Agro-virtual water trade in relation to water availability and attributes of crop import of Lungnyi Gewog, Bhutan.

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Abstract

Virtual Water Trade is the product of Specific Water Demand and quantity of a commodity traded in tons. The water availability, water utility patterns, attributes of agricultural products imports, and quantity of 4 selected crops traded were collected through a questionnaire survey with a systematic circular design. The Specific Water Demand of crops was collected from published FAO guidelines and data was analyzed using MS-Excel and Statistical Package for Social Science (SPSS). The Net Virtual Water Trade was calculated using MS Excel. The study showed positive NVWT with higher virtual water export than an import for the study area. The independent sample t-test showed a significant difference between NVWT of farmers that has and that do not have enough water for agriculture t¬ (88) =3.129, p=0.002. The Pearson Chi-Square test showed no significance in the relationship between attributes of import of agri-products and availability of water resources in the Gewog; X2 (4, N=90) = 63.68, p=0.000. The study revealed a strong correlation between household size and VWI of apple and rice and VWE of apple, potato, chilli, and rice at p <0.01. However, no significant correlation was observed between household size and VWI of potato and chilli.

Keywords: *Crops, Net Virtual Water Trade, Specific Water Demand, Virtual Water Trade, water allocation, water scarcity.*

1. Introduction

Water scarcity is in center of major socio-economic and political problems and has become a major economic asset with its increasing utility in agriculture and industries. The increasing demand of water over renewable domestic water resources, water scarcity and its implications for food security have created major concern in most countries (Ashktorab, 2019). The agriculture sector is accredited with about 90% of water use and other sectors acquiring less than 10% (Siebert & Döll, 2010). It was found that conservation, research, and innovative activities should be streamlined towards sectors that take the greater share of the water resource (Gleick, 1993). Water resource management is the activity of planning, developing, distributing and managing optimum use of water resources with balanced allocation (Yang & Zehnder, 2007). The traditional water resource management strategies in Bhutan were primarily conducted within the catchment and watershed perspectives (NEC, 2012). The scope of the water resource management can be extended beyond the boundary of the natural watershed and into the trade of water resources (Zehnder et al., 2003).

Virtual water (VW) is the amount of water that is used to produce a commodity which is also called water foot print (Hoeskstra, 2002). The term “Virtual Water Trade” (VWT) was introduced in 1993 by Professor Tony Allan to indicate the amount of water made available in the global system through agricultural commodity trade (Allen, 1997). The global trade of goods is associated with a virtual transfer of water required for their production and it has become increasingly important to put food trade in analysis of water availability and scarcity (Hoekstra & Hung, 2002). The concept was originally developed in the context of water scarce Middle Eastern and North African countries which import a large portion of their food to alleviate local water scarcity. It becomes more efficient to import crops that consumes more water than to grow locally and the limited water resource available can be allocated to other important sectors (Carr et al., 2013). Almost 90–95% of the domestic cereal supply relies on import in Israel and Libya where water resources are extremely scarce. The gap between the local demand and supply of water-intensive commodities is compensated by virtual water trade through food trade (Antonelli and Sartori, 2015).

Agriculture in most countries has by far the largest water use and discussions on virtual water issues have focused primarily on food commodities. The virtual water flow, entering and leaving a country can indicate actual water scarcity and water allocation of a country (Chapagain and Hoekstra, 2008). In 2008, the total water withdrawal in Bhutan was about 338 million m3 and about 94% of this water was used for agriculture (FAO, 2011). Agriculture consumes over 90% of the water resources in Bhutan (Dorji, 2016). Currently, Bhutan experiences localized and seasonal water shortages for drinking and irrigation although the nation is bestowed with substantial water resources. The escalating demand of water resource increases the need to conserve and manage water resources with research and development that include water balance studies and crop water requirement (ADB, 2016). However, it was also observed that countries which face acute water scarcity problems cannot meet their water demand for food production through cereal imports from water-rich countries (Kumar, 2018). Moreover, influx of foreign food with availability of enough water resources could suppress the domestic efforts in mobilizing the internal water resources (Neubert et al., 2006). The study calculated the VWT and NVWT (Net Virtual Water Trade) of 4 selected crops for the study area from the trade pattern of these crops based on a questionnaire survey. The availability of water for agricultural production and water use patterns in the study area were studied and its relationship with the calculated NVWT of the individual respondents were assessed. The study also analyzed the relationship between the import of the selected crops and the NVWT of the individual respondents of the study area.

2. Materials and Methods

2.1 Primary data collection

2.1.1 Study area

Lungnyi Gewog has total area of 59.7 km2 from which 12,687.50 acres are covered by forest with elevation ranging from 2,200 to 3,400 masl (Rai & Phuntsho, 2016). The Gewog lies in the central region of the Dzongkhag.

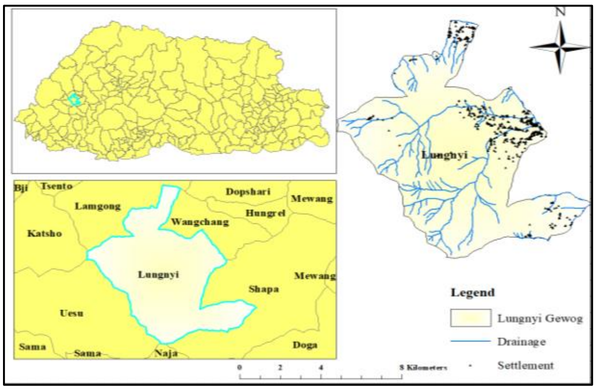


Figure 1: Study area-Lungnyi Gewog, Paro Dzongkhag

The Gewog shares its boundary with Shaba Gewogs in the East, Lamgong and Wangchang Gewogs in the North and Naja Gewog and Uesu Gewog in the south and south-west respectively. Though the Gewog is centrally located, agricultural land use is dominated by dry land (~300 acres) closely followed by wetland (~100 acres) cultivation. Agricultural farming and livestock products are major sources of income and livelihood in the study area. Paddy and wheat are the principal cereal crops cultivated while apple, chilli and potatoes are the major cash crops cultivated in the Gewog (MOAF, 2015).

2.1.2 Sample size and sampling design

The study area has a total of 181 households and almost 90% of the households practice agriculture farming. Fifty percent of the population were taken as sample size for the study and individuals from ninety households were interviewed. Circular systematic sampling method was used to select households from each chiwog for the survey. The farmers were selected from the household lists collected by Agricultural Extension officers (AEO) at the Gewog center. A semi-structured questionnaire was deployed focusing primarily on the quantity of 4 selected crops; apple, potato, chilli and rice, traded by farmers of the study area for calculation of NVWT. The availability of water for agricultural production, demographic data, attributes of crops import and maximum water use patterns was also assessed through the questionnaire survey.

$$\mathrm{SWD} = \frac{\mathrm{CWR[n,c]}}{CY\ [n,c]} \qquad \text{(Equation 1)}$$

Here, SWD denotes the specific water demand (m3 ton-1) of crop *c* in country *n*

CWR the crop water requirement (m3 ha-1)

CY the crop yield (ton ha-1).

Crop water requirement CWR (in m3 ha-1) is calculated as:

$$ETc = ET0 \times Kc \qquad \text{(Equation 2)}$$

ET0 = reference crop evapotranspiration’

Kc = crop coefficient

2.2.2 Calculation of virtual water trade flows and the National Virtual Water trade balance.

Virtual water trade was calculated as follows (Hung, 2002)**:**

$VWT\,[n_e, n_i, c, t] = CT\,[n_e, n_i, c, t] \times SWD\,[n_e, c]$ (Equation 3)

The gross virtual water import to a country n_i is the sum of all imports:

$GVWI\,[n_i, t] = \sum VWT\,[n_e, n_i\, c, t]$ (Equation 4)

The gross virtual water export from a country n_e is the sum of all exports:

$GVWE\,[n_e, t] = \sum VWT\,[n_e, n_i, c, t]$ (Equation 5)

The NVWT of country *x* for year *t* can thus be written as:

$NVWT\,[x, t] = GVWI\,[x, t] - GVWE\,[x, t]$ (Equation 6)

2.2 Secondary data

2.2.1 Calculation of specific water demand per crop type.

The Crop Water Requirement (CWR), Crop Yield (CY) and Specific Water Demand (SWD) were collected from published research papers, articles and reports related to this concept as data on agricultural products SWD had not been assessed in Bhutan. The SWD and CWR guideline of FAO are used for countries where these data are unavailable (Gleick, 1993). The SWD for 4 selected crops were used from the guidelines of FAO that were calculated for China (Table 1). Bhutan and China fall under similar climatic conditions and China has calculated SWD data for almost all crops. The average specific water demand for individual crops is calculated as follows (Hoekstra & Hung, 2002):

Table 1: *Specific Water Demand of selected crops-FAO CWR guidelines (Hoekstra & Hung, 2002).*

Sl. No	Crop	SWD (m3/ton)
1	Apple	822
2	Potato	287
3	Chilli	379
4	Rice	1673

2.3 Data Analysis

The primary data on major crops traded and SWD, GWTI, GWTE, VWT and NVWT were organized and calculated using MS excel. All data sets were subjected to Shapiro-Wilkinson normality test. Descriptive statistics of demography, water utilities and availability water were analyzed using SPSS. Pearson Chi-Square test was used to compare the attributes of crops import with maximum water utility. The relationship between availability of water resources for irrigation and NVWT of individual respondents was assessed using independent sample t-test. The relationship between NVWT of individual and household size and between NVWT and import of selected crops were analyzed using linear regression.

3. Results and Discussion

3.1 Demography, crop production and crop trade.

From the total of 90 respondents, 50 respondents were females and 40 were male. About 84% of the respondents fall between the productive age of 15 to 64 and 16 % of the respondents were above the age of 60 years. The result also shows that 60% of the respondents have household size between 2-5 members and 30% of the respondents have household size between 5-9 members. The crop production increases with increase in members of the household due to sufficient human resource for agriculture.

***Table 2**: Demographic, crop production and crop trade statistics.*

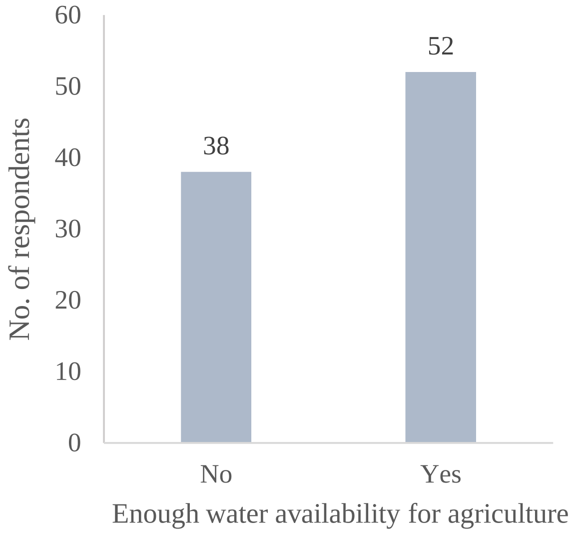
Parameters	Category	Respondents	Percentage
Gender	Female	50	55.6
	Male	40	44.4
Age	15-64	76	84
	64 above	14	16
Household size	2 to 5	54	60
	5 to 9	36	30
Major cash crops grown	Cereals	20	22.2
	Dairy products	19	21.1
	Horticulture	1	1.1
	vegetables	50	55.6
Idea about VWT	Yes	Nil	Nil
	No	90	100
Import crops	Yes	90	100
	No	Nil	Nil
Export cash crops	Yes	87	96.7
	No	3	3.3

The major crops grown were cereals for 22.2% of the respondents, dairy products for 21.1% of respondents, horticulture for 1.1% and vegetables for 55.6% of the respondents. It was observed that none of the respondents (Nil) have any idea about the VWT and all (100%) of the respondents import crops for consumption.

Moreover, the results shows that 96.7% of the farmers export crops where as 3.3% of the respondents does not export any crops and practice subsistence farming.

3.2 Water availability for agriculture and water utility patterns.

It was observed that 42.2% of the respondents does not have enough water for irrigation whereas 57.7% of the respondents have enough water for irrigation for agriculture (Figure 2a). According to FAO (2011), almost 92% of the total population in Bhutan has access to improved drinking water. The per capita water in Bhutan was more than 100,000 m^3 and one of the highest in the region (NEC, 2018). About 82.2% of the respondents allocate maximum water for irrigation, 10% for animal chores and only 7.8% of allocate maximum water for drinking water (Figure 2b). The results also shows that 52.2% of the respondent resort to import of crops due to insufficient lands and 38.9% due to insufficient water supply (Figure 2c). The results also shows that 8.9% of the farmers resort to import of crops as it is cheaper than growing locally. The water withdrawal for irrigation and livestock rearing accounts to 318 million m^3/year of water for Bhutan in 2008. The farmers in the study area mostly practice agricultural-farming that focuses on producing cereal crops and vegetables.



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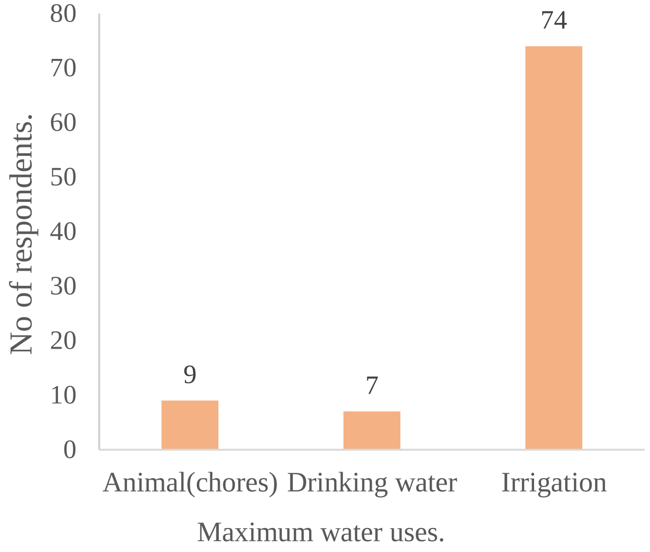

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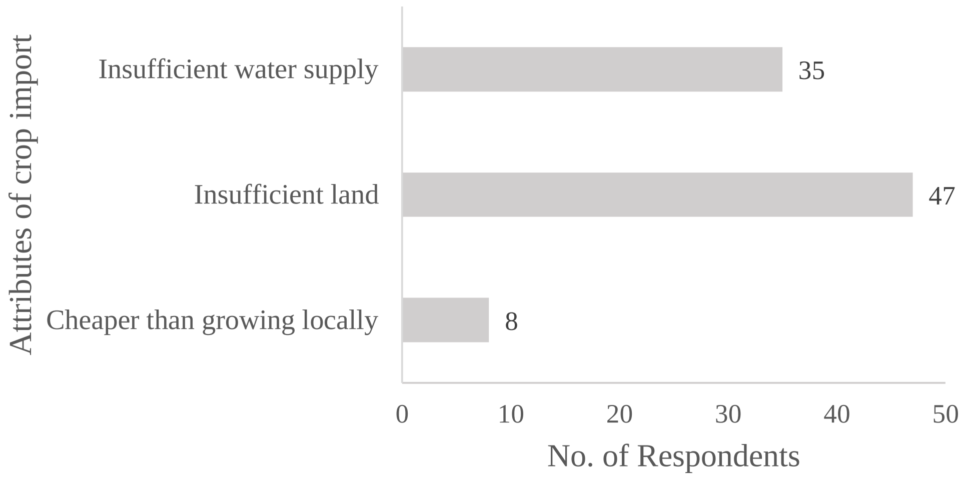

(c)

Figure 2*: (a) Enough water availability for agricultural practice. (b) Respondents maximum water utility for different sectors. (c) attributes of crops import.*

3.3 Trade pattern of selected crops in the study area.

The average quantity of import and export of 4 selected crops by respondents of the study area based on questionnaire survey are shown in Figure 3. The average quantity of apple imported was 0.002 ± 0.002 tons/year whereas the average quantity exported was 1.53±1.253 tons/year. According to Bhutan Trade Statistics (BTS) of 2019, Bhutan imported a total of 165.723 tons of apple, majorly from India whereas, exported 2,517.995 tons of apple to India (MOF, 2019). The highest amount of agri-products export can be attributed to availability of water resources for irrigation and carrying out extensive commercial agriculture. The average quantity of potato exported (0.847 ± 0.904) was also higher than average quantity imported (0.024±0.034) per year for the study area. Bhutan exported 20,134.835 tons and imported 45,875 tons of potato to India in 2020 (MOF, 2020). The result also showed that the average quantity of chilli exported (104.734 ± 134.345) was higher than the average quantity imported (0.012 ± 0.01). Correspondingly, in 2020, Bhutan did not import any fresh chilli whereas exported about 3.175 tons to India. Similarly, the average quantity of rice exported was higher than the average quantity imported (1403.182 ± 2080.889) per year for the study area. However, in 2020, Bhutan imported 90,473.997 of rice from India and 8.106 tons form countries other than India and did not export any rice in 2020 (MOF, 2020). The NVWE of rice was 32 billion[3] in 2018 (Nishad & Kumar, 2022) with positive trade balance and at this rate of net export of water, India may lose its entire available water in less than 300 years (Goswami & Nishad 2015).

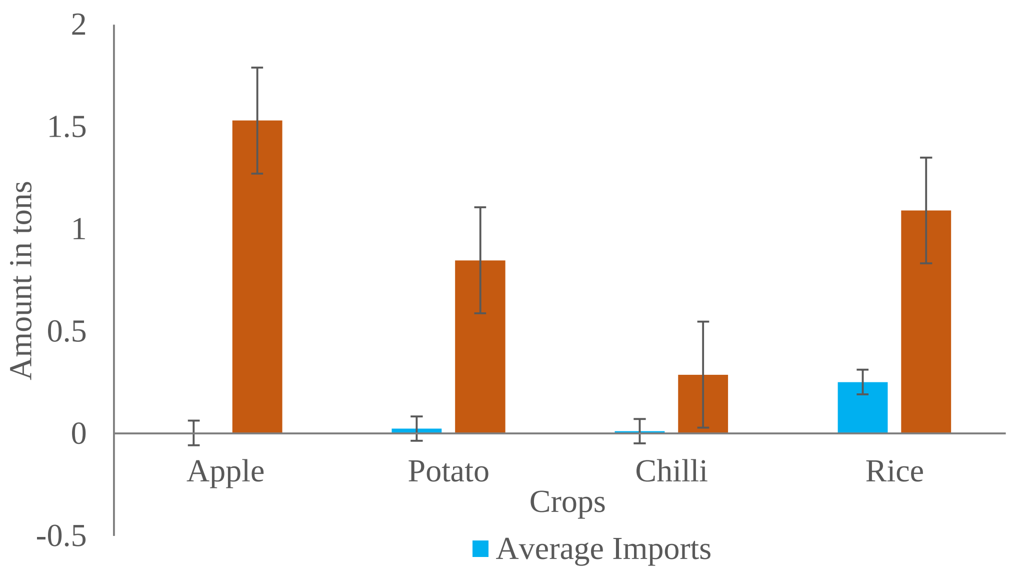

Figure 3: *Mean quantity of selected crops traded per annum in tons of the study area.*

3.4 Net Virtual Water Trade of selected crops for the study area.

The calculated per annum VWI, VWE and NVWT for 4 selected crops for the study area is shown in Table 3. The NVWT results demonstrates positive NVWT with higher GVWE than GVWI and are losing virtual water through trade of agriculture products. The total NVWT of respondents of the study area for apple was 21,695 m^3/ton with higher VWE (21,898.1 m^3/ton) than VWI (203.034 m^3/ton) per year. It was also observed that the NVWT of potato was 21,268.135 m^3/ton with lower VWI of 629.965 m^3/ton than VWE of 21898.1 m^3/ton per year. Similarly, the VWI (424.101 m^3/ton) of chilli is lower than export (9850.21 m^3/ton) with NVWT of 9426.109 m^3/ton annually. The results also showed positive NVWT of 126,286.41 m^3/ton for rice with maximum VWE (164,288.6 m^3/ton) than VWI (38,002.195 m^3/ton) per year. The quarter of global cereal trade occurs from water abundant to water scarce countries (Yang & Zehnder, 2007). However, positive NVWT can impede the government and the policy makers in allocation of water resources to primary and other important sectors such as Hydro power projects that bring in more income per unit volume. The intensification of agriculture with less dependence on import effects availability of water resources for other sectors.

Table 3: *calculated per annum VWI, VWE and NVWT of the selected crops for the study area.*

Crops	n	VWI (m^3/ton)	VWE (m^3/ton)	NVWT (m^3/ton)
Apple	90	203.034	21898.1	21695.066
Potato	90	629.965	21898.1	21268.135
Chilli	90	424.101	9850.21	9426.109
Rice	90	38002.195	164288.6	126286.41

3.6 Net Virtual Water Trade and Water availability.

The independent sample t-test showed significant difference in total NVWT of the respondents who have enough water for irrigation (m=2565.67, SE=351.9) and who does not have enough water (m=1191.06, SE=263.12) for irrigation; $t_{(88)} = 3.129,$

p=0.002. The significant difference in the NVWT of the farmers could be due to higher crop production with enough availability of water. However, no significant difference was observed in NVWT of apple for respondents with enough water availability (m=249.636, SE=262.499) and those without enough water (m=229.315, SE=260.301) for irrigation; $t_{(88)}$=0.364,p=0.716. The large export of water-intensive crops in Mediterranean basin is not necessarily due to large water endowments (Fracasso et al. 2016). Kumar and Singh (2005) also found no significant relationship between freshwater availability and NVWT of 146 countries across the world. Similarly, no significant difference was observed in NVWT of potato between respondents who have enough water (m=245.522, SE=263.633) and those who does not have enough water (m=223.708, SE=262.210) for irrigation; $t_{(88)}$=0.389,p=0.699. There were many studies that found regions with inadequate water resources as net exporter of virtual water (Ramirez-Vallejo & Rogers 2004; Verma et al. 2009; Roson & Sartori 2010, 2013). However, the NVWT of chilli is higher (m=129.515, SE=162.021) for the respondents who have enough water for irrigation than those respondents who does not have enough water for irrigation (m=70.823, SE=72.015); $t_{(88)}$=2.318, p=0.023.

Moreover, significant difference was also observed in NVWT of rice between the respondents who have enough water for irrigation (m=1941.001, SE=2368.352) those who does not have enough water (m=667.218, SE=1312.019) for irrigation; $t_{(88)}$=3.255,p=0.002. The regions with higher water resources endowment have higher quantity of production due to efficient water supply for cultivation and irrigation and generally categorized as the gross virtual exporters (Hoekstra & Hung, 2002). Similarly, Yang and Zehnder (2007) found decline in per capita water resources availability as a dominant attribute for import of water-intensive crops in southern and middle-eastern countries. The high SWD of rice (1673 m^3/ton) could be possible explanation for significant difference in NVWT of rice for the respondents with enough and without enough water endowments for irrigation. On average, greater amount of water is lost and exported in the form of virtual water for those who have enough water for agriculture than for those who does not have enough water for irrigation.

3.4 Water availability and attributes of crop import.

The Pearson Chi-Square test showed significant association between availability of water for irrigation and attributes of import of crops of individual respondents; X^2 *(4,* *N=90) = 63.68, p=0.00* (Table 4). The water availability for agriculture practice affects the attributes of import of crops. The number of respondents with insufficient land with enough water availability is 43 respondents whereas 4 respondents have enough water availability and imports crops due to insufficient land. The relation of arable land with available water resources should also be considered as a variable affecting the virtual water flows (Kumar & Singh, 2005). It was observed that many of the humid, water-rich countries cannot produce surplus food and feed the water scarce nations and virtual water often flows out of water-poor, land rich countries to land-poor water-rich countries (Singh, 2005). However, Tamea et al. (2014) found GDP and distance as central factors for VWT and no significant relation was found with arable land. It was also observed that 33 respondents do not have enough water and imports crops due to insufficient water supply whereas only 2 respondents have enough water and imports crops due to insufficient water supply. This could be due to farmers having enough water for subsistence farming and who does not grow cash crops for trade. The results also shows that 7 respondents have enough water and imports crop due to cheaper prices whereas 1 respondent does not have enough water and imports crops due to cheaper prices.

Table 4: *Contingency table showing count data for water availability and import of crops.*

Parameter		**Attributes of crops import**			
		Cheaper than growing locally	Insufficient land	Insufficient water supply	Total
Water availability for agriculture practice.	Yes	7	43	2	52
	No	1	4	33	38
	Total	8	47	35	90

In most of the European countries, the import of the food has been inversely correlated with water scarcity (Hoekstra, 2002). The insignificant association between attributes of agri-products import and maximum utility of water could be regarded for the indicators such as “cheaper than growing locally”. The result also shows majority (55.5%) of the farmers have vegetables as cash crops that are seasonal that leads to scarce productivity during winter. According to the agricultural statistics of Bhutan 2019, 2,960,252.725 tons of vegetable products were exported but imported 4,021,235.122 tons of vegetable products in 2020 from India only (MOF, 2019).

3.7 VWI and VWE in relation to household size.

The correlation of household size with VWI and VWE of the 4 crops of the individual respondents of the study area are given in Table 4. There was strong correlation between household size and VWI of apple (r=0.533, p=0.000) and also strong correlation was observed between the VWE of apple (r=0.498, p=0.000) and household size. Similarly, there was also strong correlation between household size and VWI of rice (r=0.560, p=0.000) and between VWE of rice (r=0.426, p=0.000) and household size. It was observed that the correlation of household size is stronger for VWI of than VWE of apple and rice. The requirement of intensive arable land for apple orchards and paddy cultivation and huge dependence of land size on their productivity could be possible explanation for weaker correlation of household size with VWE compared to VWI. According to MOAF (2015), the highest agri-product imported in 2015 mainly comprised of rice and vegetable. The household size has more effect on the consumption than on production as the latter is dependent on variables such as water availability, arable land and labor productivity of the family members. The result showed no significant correlation of household size with VWI of potato (r=0.089, p= 0.402) whereas very strong correlation was found between household size and VWE of potato (r=0.746, p=0.000). Similarly, no significant correlation was found between household size and VWI of chilli (r= 0.045, p=0.675) whereas household size had very strong correlation with VWE of potato (r=0.746, p=0.000). The labor productivity of the household increases by 0.21 units for every unit increase in the household member (Urgessa, 2015). The VWT between Iran and other countries would increase by 41 to 66% in the periods of 2016-2045 and 2070-2099 under the population growth rate of 0.98 and 0.44% respectively (Ashktorab & Zibaei, 2022). The enough availability of water for agriculture in the study might be a contributing factor for significant relationship between NVWT and household size, otherwise, the agricultural productivity could be low even with higher household size without enough water for agriculture.

Table 5: *Correlation of VWI and VWE of the 4 crops with household size.*

	Apple		**Potato**		**Chilli**		**Rice**	
	r	p	r	p	r	p	r	p
Household Size and VWI	0.553	0.000*	0.089	0.402	0.045	0.675	0.56	0.000*
Household Size and VWE	0.498	0.000*	0.746	0.000*	0.456	0.000*	0.426	0.000*

*Correlation significant at 0.01

4. Conclusion

The study showed that majority of the respondents have enough water endowments for intensive and profitable agriculture practice. The maximum utility of water in the study area were predominantly for irrigational purpose, fewer for animal chores and least for the drinking water purpose. It was found that majority of the respondents import crops due to insufficient land for agriculture practice and fewer due to water unavailability of enough water supply and economic reasons. The average quantity of crop export is higher than import for all 4 crops. The total NVWT of the 4 selected crops for the respondents was positive with more GVWE than GVWI for the study area. The study area was losing virtual water through trade of these crops. However, positive NVWT can streamline the water use towards agriculture and make it difficult for the policy makers in allocation of water for other primary sectors that have more income per unit volume. There was no significant difference between availability of enough water for the respondents and total NVWT of apple and potato. However significant difference was observed between availability water for the respondents and NVWT of chilli and rice. The regions with higher water resource endowment have greater production capacity and many studies found declining per capita water availability as dominating attribute for crop import. The study also found significant association between availability of water for irrigation and attributes of import of crops.

The study was localized to only Lungnyi Gewog and further research of NVWT of all the Gewogs in Bhutan will be beneficial in regionalizing and documenting more inferences on the VWT of the country. Assessment of the regional flow of virtual water within a country is nifty for proper distribution and allocation of the developmental activities that utilizes high amount of water resources there in achieving efficient water management. The availability of climatic data on the CWR and SWD of Bhutan will allow to make greater inferences on virtual water trade where in the benefits of the water conservation by importing agri-products and water loss by exporting agri-products can be precisely quantified. Moreover, the NVWT of the industrial products of Bhutan has not been studied yet as well which can also be quantified precisely on basis of this concept VWT.

5. Recommendations

The NVWT of the agriculture products is the indicator for water resources flow in the agricultural system. It is now timely that the research and development centers of Ministry of Agriculture and Forests and related agencies to collect SWD and CWR for crops in Bhutan. These data can be used in enhancing the efficiency of the water resource utility in changing climatic system for agricultural production. The quantity of yield for specific crops in metric tons that can be produced from the amount of water available in Bhutan needs to be quantified. Currently, it is certain that the rural areas like Lungnyi Gewog have higher NVWE than NVWI and water is being intensively used for agriculture practice which diverts its utility from other sectors. The policy makers and regulatory agencies should take this into consideration while identifying other sectors that have higher income per unit volume. However, it can be foreseen that Bhutan will have negative NVWT with higher NVWI than NVWE in the urban areas. It is also worth noting for the policy makers that the negative NVWT with higher NVWI than NVWE reimburses the economy with greater allocation of water resources in Hydropower projects. The policy makers can also take into consideration that insufficiency of land holdings are greater attributes compared to water availability for agricultural productivity.

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