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RESEARCH ARTICLE

WATER FOOTPRINT OF PADDY CULTIVATION UNDER CONTROLLED RUNOFF CONDITIONS: A CASE STUDY IN KURUNAGALA DISTRICT, SRI LANKA

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ABSTRACT

Paddy cultivation is the largest global consumer of water, and it also significantly contributes to water pollution. Investigating the water footprint of paddy agriculture can provide insights into how pollutants affect the ecosystem. This study aimed to quantify the total water footprint for paddy grown in Sri Lanka's Low Country Intermediate Zone under supplementary irrigation. A lysimeter study was carried out to determine the amount of leached nutrients below the root zone. The experimental design was a Complete Randomized Block Design (CRBD) with two factors (cropping season and gradient) and two levels (Yala and Maha; upper and lower). The green and blue water footprints for both sites were estimated using the CROPWAT 8.0 model by crop water requirement option. The results revealed that the loss of NO_3-N through leaching accounted for 8.61 ± 1.84 kg/ha (8%), and the leaching losses of PO_4^{3-}- P were 0.49 ± 0.1 kg/ha (2%) under controlled runoff conditions during the experimental period. The nitrogen fertilizer-induced grey water footprint (WF_{grey}) for one tonne of rice produced was 193 ± 27 m^3/t, and the phosphorous fertilizer-induced WF_{grey} was 61 ± 7 m^3/t. The study identified nitrate as the critical element for water pollution. The estimated total water footprint (WF_{total}), which was the sum of green, blue, and grey water footprint, was 1409 ± 95 m^3/t under controlled runoff conditions, while the global average value is 1325 m^3/t. The estimated value is about 6% higher than the global average value. Therefore, these findings demonstrate the need for further research.

Keywords: Grey water footprint, Nitrate and Phosphate leaching, Rice, Total water footprint

INTRODUCTION

Paddy cultivation is the largest water consumer in the globally (Chapagain and Hoekstra 2011). Two thirds of the total paddy are cultivated under irrigation (International Rice Research Institute, 2002). The potential crop yield is greatly determined by the availability of water (Arora 2006). Since rice production is hampered by water scarcity, large irrigation schemes are built to meet the water requirement of paddy cultivation (Arora 2006) and play a greater part in supplying food demands in the future than in the past. Rice production has been a tradition in Sri Lanka for a century, and it is accompanied by complex irrigation systems (Jayawardana and Wijithadhamma 2015). Paddy farming is mostly practiced in the dry zone in Sri Lanka under irrigation while rain-fed paddy farming practiced in Intermediate zone in Sri Lanka with supplementary irrigation (Central Bank of Sri Lanka 2020). The limiting nutrient in wetlands is Nitrogen (Hou *et al.* 2012). Therefore, Nitro-

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gen fertilizers are frequently utilized in rice farming to increase grain yield, in order to meet the current food demand (Iqbal 2011). The most common Nitrogen-based straight chemical fertilizers are urea and Ammonium Nitrate (NH_4NO_3) (Illeperuma 2000). Only a fraction of the total fertilizer application was utilized by plants (Iqbal 2011), and the remainder was converted into Nitrate, which is extremely water-soluble, quickly leached, and diffusely enters freshwater systems (Choudhury and Kennedy 2005). The considerable amount of Nitrogen and Phosphorus losses from paddy fields by runoff and leaching make their way into the nearby surface water bodies, where they cause severe pollution, eutrophication, and environmental deterioration of aquatic ecosystems (Yan *et al.* 2017). In the rice fields, these nonpoint sources of pollution appeared to be more prominent (Han *et al.* 2007).

Since rice cultivation consumes a significant amount of fresh water and chemical fertilizers in Sri Lanka (CBSL 2020), increasing pressure into fresh water bodies. The amount of fresh water utilized and the amount of polluted water associated to the use of fertilizers in the rice crop need to be quantified. This is known as the water footprint (WF). The WF provides a measurable indication to calculate both the amount of water consumption and the amount of water pollution per unit of crop (Mekonnen and Hoekstra 2014). A crop WF measures, evapotranspiration, irrigation and pollution of freshwater (Brueck and Lammel 2016). The green water footprint (WF_{green}), blue water footprint (WF_{blue}), and grey water footprint (WF_{Grey}) are the three parts of the WF. The WF_{green} is the amount of green water resources (rainwater stored as soil moisture) that are used by crops (Sikirika, 2011). The WF_{blue} is an indicator of consumption of surface fresh water and groundwater resources by crops (Vanham and Bidoglia 2013). The WF_{grey} refers to the amount of water required to assimilate contaminants to the ambient water quality requirements (Hoekstra *et al.*, 2011). It is a useful arithmetic tool to assess and comprehend the potential environmental impact of paddy farming by non-point source pollution that difficult to measure and regulate directly (Hoekstra *et al.* 2011). The chemical application rate determines the grey component of a crop's water footprint. In generally, pollutants associated with paddy cultivation are pesticides, insecticides, and fertilizers (such as Nitrogen, Phosphorus, and others) (Hoekstra *et al.* 2011). Nitrogen (N) and Phosphorous (P) fertilizer induced grey water footprint for growing rice has been evaluated with leaching pollutant loads (N and P).

This study was conducted at Rice research and development institute (RRDI), Sri Lanka aiming to measure the environmental impact of water consumption by quantifying the components that contribute to the grey water footprint and the water footprint of rice production.

MATERIALS AND METHODS

Site description and Experimental Design

The study was conducted in an experimental field (10 m x 10 m) at RRDI situated in the Kurunegala District, which is a major paddy cultivation area under supplementary irrigation in Intermediate Zone, Sri Lanka (7.53 N, 80.44 E, 115 m). The study carried out from 2015 to 2016 during two cropping seasons per year: Yala season (the South-West monsoonal period of May to September) and Maha season (the North-East monsoonal period from September to March in the following year) in which cultivation was carried out by supplimentary irrigation. The area belongs to the Low country Intermediate Zone with an average annual temperature of 26.5-28.5 ^{0}C, average annual relative humidity of 70-90%, and annual rainfall of 1750-2500 mm (Mapa *et al.* 2005). The soil type is a Red yellow Podzolic, classified as Kurunegala Series and the reaction of the soil is slightly acid (pH, 5.0 to 6.0), and cation exchange capacity is lower than 10 cmol/kg, bulk dencity 1.7 Mg/m^3, texture is sandy loam, poorly dranaged, organc C, 0.6% and avalable P, <10 ppm (Mapa *et al.* 2005).

Urea 225 kg/ha (103.5 kg N ha^{-1}) in four splits, Triple Super Phosphate 55 kg/ha (25.3 kg P ha^{-1}) in basal and Muriate of Potash (70 kg K ha^{-1}) in two splits were applied as chemical fertilizers to provide Nitrogen, Phosphorous, and Potassium needs for the field as practiced by the RRDI. Weedicides and pesticides were applied when required. The normal agronomical practices were followed in field management and cropping systems.

Estimation of Green and Blue water footprint of rice

Green and blue water footprints for growing rice were calculated based on effective rainfall, reference evapotranspiration, blue and green evapotranspiration, and crop water use (CWU), estimated using decision support software CROPWAT 8.0 based on FAO Irrigation and Drainage Paper 56 (Allen *et al.* 1998). Climate data including monthly total rainfall (mm), monthly mean minimum and maximum temperature (^{0}C), and monthly total sunshine hours (hours/day) were collected from Bathalagoda agro-meteorological station which is located at the research site (7.53 N, 80.44 E 115 m) for each cropping season from May 2015 to February 2017 (starting and ending months of the four cropping seasons). The other climate data that were not available in the Bathalagoda agro-meteorological station such as monthly relative humidity and average monthly wind speed were collected from Kurunegala meteorological station (7.47 N, 80.37 E, 116 m) which is the nearest meteorological station to the research site.

The green and blue components in crop water use (CWU, m^3/ha) were calculated to determine green and blue water footprints separately by the accumulation of daily evapotranspiration (ET, mm/day) over the complete growing period. The estimated consumptive use of green and blue water components was calculated by converting measured evapotranspiration as a depth (mm) to the volume per hectare by equations 1 (Hoekstra *et al.* 2011).

$$CWU = 10\,x \sum_{d=1}^{lgp} ET \left[\frac{\text{volume}}{\text{area}}\right] \quad \text{......Eqn 01}$$

Where,

CWU - The green/ blue component of crop water use

ET - Green/ blue water evapotranspiration

Factor 10 - Conversion factor water depth in millimeter to water volume per land surface in m^3/ha

The WF_{green}, m^3/t and WF_{blue} m^3/t of rice were calculated, dividing CWU_{green} and CWU_{blue} by the crop yield (t/ha) of research site for each cropping season in the year 2015 and 2016 as shown in equations 2 (Hoekstra *et al.* 2011).

$$WF = \frac{(CWU\;)\,(m^3/ha)}{Y\,(t/ha)} \quad [\text{volume}/\text{mass}] \quad (m^3/t)$$

..Eqn 02

Where,

WF - The green/blue component in the process water footprint

CWU - Green/blue component in crop water use

Y - Crop yield

Nitrogen and Phosphorous Fertilizer induced Greywater Footprint under runoff controlled condition

A lysimeter study was carried out to quantify the leached amount of Nitrate and Phosphate from rice field which are representation elements for the estimation of the grey water footprint associated with rice production. Six non-weighable lysimeters (45 cm long, 6 cm diameter) were arranged in the research plot having dimensions of 10 m x 10 m at the upper gradient and lower gradient with three replicates. The experimental layout was a Randomized Complete Block Design (RCBD) with two factors (cropping season and gradient) and two levels (Yala, Maha and upper gradient, lower gradient). Leached water collected in lysimeters was subjected to analyze Nitrate and Phosphate contents to quantify the pollutant load (L), Nitrate-N, and Phosphate-P. The quantified pollution load was used to calculate the Nitrogen (N) fertilizer induced WF_{grey} and Phosphorous (P) fertilizer induced WF_{grey} individually to find out the most critical pollutant which yields the highest water volume. The field experiment was conducted with the same rice variety (BG358) and the same treatments for four consecutive cropping seasons: Yala and Maha in 2015 and 2016.

The grey components in the process water footprint (WF_{grey}, m^3/t) of rice production was calculated as the load of a pollutant divided by the differences between the ambient water quality standard for the pollutant (C_{max}) and its natural concentration in the receiving water body (C_{nat}) by equation 3 (Hoekstra *et al*., 2011).

$$WF_{grey} = \frac{L}{(C_{max}-C_{nat})} = \frac{(Effl \times C_{eff} - Abstr \times C_{act})}{(C_{max}-C_{nat})} \quad [volume/time]$$

……………………………………….Eqn 03

Where,

WF_{grey} - Grey water footprint (volume/time)

L - Pollutant load entering to a water body (mass/time)

C_{max} - Maximum acceptable concentration (kg/m^3)

C_{nat} - Natural background concentration (kg/m^3)

E_{ffl} - Effluent volume (volume/ time)

A_{bstr} - Abstraction volume (volume/ time)

C_{eff} - concentration of the chemical in the effluent (kg/m^3)

C_{act} - Actual concentration in the point of abstraction (kg/m^3)

Effluent volume (E_{ffl}) was estimated by leached water volume collected into lysimeters. Effluent concentration (C_{eff}), Nutrient concentation of leached were mesured. The pollutant load (L, kg of Nitrate-N, Phosphate-P per entire cropping season) were calculeted by suming up the leached Nitrate, Phosphate amount in each sample time.

WF_{grey} was calculated based on C_{max} for Nitrogen is 11.3 mg/L as NO_3^- - N and C_{max} for Phosphate (PO_4^{3-}) is 2 mg/L (SLS 614, 2013). C_{min} for NO_3^-- N (0.1 mg/L) and (PO_4^{3-}) is 0.01 mg/L^{-1} (Hoekstra *et al.* 2011).

Sampling and analysis

Leached water below the root zone was collected into the bottom part of the lysimeters layout in the experimental plots. Sampling was carried out a day before the fertilization and successive intervals throughout the entire crop growing period. Sample volumes were measured and were subjected to analysis of Nitrate and total Phosphate concentrations (mg/L). Random sampling was done for irrigated flow was subjected to the same analysis. Rice crops were harvested and grain yield was recorded.

Determination of Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) content in leached water

Water samples were subjected to analysis concentration of Nitrate (mg/L) by UV-visible spectrophotometric screening method: APHA 4500-NO_3^- - B. The total Phosphate concentration (mg/L) was analysis by the vandomolybdophosphoric acid colorimetric method as per APHA 4500-P C (American Public Health Association 2000). Random sampling was followed for irrigated flow and subjected to the same analysis.

Quantification of loss amount of Nitrate and Phosphate by leaching under the root zone

Loss amount of Nitrate-N and Phosphate-P by leaching below the root zone, 30 cm soil depth, were quantified based on the concentration of Nitrate and Phosphate and volume of leached water. The loss amount of leached NO_3^--N and PO_4^{-3}-P per area (kg/ha) for an entire growth cycle was estimated.

Calculation of the total water footprint of rice under controlled run-off condition

The total water footprint of the process of rice (WF_{total}) was estimated by summing of the green, blue and grey components by equation 4 (Hoekstra *et al.* 2011). The most critical pollutant which need more freshwater to assimilate the pollutant lode involved in rice cultivation was used to estimate grey water footprint.

$$WF_{total} = WF_{green} + WF_{blue} + WF_{grey} \quad [m^3/t]$$

……………………………………….Eqn 04

Where,

WF_{total} - The total water footprint of the process of rice

$WF_{.green}$ - The green component

of the process water footprint
WF_{blue} - The blue component in the process water footprint
WF_{grey} - The grey component in the process water footprint

Statistical analysis

A two-way Analysis of Variance (ANOVA) was applied to investigate the effect of cropping seasons (Yala and Maha) and the effect of gradient and interaction effects on Nitrate and Phosphate amount in leached water. Treatment differences were considered statistically significant at $P < 0.05$. Statistical analysis was done by Minitab 17 (Minitab Inc, 2017) statistical and data analysis software package.

RESULTS AND DISCUSSION

Concentration of Nitrate in leached water under run-off controlled condition

The mean values of concentration of Nitrate (mg L^{-1}) are given in figure 1. Urea applied as the sole source of N fertilizer at 225 kg/ha (103.5 kg N ha^{-1}) as splits at 2nd, 4th, 6th, and 8th week after transplanting as 50 kg/ha, 75 kg/ha, 65 kg/ha and 35 kg/ha respectively indicated by arrows.

The lower end of the gradient always exhibited a higher Nitrate concentration than that of the upper end for all four seasons. This signifies the downward movement of water with the gradient and concentrating at the lower ends of the field increasing the leaching of Nitrate with water at all times. As per the cropping season, always the 2nd and 3rd sampling points recorded the highest Nitrate concentrations which coincide with the first fertilizer application. The depth of the root zone is normally about 30 cm under irrigated and ponded conditions (Suprapti *et al.* 2010). There was a vertical downward movement of water containing Nitrates from the upper layer to the lower layer by percolation process. The flowing water contains dissolved elements including Nitrate and resulting in comparatively high Nitrate concentration in the leachate at a lower gradient than the upper gradient (Suprapti *et al.* 2010).

Nitrogen fertilizer (urea) was applied at 2nd, 4th, 6th, and 8th weeks after transplantation which was in the early vegetative stage. In general, a high Nitrate concentration was recorded at the 3rd week (21-28 days) after transplantation. The same observations were recorded by Meng *et al.* 2014 showing the highest Nitrate concentration of 4 mg/L (as NO_3-N) at 3rd week of transplantation at 50 cm soil depth. Similar findings were found in the current experiment, where the highest Nitrate content (as NO_3-N) at the third post-transplantation week fluctuated between 4 mg/L and 9 mg/L over the course of four growth seasons. The demand for N by plants increases rapidly during the early phases of plant growth and then diminishing later when plant growth rate declines (Glass, 2003). Hence N fertilization takes place aiming at those vegetative growth demands and that is the reason to observe high leaching losses at the beginning of the cropping season.

Variety BG 358 is medium-duration rice that takes 100-120 days to harvest (International Rice Research Institute, 2015). During the early stage of growth until the 11th week after transplanting, rice is at the vegetative and reproductive stage (Hashim *et al.* 2015). The key period for nitrogen absorption by rice plant is from tillering to flowering, during this period the absorption of soil Nitrogen is at its maximum rate (Qiao-gang *et al.* 2013), which account for 34% to 38% of the Nitrogen absorbed during the whole rice growth period (Wang *et al.* 2014). It was noted that more Nitrate losses occurred in the early vegetative stage than the late vegetative stage and reproductive stage. At late vegetative and reproductive stages, the plant absorbed N more efficiently and leaching losses were decreased. This phenomenon was reflected in the findings of this study as well.

It takes 35 days for the reproductive stage and 30 days for the ripening stage (IRRI, 2015). The plant undergoes grain filling and maturing during the ripening state. At that point, rice uses N that is already present in plant tissue rather than absorbing N from the soil (Hashim *et al.* 2015). Plant demand for N began to decreasing later stage as plant growth

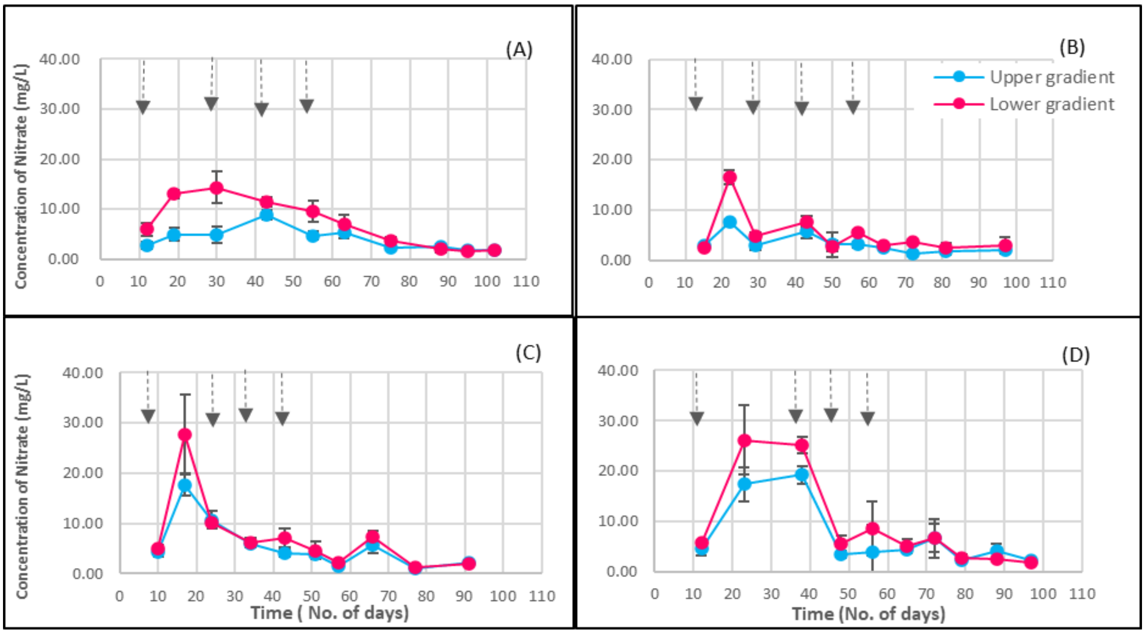

Figure 1: Changes in Nitrate content of leached water at 30 cm soil depth; A: 2015 Yala, B: 2015/16 Maha, C: 2016 Yala, D: 2016/17 Maha. The arrows indicate the time of fertilizer (urea) applications

rates slowed down (Glass 2003). It was observed that minimum leaching losses occurred in the late growth stages of the current study. The similar observations were made by Iqbal 2011, and Meng *et al*. 2014.

Concentration of phosphate in leached water under run-off controlled condition

The mean values of concentration of Phosphate (mg/L) in leachate below the root zone, 30 cm soil depth for four consecutive cropping seasons from 2015 to 2016 are given in figure 2. Triple super Phosphate applied as the sole source of P fertilizer at 23.5 kg P ha^{-1} as a basal application.

In general, for all four seasons, the highest phosphate concentration was exhibited at the 1st sample point a week after fertilization be specific. Thus, P fertilizer (TSP) was applied

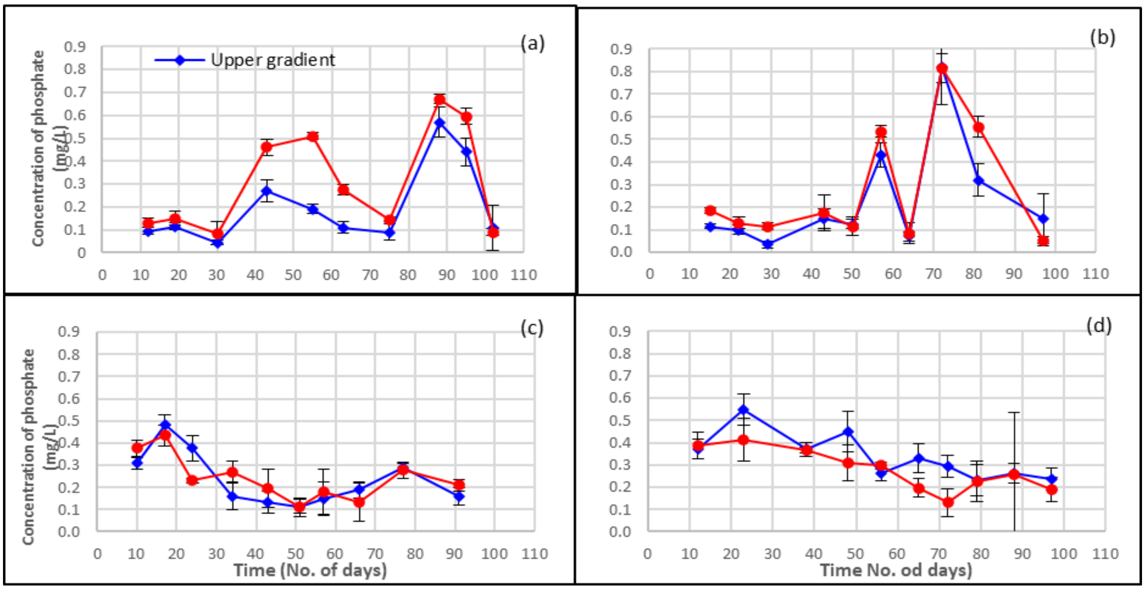

Figure 2: Changes in phosphate content of leached water below the root zone, 30 cm soil depth, a: 2015 Yala, b: 2015/16 Maha, c: 2016 Yala, d: 2016/17 Maha

as a basal medium. There were no noticeable changes in the pattern of variation on phosphate concentration recording increases and decreases for the rest of the samples for the lower and upper ends of the gradients.

According to Xiao *et al*. (2015), the observation was explained by the fact that during the early stages of paddy flooding, the Nitrogen and Phosphorus load were relatively high then gradually dropped as the flooding last. Applied excessive Phosphorus deposition in the rice field (Naguma *et al*. 2013) and some Phosphorus runoff and drainage from paddy fields (Lu *et al*. 2016).

Loss amount of Nitrate and Phosphate by leaching under the root zone

The study plot was run-off controlled and maintained the standard water level. Therefore, it could be assumed that all excess nitrate and phosphate amount was lost through leaching. In this experiment, only the leached nitrate-nitrogen amounts and phosphate-phosphorous amounts were quantified. The leaching loss rate NO_3^--N and PO_4^{3-} -P was quantified per unit area (kg/ha) and % relative to the applied fertilizer amount as methodology and results are given in Table 1.

As explained in the table 1, the maximum Nitrate-N losses (11.28 kg/ha) were recorded in the 2016 Maha season. Average NO_3^-- N losses were 8.61 ± 1.84 kg/ha and PO_4^{3-}-P losses were 0.49 ± 0.10 kg/ha.

Similar observations as reported by Iqbal 2011 recording the NO_3^- -N losses was 1.25 kg/ha (1.38%) when applied urea as a rate of 196 kg/ha (90 kg N ha^{-1}). He also explained that the leaching losses were increased with increases in applied urea rates. When the application of urea rate was increased up to 784 kg/ha (360 kg N ha^{-1}), the leached NO_3^- -N losses were reported as 2.20 kg/ha (0.61%) (Iqbal 2011). Guo *et al*. 2004, revealed that loss of total phosphorous was 1.16 kg/ha in the rice season.

According to the P values of Two-Way ANOVA, it was evident that gradient effect and seasonal effect were significant on leaching losses of Nitrate-N and Phosphate-P. However, an interaction effect of cropping season and gradient was not significant in given settings.

Nitrate is highly water-soluble and relatively stable and was found to migrate into aquifer heavily (Lu *et al*. 2016) and readily lost through water flow and observed a significant variation. P fertilizer, TSP, is smeared as basal application. Phosphate iron is bound to the soil particles and in contradiction of move with soil water like nitrate. P concentration in water percolating through the soil profile by leaching is small due to sorption of P by P-deficiency subsoil (Islam *et al*. 2015). It is proved by the result of this experiment.

Table 1: Leaching losses of NO_3^- -N and PO_4^{3-}-P (kg/ha) and loss % below the root zone, 30 cm soil depth, for each cropping season in years 2015 and 2016

Cropping season	NO_3^- -N (kg/ha)	NO_3^- -N loss %	PO_4^{3-} P (kg/ha)	PO_4^{3-} P loss %
2015 Yala	7.06	6.8	0.45	1.8
2015 Maha	7.95	7.7	0.46	1.8
2016 Yala	8.16	7.9	0.40	1.6
2016 Maha	11.28	10.9	0.63	2.5
Average	8.61 ± 1.84	8.3 ±1.8	0.49 ± 0.10	1.9 ± 0.4

Relative leaching losses of nitrate and phosphate below the root zone

Percentage of NO_3^-- N losses (% of applied N, kg/ha) relative to the applied N fertilizer amount and percentage of Phosphate-P losses (% of applied PO_4^3 -P, kg/ha) relative to the applied P fertilizer amount below root zone for the study period were quantified by the percentage of the total N, P applied and results are given in the table 2 and figure 3.

Figure 3 illustrates the relative leaching losses of N and P in the experimental site for four cropping seasons. The moderate increases of relative N and P losses were observed in the 2016 Maha season. The year 2016 is a dry year and effective rainfall was low during the Maha season. Sufficient irrigation was provided to the research plot to maintain the standard water level. However, that cropping season gained comparatively high leaching losses and also high grain yield.

It was observed that relative leaching losses of Nitrate-N were varied with the range of 6.8% to 10.9% where the total application of urea was 103.5 kg N ha^{-1}. The highest relative Nitrate-N loss was noted (10.9%) at the 2016 Maha season. The average percentage of NO_3^- - N losses for the RRDI site was (8.3 ± 1.8) % during the study period.

Zhu *et al*. (2000) made a similar observation in a lysimeter experiment, where leaching losses of N were 6% of applied urea with ten identical dosages (total application 120 kg N ha^{-1}). However, a single dose at transplanting led to 13% N leaching losses (Zhu *et al.* 2000). Russian data revealed leaching losses of 3-9%. (Zhu *et al*. 2000). In China, the percentage of Nitrogen fertilizer losses due to leaching ranged from 0.1 to 15% of the total amount of N applied (Zhu *et al*. 2000). A lysimeter experiment looked into the Nitrogen leaching from double rice cropped soil, which was found to be up to 27.5 kg N ha-1 when 200 kg N ha-1 were applied (Zhu *et al*. 2000). However, in the same double rice cropped soil, a field experiment recorded 7 kg/ha were lost by leaching when 300 kg N ha^{-1} were applied (Zhu *et al*. 2000).

The maximum percentage of Phosphate-Phosphorous (PO_4^{3-}-P) losses was observed at the 2016 Maha season by reporting 2.5%. The average percentage of phosphate-phosphorous losses was (1.9 ± 0.4) % for the site. Sufficient literature for leaching losses of phosphorous is not available. However, Nagumo *et al.* (2013) was reported that increased available P content in paddy soil may cause an enhanced P runoff to the surface water. Nitrogen and phosphorous run-off and drainage associated with paddy fields are identified as a major nonpoint source pollution (Hu and Huang, 2014).

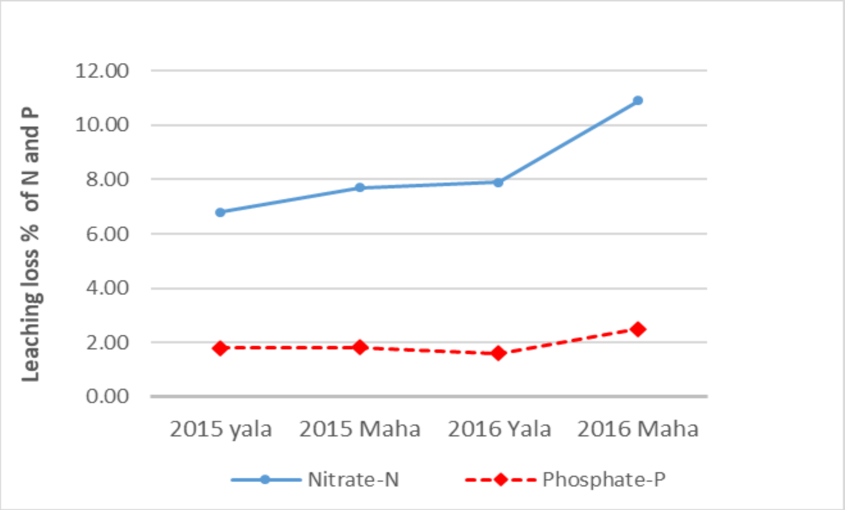

Figure 3: Relative leaching losses (%) of NO_3^-- N and PO_4^3 -P below the root zone, 30 cm soil depth, for four consecutive cropping seasons

Fertilizer-induced N and P leaching and related Grey Water Footprint under run-off controlled condition

The total amount of NO_3^--N and PO_4^{3-}-P, pollutant load (L), leached from the paddy field during the whole cultivation period was calculated.

In run-off controlled condition, run-off losses were assumed as zero. Nutrient concentration of irrigated water was negligible and not consider for the calculations. The fertilizer-induced N and P leaching and related WF_{grey} were calculated and given in table 2.

Considering Table 2, Nitrogen fertilizer induced WF_{grey} was 193 ± 27 m^3/t and Phosphorous fertilizer induced WF_{grey} was 61 ± 7 m^3/t . It was observed that the most critical pollutant, Nitrate, compared to the Phosphorous pollutant associated with rice production, where the above calculation yields the highest $WF_{grey,}$ was defined as the volume of freshwater that is required to assimilate a load of pollutants based on natural background concentrations and existing ambient water quality standards.

Similar results were noted for the global average grey water footprint for rice was reporting 187 m^3/t for Nitrogen pollutants (Mekonnen and Hoekstra 2014). Mekonnen and Hoekstra (2011) estimated that the WF_{grey} for rice production in irrigated agriculture from 1996 to 2005 was 185 m^3/t and 190 m^3/t in rain-fed agriculture. Yoo *et al* (2014) was reported the average WF_{grey} in Korea was 48.4 m^3/t, based on the run-off N and P (pollutant load) of 12.90 kg/ha and 1.01 kg/ha, respectively, during the growing season. Chapagain and Hoekstra (2011) reported the WF_{grey} for rice production was 109 m^3/t.

The total water footprint of rice grown in the Intermediate Zone of Sri Lanka

The green, blue, and grey components that were estimated are shown in Table 3 together make up the total water footprint of the production of paddy rice (WF_{total}). Since Nitrogen fertilizer is the most critical pollutant used to calculate the grey water footprint of rice farming.

Table 3 described, the WF_{green}, WF_{blue}, WF_{grey} and WF_{total} in Intermediate Zone, Sri Lanka under supplimentory irrigaton from 2015 to 2016 under runoff controlled situation.

The green and blue water footprints for an irrigated rice farming system were reported by Mekonnen and Hoekstra (2011) was 869 m^3/t and 464 m^3/t, respectively. Between 1996 and 2005, the average green and blue water footprints of rice were recorded as 1146 m^3/t and

Table 2: N and P fertilizer-induced WF_{grey}, under run-off controlled condition for each cropping season in the year 2015 and 2016

Cropping season	NO_3^- -N leaching related WF_{grey} (m^3/t)	PO_4^{3-}-P leaching related WF_{grey} (m^3/t)
2015 Yala	158	57
2015/16 Maha	192	62
2016 Yala	199	55
2016/17 Maha	224	70
Average WF_{grey}	**193 ± 27**	**61± 7**
Yala (average)	178 ± 29	56 ±1
Maha (average)	208 ± 23	66 ± 6

Table 3: The total water footprint of production paddy rice for each cropping season in the years 2015 and 2016 based on actual pollution load

Cropping season	Yield (t/ha)	WF_{green} (m^3/t)	WF_{blue} (m^3/t)	WF_{grey} (m^3/t)	WF_{total} (m^3/t)
2015 Yala	4.0	795	401	158	1353
2015/16 Maha	3.7	916	401	192	1509
2016 Yala	3.7	646	624	199	1469
2016/17 Maha	4.5	729	353	224	1306
Average	**4.0 ± 0.2**	**772 ± 114**	**445 ± 122**	**193 ± 27**	**1409 ± 95**
Average (Yala)	3.8 ± 0.2	721 ± 105	513 ± 158	178 ± 29	1411 ± 82
Average (Maha)	4.1 ± 0.6	823 ± 132	377 ± 34	208 ± 23	1407 ± 143

341 m^3/t, respectively (Mekonnen and Hoekstra 2011). With an average yield of 3.5 t/ha in Sri Lanka, Chapagain and Hoekstra (2011) calculated the blue and green water footprints for rice production were 1784 Mm^3/year and 1648 Mm^3/year, respectively for the years from 2000 to 2004.

Similar observations were noted by Chapagain and Hoekstra (2011) that reporting the global average water footprint of rice production was 1325 m^3/t which is 48% green, 44% blue, and 8% grey from 2000 to 2004. Mekonnen & Hoekstra (2011) were stated the total water footprint for an irrigated farming system of rice was 1519 m^3/t. At the same time the water footprint of rice, paddy was reported as 1673 m^3/t between 1996 and 2005 (Mekonnen and Hoekstra, 2011). Ewaid *et al.* (2021) reported WF_{total} in Iraq was 3072 m^3/t, in Thaiwan was 7580 m^3/t and in Argentina was 845 m^3/t.

CONCLUSONS

The study attempted to investigate the Water Footprint (Blue, Green, and Gray) of process of rice cultivated in low country Intermediate zone, Sri Lanka. The results showed that the estimated total water footprint was 1409 ± 95 m^3/t with supplementory irrigation under run-off controlled condition. This value represents a 6% increase from the global average value of 1325 m^3/t. This study also found that the average green and blue water footprints were 772 m^3/t and 445 m^3/t respectively. Furthermore, the study found that that WF_{gray} induced by N fertilizer (193 ± 27 m^3/t) was larger than that induced by P fertilizer (61± 7 m^3/t). Based on the study, the lost total Nitrate-N and Phosphate-P pollutant loads at rates of 8.5 kg/ha (8%) and 0.5 kg/ha (2%) respectively from the paddy field.

This study revealed that Nitrate was the critical factor contributing to water pollution in paddy cultivation. Moreover, a significant amount of Nitrogen and Phosphorous leaching losses could occur under the root zone, posing possible threats of surface and groundwater pollution. It is recommended further studies on water footprints of agricultural sector to disclose the impacts of fertilizer application on the environment as well as the communities that consume polluted water.

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AUTHOR CONTRIBUTION

Palliyaguru MPGNM conducted research under supervision of Navaratne CM. All authors discussed the results and corrected the manuscript.

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