Southampton, UK. pp. 181-194.

Hunt, P.G., Stone, K.C., Matheny, T.A., Poach, M.E., Vanotti, M.B., Ducey, T.F., 2009. Denitrification of nitrified and non-nitrified swine lagoon wastewater in the suspended sludge layer of treatment wetlands. Ecol. Eng. 35, 1514-1522.

Jessen, P.D., Maehlum, T., Krogstad, T., 1993. Potential use of constructed wetlands for wastewater treatment in northern environments. Wat. Sci. Technol. 28, 10, 149-157.

Justin, M.Z., Vrhovšek, D., Stuhlbacher, A., Bulc, T.G., 2009. Treatment of wastewater in hybrid constructed wetland from the production of vinegar and packaging of detergents. DESALINATION. 246, 100-109.

Kadlec, R.H., Axler, R., McCarthy, B., Henneck, J., 2003. Subsurface treatment wetlands in the cold climate of Minnesota. In: Mander, Ü., Jenssen, P. (Eds.), Constructed Wetlands for wastewater treatment in cold climates. WIT Press, Southampton, UK. pp. 19-51.

Kantawanichkul, S. and Neamkam, P., 2003. Optimum recirculation ratio for nitrogen removal in a combined system: vertical flow vegetated bed over horizontal flow sand bed. In: Wetlands: Nutrients, Metals and mass cycling, J. Vymazal, eds., Backhuys Publishers, Leiden, The Netherlands, pp. 75-86.

Kern, J. and Idler, C., 1999. Treatment of domestic and agricultural wastewater by reed bed systems. Ecol. Eng. 12,(1-2), 13-25.

Kern, J., Idler, C. and Carlow, G., 2000. Removal of fecal coliforms and organic matter from dairy farm wastewater in a constructed wetland under changing climate conditions. J.Environ. Sci. Health. A 35, 8, 1445-1461.

Kern, J. and Brettar, I., 2002. Nitrogen Turnover in a Subsurface Constructed Wetland Receiving dairy Farm Wastewater. In: Treatment Wetlands for Water Quality Improvement; Pries, J., Ed., CH2M Hill Canada Limited: Waterloo, Canada, pp. 15-21.

Kern, J., 2003. Seasonal efficiency of a Constructed Wetland for treating dairy farm wastewater, In: Mander, Ü., Jenssen, P. (Eds.), Constructed Wetlands for wastewater treatment in cold climates. WIT

Press, Southampton, UK. pp. 195-212.

Maehlum, T. and Stalnacke, P., 1999. Removal efficiency three cold cold-climate constructed wetlands treating domestic wastewater: effects of temperature, seasons, loading rates and input concentrations. Wat. Sci. Technol. 40, 243-281.

Molle, P., Prost-Boucle, S., Lienard, A., 2008. Potential for total nitrogen removal by combining vertical flow and horizontal flow constructed wetlands: A full- scale experimental study. Ecol. Eng. 34, 23-29.

Montavi, P., Piccinini, S., Marmiroli, M., Maestri, E., 2002. Treating dairy parlor wastewater using sub-surface flow constructed wetlands. In: Wetlands and Remediation II. K.W. Nehring and S.E. Brauning, eds.,Battelle Press, Columbus, Ohio, pp. 205-212.

Montavi, P., Marmiroli, M., Maestri, E., Tagliavini, S., Piccinini, S., 2003. Application of horizontal sub-surface flow constructed wetland on treatment of dairy parlor wastewater. Biores. Technol. 88, 85-94.

Öövel, M., Tooming, A., Mauring, T., Mander, Ü., 2007. Schoolhouse wastewater purification in a LWA-filled Hybrid Constructed Wetland in

Estonia. Ecol. Eng. 29, 17-26.

Reeb, G., Werckmann, M., 2005. First performance data on use of two pilot constructed wetlands for highly loaded non-domestic sewage. In: Natural and constructed wetlands: Nutrients, Metals and Management, J. Vymazal, ed., Backhuys Publishers, Leiden, The Netherlands, pp. 43-51.

Sharma, P. K., Inoue, T., Kato, K., Ietsugu, H., Tomita, K., Nagasawa, T., 2011. Potential of hybrid constructed wetland system in treating milking parlor waste water under cold climatic conditions in northern Hokkaido, Japan, Water Practice and Technol. IWA Publishing, doi:10.2166/wpt.2011.052.

Serrano, L., Varga, D. De la., Ruiz, I., Soto, M., 2011. Winery wastewater treatment in a hybrid constructed wetland. Ecol. Eng. 37, 5, 744-753.

Singh, S., Haberl, R., Moog, O., Shrestha, R. R., 2009. Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high strength waste water in Nepal-A model for DEWATS. Ecol. Eng. 35, 654-660.

Tanner, C.C., Clayton, J.S., Upsdell, M.P., 1995. Effect of Loading rate and Planting on treatment of Dairy Farm Wastewaters in Constructed Wetlands-II :Removal of Nitrogen and Phosphorus. Wat. Res. 29, 27-34.

Tunçsiper, B., 2009. Nitrogen removal in a combined vertical and horizontal subsurface-flow constructed wetland system. DESALINATION. 247, 466-475.

Tszynska, A., Obarska-Pempkowiak, H., 2008. Dependence between quality and removal effectiveness of organic matter in hybrid constructed wetlands. Biores. Technol. 99, 6010-6016.

Veenstra, S., 1998. The Netherlands. In: Constructed Wetlands for Wastewater Treatment. J. Vymazal, H. Brix, P.F. Cooper, B. Green and Haberl, R., Backhuys Publishers, Leiden, The Netherlands, pp. 289-314.

Vymazal, J., 2005. Horizontal subsurface flow and hybrid constructed wetlands systems for wastewater treatment. Ecol. Eng. 25, 478-490.

Vymazal, J., 2011. Long-term performance of constructed wetlands with horizontal sub-surface flow: Ten case studies from the Czech Republic. Ecol. Eng. 37, 1, 54-63.

Yalcuk, A. and Ugurlu, A., 2009. Comparison of horizontal and vertical constructed wetland systems for land fill leachate treatment. Biores. Technol. 100, 2521-2526.

Züst, B., Schönborn, A., 2003. Constructed wetlands for wastewater treatment in cold climates: planted soil filter Schattweid-13 years'^{s} experience, In: Constructed Wetlands for wastewater treatment in cold climates, (Eds.), Mander, Ü. and Jenssen, P. WIT Press, Southampton, UK, pp. 53-68.