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The estimation and optimization of socio-economy-environment response on West Timor's staple food consumptive water use

Jonathan E. Koehuan

Department of Agricultural Engineering, Faculty of Agricultural Technology, The Artha Wacana Christian University,
Kupang 85228, NTT, Indonesia

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Abstract

Crop consumptive water use (CWU) is a key factor in sustainable agricultural water management. However, there has been rare discussion on the broader factors affecting CWU particularly in semi-arid region. The aim of this paper was to determine the West Timor main food consumptive water use (CWU_{Food}), to model and to optimize the effect of socio-economy-environment on CWU and food production. This study applied a sixteen-year balanced climate and non-climate panel data. The estimated method is based on crop evapotranspiration by FAO-PM method. The modeling and optimization using response surface methodology (RSM). The results showed that West Timor traditional subsistence agriculture experienced fluctuation and increasing water consumed by main food during 2000 – 2015 that averaging reached 572 Mm^3/year in which corn had consumed total water much higher than paddy. Model evaluation proved that a reduced quadratic model was robust. The amount of rainfall, farmer expenditure, district and part of their interactions had significant responses towards CWU_{Food} and Food Production. In addition, the optimized result showed that by 25% reduction of CWU_{Food} impacted on 33.18% reduction of maximum food production that equivalently with 111.22% increased from mean food production.

Keywords: Corn, Paddy, Panel data, Crop water use, Response surface methodology, Water saving

1. Introduction

One of the prime concerns in this century is the sustainable use of agriculture water; the challenge is how to increase food production while protecting the environment. Li et al. [1] stated that crop water consumption is a prominent factor to crop growth and its production particularly in semi-arid region where annual rainfall is sparse and unevenly temporal distribution take place. Blaney and Criddle [2] assert that CWU is the amount of water used to build plant tissues; it retains in plant and is evaporated from nearest soil and water bodies. CWU is expressed in a unit of water volume per unit area and for practical purposes; CWU is identical with evapotranspiration. There are two main methods for estimating evapotranspiration that are direct and indirect method. The direct method is based on mass balance or energy balance. The main advantage is an *in situ* accurate result. However, Arayaa et al. [3] argue that direct methods are time consuming, expensive, ineffective in long term analysis and the data tend to influence by crop, soil and weather throughout measurement period. The indirect method, on the other hand, is utilized to fill the disadvantages of the previous method. The widely used is the empirical approach based on a crop coefficient and climatic data [4]. In order to predict CWU on the large scale and longer term, the other appropriate approach is by using statistical data [5].

Realizing the importance, the complexity and the degradation of natural resources, Laniak et al. [6] insist that nowadays there is a need to understand the environment well with taking into consideration the social and economic aspects in their dynamic interconnections. In order to study the response of independent variables and its interactions on dependent variables, a response surface methodology (RSM) is appropriate.

Box and Wilson introduced RSM in 1951. The response surface methodology is a compilation of statistical and mathematical techniques beneficial in the analysis of responses with an ultimate goal to optimize the response [7]. Kostić et al. [8] was conducted a study in the development of rainfall-runoff model using secondary data with RSM historical data design. This study concluded that rainfall (1.80 mm - 157.90 mm) and air temperature (-7.00^{0C} - 24.80^{0C}) significantly has linear, quadratic, and cubic impact on flow rate. Graveline [9] based on literature review of agriculture production economic model, proposes the interconnection research regarding hydro-agronomic-economic model using RSM.

In terms of the West Timor agriculture, prime food crops have been corn and rice that are cultivated by mostly subsistence traditional farmers in dry land cropping system. Shifting cultivation still dominates the cultivation of main food. It has been believe that the environment and local culture affected the cultivation system. The island also strongly affected by the El Niño Southern Oscillation (ENSO) cycle. Moreover, Timor Island has a complex topography that causes a variability of rainfall [10]. Semi-arid climate dominated the agriculture in this region, where extreme dry season extend from April to November caused by south-east monsoon from Australia affected plant growth which lead to plant failure as frequent as one year in five [11].

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*Corresponding author.
Email address: jekoehuan@gmail.com
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Despite in the past 10 years the West Timor region has experienced an increase in rice and corn production by 10% and 1% annually respectively. However, there are 7% of districts in this region were classified as high vulnerable (priority 2) and 23% of the districts were categorized as moderately vulnerable (priority 3) [12]. These imply that some of the population was struggling with food adequacy.

Realizing the importance of food for people who living in semi-arid that similar with West Timor region concurrently to fill the gap of the appropriate method in estimating and modeling the broader factors affecting CWU and crop production that based on publicly available and inexpensive statistical data to cover a large administrative area. This study was furthermore focus on estimating the main food water use, modeling and optimization the simultaneous influence of socio-economic-environment factors to meet water saving target and the implication for food production.

2. Materials and methods

2.1 Research location

The research location was in West Timor, a part of the East Nusa Tenggara Province (NTT) - Indonesia, located at 123^0 27' 40" - 125^0 11' 59" East Longitude and 08^0 56' 17" - 10^0 21' 56" South Latitude that consists of four districts include Kupang district, South Central Timor (TTS) district, North Central Timor (TTU) district and Belu district; and a municipal namely Kupang municipal. The research location map is presenting in the Figure 1.

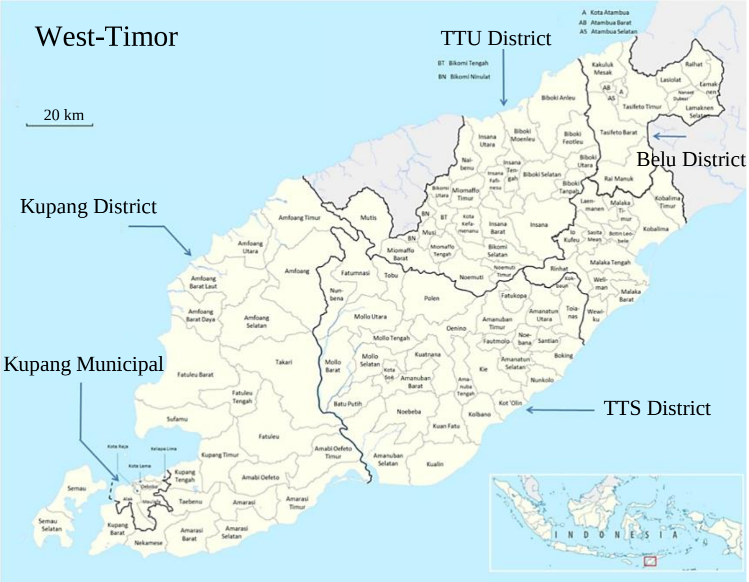


Figure 1 Maps of Research Location (West Timor)
Source: wikimedia.org [13]

The topography of Kupang District consists of mountainous, hilly and highland areas in which an altitude of 150 - 500 meters above sea level (MASL) dominate this district (41.55%). Most of the slopes are between 15° - 40° (44.26%). The topography of Kupang municipal consists of the highest altitude of 100-350 MASL, mostly in the southern part. The lowest areas 0-50 meters above sea level are mostly in the northern part. The average slope rate is 15 percent. The TTS District is generally located at an altitude 500 MASL (51%). TTS District has the highest peak on Timor Island and NTT Province at 2,477 MASL (Mount Mutis). The slope of 8-25% dominates the TTS district (49.39%). Most of the TTU District area is at an altitude of 100 – 500 MASL (56.17%). Areas with a slope of less than 40% dominate the slopes in TTU District (77.4%). The topography of the Belu District area is a plain area with hills to mountains. The altitude varies between 0 - 1500 MASL, dominated by medium plains (200-500 MASL) [14].

2.2 Data sources and preparations

This study used secondary panel data of climate and non-climate data from 2000 to 2015. The climate panel data include monthly rainfall, maximum, minimum, and average air temperature, humidity, and wind speed. In the region, only Kupang had all the climate data provided by Lasiana Climate station ($10^0$08'19"SL; $123^0$40'02") at the elevation of 19 m above mean sea level (MASL) , while the others districts only provide rainfall and air temperature data. A normal ratio method was applied to fill the climate missing data [15]. With regard to the consistency test, a Rescaled Adjusted Partial Sums (RAPS) or Buishand Test is applied. This method is appropriate for the developing countries. The consistency was determined by lower value of RAPS compared to RAPS table value [16].

The non-climate data provided by NTT Provincial Bureau of Statistic [14], except for the average crop planting time, which was from Runtunuwu et al. [17], and crop coefficient, which was from Indonesian Directorate General of Water Resources [18]. Data preparation was conducted in order to get balanced panel data and to meet the consistency and normal distribution. A two-point Lagrange interpolation applied for the missing value. A normality test using Shapiro-Wilk test is applied; the test is suitable for small data. This procedure was carried out with the help of SPSS version 19. Coefficient of variance (CV) is the percentage ratio of standard deviation to mean was used to indicate the variation of the data.

2.3 Crop Water Use (CWU) estimation

CWU is an evapotranspiration from the crop growing areas. The estimation method was modified from Alauddin and Sharma [19] that applied by Koehuan et al. [20, 21]. The estimation meets the following equations.

$$CWU_{Food} = CWU_{paddy} + CWU_{corn} \quad (1)$$

$$CWU_{Paddy} = HA_{Pd}\left[\sum_{j\varepsilon mth}\sum_{i\varepsilon period} \min\left(Kc_{Pd} \text{ x } ETo_j, EFFRF_j\right) \text{x } \frac{d_{ij}}{n_j} + \sum_{j\varepsilon mth}\sum_{i\varepsilon period}\left(Kc_{Pd\text{-}i} \text{ x } ETo_j\right) \text{x } \frac{d_{ij}}{n_j}\right] \quad (2)$$

$$CWU_{Corn} = HA_{corn}\left[\sum_{j\varepsilon mth}\sum_{i\varepsilon period} \min\left(Kc_{corni} \text{ x } ETo_j, EFFRF_j\right) \text{x } \frac{d_{ij}}{n_j} + \sum_{j\varepsilon mth}\sum_{i\varepsilon period}\left(Kc_{corn\text{-}i} \text{ x } ETo_j\right) \text{x } \frac{d_{ij}}{n_j}\right] \quad (3)$$

Remarks: HA_{Paddy} and HA_{Corn} were harvested area of paddy and corn respectively. $Kc_{paddy\text{-}i}$ and $Kc_{corn\text{-}I}$ were crop coefficients of paddy and corn respectively. ETO_j and $EFFRF_j$ were references of evapotranspiration and effective rainfall respectively.

Since the main food in West Timor consists of paddy (*Oryza sativa* L.) and corn (*Zea mays* L.), the CWU_{Food} was the sum of CWU_{Paddy} and CWU_{Corn}. Indonesian Directorate General of Water Resources [18] provides a crop coefficient (Kc) of paddy and corn that suitable for the condition of this study area that having a growing period of 120 days and 80 days respectively. The value of Kc of paddy and corn is presented in Table 1.

Table 1 Crop coefficient (Kc) of paddy and corn

No.	Crops	Growing period (days)	Fortnight period of:							
			1	2	3	4	5	6	7	8
1	Paddy (Common varieties)	120	1.10	1.10	1.10	1.10	1.10	1.05	0.95	0
2	Corn	80	0.5	0.59	0.96	1.05	1.02	0.95		

Source: Indonesian Directorate General of Water Resources [18].

The reference evapotranspiration (ETo) was estimated based on FAO Penman-Montieth method that taking into consideration the main climate factors of air temperature, humidity, radiation, and wind speed. The estimation of ETo was carried out with the help of FAO ETo calculator open access software [22].

The effective rainfall was estimated based on a 75 percent exceedance probability of monthly rainfall. The effective rainfall is expressed as follow.

$$EFFRF_{E,F} = AMR_{A,F} \text{ x } [1-(0.25 \text{ x } AMR_{A,F})/125] \text{ if } AMR_{A,F} \leq 250 \text{ mm or} \quad (4)$$

$$EFFRF_{E,F} = 125 + (0.1 \text{ x } AMR_{A,F}) \text{ if } AMR_{A,F} \geq 250 \text{ mm} \quad (5)$$

Remarks: $EFFRF_{E,F}$ was effective rainfall; $AMR_{E,F}$ was an average monthly rainfall of a particular year (E) and district (F) respectively.

2.4 Model development, evaluation, and optimization

The development, evaluation and optimization of multi input – multi response model that consists of six inputs and six responses was using Response Surface Methodology (RSM). The independent variables (IDVs) consisted of environment variables include the volume of rain water (million m^3) and food cultivated areas (thousand Ha). The volume of rainfall was the average monthly rainfall (mm) multiply by the districts area (m^2). The food cultivated area (ha) was the sum of paddy and corn cultivated area. The Human Development Index (HDI) indicated the social variable that intended to explain the quality of farmers. Farmer expenditure in (billion IDR) indicates the economic variable that estimated as follow.

$$FEXP_{E,F} = FRM_{E,F} \text{ x } (FDEX_{E,F} + SGEX_{E,F} + DGEX_{E,F}) \quad (6)$$

Remarks: FEXP refers to farmer expenditure; FRM refers to farmers; FDEX refers to expenditure for food; SGEX refers to expenditure for services and goods; DGEX refers to expenditure for durable goods; E refers to district; and F refers to year.

Independent variable Year denote years of observation from 2000 to 2015. Independent variable District denotes the location that expressed in numerical value of 1 for Kupang District; 2 for TTS district; 3 for TTU district; 4 for Belu districts; and 5 for Kupang municipal.

The responses variables were the estimated CWU_{Paddy}, CWU_{Corn}, CWU_{Food}, Paddy-production, Corn-production and Food-production. Food-production was the sum of paddy and corn production in rice bases. The conversion of corn production becomes rice equivalent was using a comparison of consumer price of corn and rice in Kupang municipal market prices.

The model was developed with Historical Data Design (HDD) of RSM using the Design Expert 7.0 trial version. The models were developed in three phases, phase one was linear model development and to be upgraded using backward selection to form linear with interaction (2FI) model subsequently to be upgraded to form a reduced quadratic model. The model evaluation was intended to select the best model that was based on model significance test, multiple coefficients of determination (R^2), an adequate precision, and a residual analysis.

The best model subsequently was optimized to meet agricultural water saving with minimum impact on crop production. Six input variables were numerical optimized to reduce CWUs while maximized crop productions. Five input variables were set to be in range except food cultivated areas was set to be maximum. CWUs was targeted to 25% reduce that in line with the study by Yan et al. [23], to save 25% water for agriculture in Hai Basin Plain, China. In this study, all three responses of crop production were setting to maximum. This intended that the inputs were not much shifting that typically happen in the traditional farming system. Additionally, the effect of agricultural water saving management should not jeopardizing crop production that badly needed by the population.

The potential amount of agriculture water saving was approximated by the subtractions of maximum CWUs values with optimal CWUs values. The potential impacts for the productions were approximated with the formulas below.

$$\text{Max Impact} = \left({}^{(\text{Max prod-Opt prod})}\big/_{\text{Max prod}} \right) \text{ x } 100\% \tag{7}$$

$$\text{Mean Impact} = \left({}^{(\text{Opt prod-Mean prod})}\big/_{\text{Mean prod}} \right) \text{ x } 100\% \tag{8}$$

Remarks: Max Impact = the impact to maximum production; Mean Impact = the impact to mean production; Max prod = Maximum production (Ton/year); Opt prod = Optimized production (Ton/year); Mean prod = Mean production (Ton/year).

3. Results and discussion

3.1 The overview of food production system

Based on Census of Agriculture in 2013 by Statistical Bureau of NTT Province [24, 25] which West Timor is the part of NTT Province, it shows that most of paddy households use hybrid seed (68.87%) while corn households mostly using local seed (92.92%). About 44.11% of paddy households utilizing tractors in land preparation by which majority using rented hand tractors, only 5.44% corn households using tractors in land preparations. In terms of fertilizer application, 60.14% of paddy households applied inorganic fertilizer, contrast with 14.74% of corn households. Paddy households that conducted pest control reach 74.86% compared to 22.87% of corn households.

About half of the farmers experience climate change and natural disaster in the forms of drought and high intensity rain. It accounted 48.47% and 57.51% for paddy and corn households respectively. In terms of external funding sources, paddy farmers (74.46%) rely on individual loans and cooperative while corn farmers (50.87%) rely on individual loans with interest. Most of the farmers harvest themselves, 92% and 98% for paddy and corn households respectively. Most of the productions are for the consumption that consists of 84.75% and 86.80% for paddy and corn households respectively [24, 25].

In terms of climate data, based on a Rescaled Adjusted Partial Sums (RAPS) results indicate that the climate station and rain observation posts have RAPS value lower that RAPS table (16, 95%) of 1.188. This implies that all of the stations had a consistent data. TTS district had highest value of rainfall while Kupang district and Kupang municipal had the lowest. In terms of rain variability that indicated by the coefficient of variance (CV) values, TTU District had the highest variability compared to Kupang district and Kupang municipal that had the lowest variability. In terms of other climate components, wind speed had the highest variability compared to the average air temperature that had the lowest. The summary of the climate data is presented in Table 2.

Table 2 The summary of climate data

Station/Locations	**Components**	**Mean**	**Std. Dev**	**CV (%)**	**RAPS**
Kupang climate station ($10^0 08^{'} 19^{''}$SL; $123^0 40^{'} 02^{''}$ EL/ 19 m msl)					
Kupang District	Rainfall (mm/year)	1,567.73	303.07	19.33	0.499
	Rainfall (mm/month)	131	25.26	19.33	
	Average Air Temperature (^{0}C/month)	27	0.26	0.96	
Kupang Municipality	Maximum Air Temperature (^{0}C/month)	32	1.01	3.11	
	Minimum Air Temperature	23	0.86	3.80	
	Air Humidity (%/month)	76	5.44	6.92	
	Wind Speed 2 m (knot/month)	6	1.58	25.38	
	Effective Rainfall - EFFRF (mm/month)	64	6.65	10.40	
Soe rain observation post (742 m msl)					
TTS District	Rainfall (mm/year)	2,183.19	447.16	20.48	0.514
	Rainfall (mm/month)	182	37.26	20.48	
	EFFRF (mm/month)	87	14.30	16.43	
Kefamenanu rain observation post (381 m msl)					
TTU District	Rainfall (mm/year)	1,171.56	361.81	30.88	0.787
	Rainfall (mm/month)	108	42.75	39.51	
	EFFRF (mm/month)	63	14.36	22.74	
Atambua rain observation post (53 m msl)					
Belu District	Rainfall (mm/year)	1,712.13	468.18	27.34	0.739
	Average Rainfall (mm/month)	143	39.02	27.35	
	EFFRF (mm/month)	74	11.17	15.11	

With regard to non-climate (agricultural, social and economic) data, based on the Shapiro-Wilk Test indicates the statistical values excess tables' value at 95% confidence interval. It implies that all of the data had a normal distribution in 95% confidence interval (sig. > 0.05). The data varies indicated by the coefficient of variation (CV) revealed that farmer expenditure and crops production had a stark variation. It appears that the variations were affected by years, districts, climate and other conditions.

During 2000-2015 rice production in West Timor in average reached 67,594 ton/year that production was dominated by Kupang district that reached 30,983 ton/year (46%). The least rice production with the highest fluctuation was Kupang municipal (CV = 41.31%). In terms of corn production, TTS districts had the biggest share with the mean production of 144,593 ton corn kernel/year (45%), the least producer was Kupang Municipal and the highest fluctuation was in Belu District.

The average rice consumer price was IDR 5,315 /kg while IDR 3,182/kg for corn kernel, corn price (CV= 52.66%) was more fluctuated than rice price (CV = 45.80%). The average ratio of corn price to rice price was 0.580. Subsequently the mean food production in West Timor during that time equal to 257,104 kg rice/year with TTS District had the biggest contributor (36%) and the least was Kupang Municipal (0.5%) while Belu District had the highest production fluctuation (CV = 33.5%). The summary of non-climate data is presented in Table 3.

Table 3 The summary of non-climate data

Locations	Components	Mean	Standard Deviation	CV (%)	Shapiro-Wilk Test (Sig.)
Kupang District	Paddy cultivated area (ha/year)	20,028	2,720	13.59	0.095
	Corn cultivated area (ha/year)	25,222	4,389	17.40	0.611
	Food cultivated area (ha/year)	45,250	4,401	9.73	0.222
	Paddy harvested areas (ha/year)	15,753	3,449.52	21.90	0.051
	Corn harvested areas (ha/year)	22,532	3,906.29	17.34	0.106
	Rice Production (ton/year)	30,982.750	11,909.293	38.438	0.440
	Corn Kernel Production (ton/year)	54,580.500	9,397.246	17.217	0.721
	Food Production (ton rice/year)	62,990.738	13,417.752	21.301	0.271
	Human Development Index (HDI)	64.17	3.41	5.32	0.266
	Farmer expenditure (MIDR/year)	265,507	93,498	35.22	0.311
TTS District	Paddy cultivated area (ha/year)	4,769	1,156	24.25	0.689
	Corn cultivated area (ha/year)	63,772	8,614	13.51	0.581
	Food cultivated area (ha/year)	68,541	9,035	13.18	0.412
	Paddy harvested areas (ha/year)	3,563.69	586.66	16.46	0.515
	Corn harvested areas (ha/year)	59,634.81	9,508.22	15.94	0.896
	Rice Production (ton/year)	7,339.623	1322.121	18.013	0.061
	Corn Kernel Production (ton/year)	144,593.375	27713.675	19.167	0.638
	Food Production (ton rice/year)	92,183.527	25699.730	27.879	0.163
	Human Development Index (HDI)	63.83	3.16	4.95	0.123
	Farmer expenditure (MIDR/year)	352,301	177,449	50.37	0.089
TTU District	Paddy cultivated area (ha/year)	10,732	2,902	27.04	0.074
	Corn cultivated area (ha/year)	21,966	3,099	14.11	0.402
	Food cultivated area (ha/year)	31,598	5,156	16.31	0.111
	Paddy harvested areas (ha/year)	9,187.56	3,090.73	33.64	0.346
	Corn harvested areas (ha/year)	20,864.88	3,591	17.21	0.258
	Rice Production (ton/year)	16,098.003	5,330.915	33.115	0.853
	Corn Kernel Production (ton/year)	49,412.313	9,978.251	20.194	0.589
	Food Production (ton rice/year)	45,658.806	13,890.836	30.423	0.084
	Human Development Index (HDI)	65.29	3.42	5.24	0.126
	Farmer expenditure (MIDR/year)	160,965	65,723	40.83	0.194
Belu District	Paddy cultivated area (ha/year)	7,349	982	13.37	0.988
	Corn cultivated area (ha/year)	36,158	6,968	19.27	0.105
	Food cultivated area (ha/year)	43,507	6,970	16.02	0.106
	Paddy harvested areas (ha/year)	6,140.31	1,596.72	26.00	0.461
	Corn harvested areas (ha/year)	31,241	5,422.43	17.36	0.906
	Rice Production (ton/year)	12,639.906	4,577.543	36.215	0.097
	Corn Kernel Production (ton/year)	71,891.688	21,266.147	29.581	0.122
	Food Production (ton rice/year)	54,524.780	14,508.570	26.609	0.923
	Human Development Index (HDI)	62.59	3.26	5.20	0.304
	Farmer expenditure (MIDR/year)	233,849	117,751	50.35	0.112
Kupang Municipality	Paddy cultivated area (ha/year)	302	54.34	17.96	0.798
	Corn cultivated area (ha/year)	493	124.20	25.21	0.761
	Food cultivated area (ha/year)	795	90.91	11.43	0.443
	Paddy harvested areas (ha/year)	243.64	73.75	30.27	0.252
	Corn harvested areas (ha/year)	455.10	87.80	19.29	0.356
	Rice Production (ton/year)	534.111	220.637	41.309	0.056
	Corn Kernel Production (ton/year)	1,051.625	237.806	22.613	0.322
	Food Production (ton rice/year)	1,183.243	305.281	25.800	0.065
	Human Development Index (HDI)	75.11	3.70	4.93	0.128
	Farmer expenditure (MIDR/year)	15,601	6,476	41.51	0.144

3.2 Crop Water Use (CWU) estimation

The estimated CWU denoted an increasing and fluctuated trend during 2000 to 2015. The total amount of consumptive water by staple food in West Timor was 9,152.15 Mm^3 with the average of 572 Mm^3/year and 14.20% coefficient of variance. The lowest point during the period was in 2005 (462.52 Mm^3) and it reached a peak in 2013 (756.72 Mm^3). Staple food production in Kupang District used 140.64 Mm^3/year; in TTS District consumed 207.02 Mm^3/year; in TTU District utilized 98.35 Mm^3/year; in Belu District consumed 123.50 Mm^3/year; and in Kupang City utilized 2.50 Mm^3/year, with the CV of each district at 15.79%; 20.28%, 26.12%, 5.8%, and 13.30% respectively. The dynamic of CWU is depicted in Figure 2.

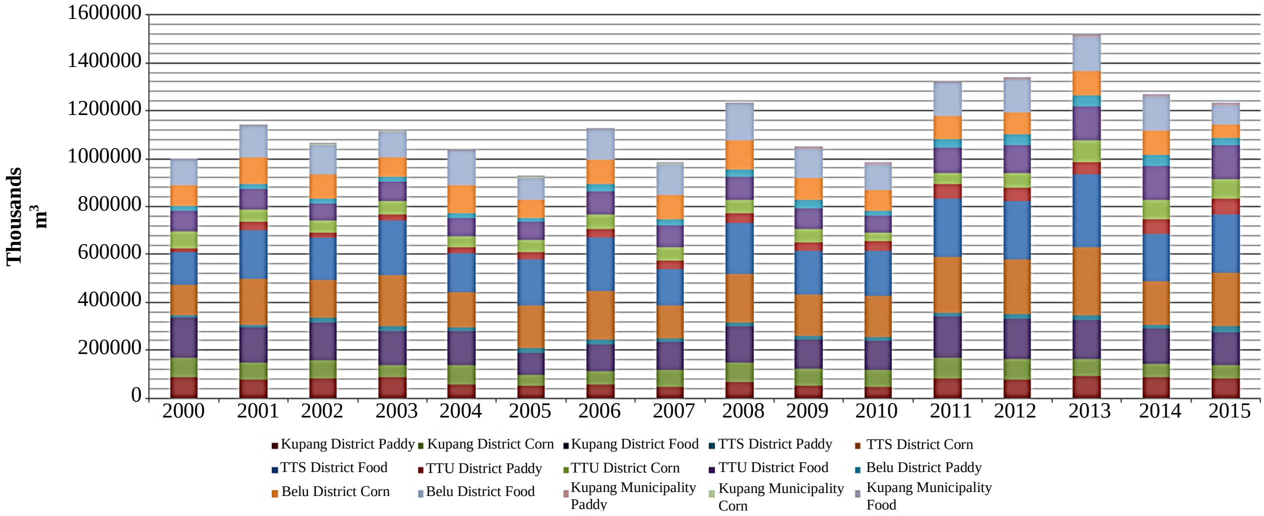


Figure 2 CWU of staple food in West Timor during 2000-2015

The rate of water consumed by major crops in the West Timor Region indicated a fluctuation trend. The most fluctuating rate was in TTS District while the least fluctuated was in Kupang Municipal. TTS District, TTU District, and Kupang Municipal had a positive rate; those districts had an increasing CWU while others have a decreasing CWU. This indicated that the capacity of farmers in managing water for food in West Timor was diverse among districts during the period. The rate of water consumed by staple food in West Timor is presented in Figure 3.

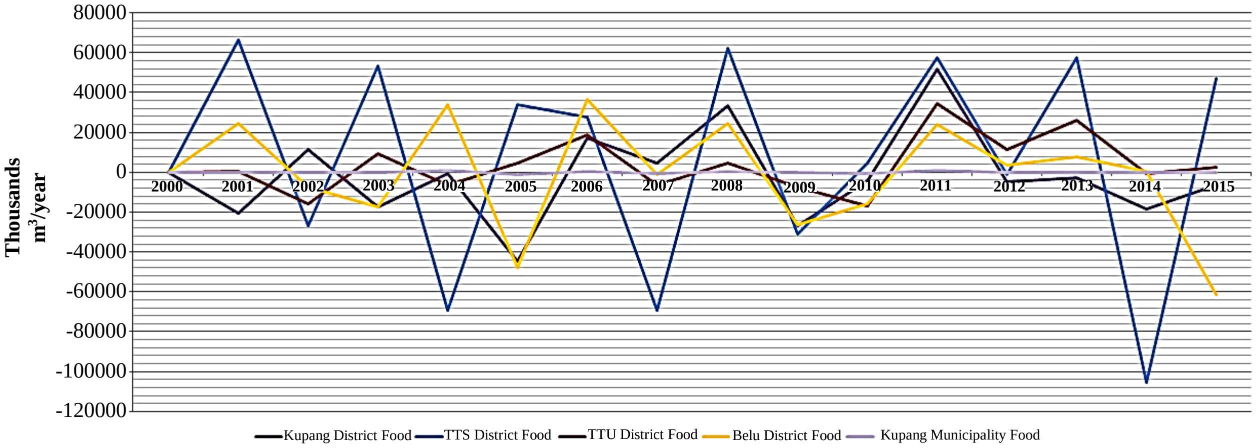


Figure 3 The rate of West Timor staple food CWU during 2000-2015

In West Timor agricultural system, the staple food production depleted about 2.35% of total rainfall volume where TTU and Belu Districts consumed the biggest part. The small portion of total rainfall used in main crops production due to the fact that although the cultivation was mostly in the rainy season, the rainfall intensity and hilly contour tended to transfer most of the rainfall into run-off and evaporation. In addition, the limitations of farmers' knowledge, technology, and economy that indicated in Census of Agriculture in 2013 by Statistical Bureau of NTT Province [24, 25] were constrained their ability to further manage the essential source of agricultural water.

Interestingly, total water consumed by corn on average was greater than water consumed by paddy, as it account for 73% compared to 27%. The percentage was relatively balanced in Kupang District but in TTS District most of the water was consumed by corn. The facts confirmed that most of the farmers preferred to cultivate corn rather than paddy; regardless paddy has become the ultimate food. The culture of corn planting and corn physiology C4 photosynthesis characteristic increase the ability to adapt in dry areas retain its dominance. The comparison of the average amount of rainfall used in food production and its consumption by corn and paddy is shown in Figure 4.

It is interesting to note that water consumed by paddy and corn in West Timor was similar to previous studies of Amarasinghe et al. in India [26] and in Bangladesh [27]. As a consequence the staple food production in West Timor consumed more water than that in India and Bangladesh. Additionally, this finding highlight that in all locations, paddy consumed more unit of water compared to corn [26, 27]. The results then underlined the validity of our estimation approach. The comparison is presented in Table 4.

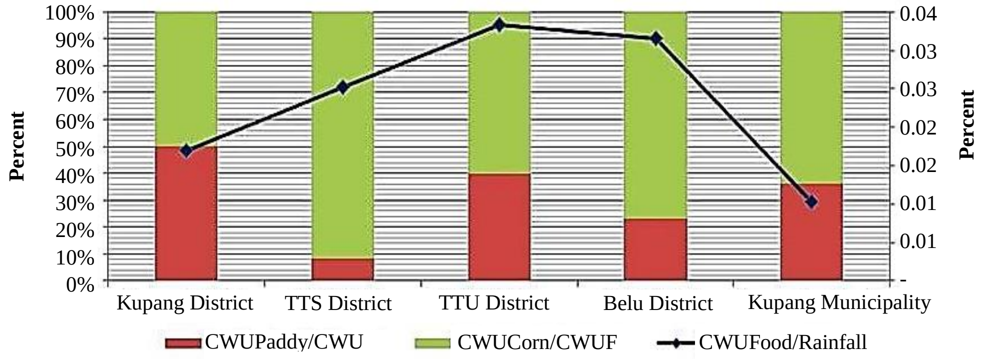


Figure 4 Ratio of CWU$_{Paddy}$ with CWU $_{Food}$, CWU$_{Corn}$ with CWU $_{Food}$ and CWU $_{Food}$ with total rainfall in West Timor in 2000-2015

Table 4 The comparison with related studies in India and Bangladesh

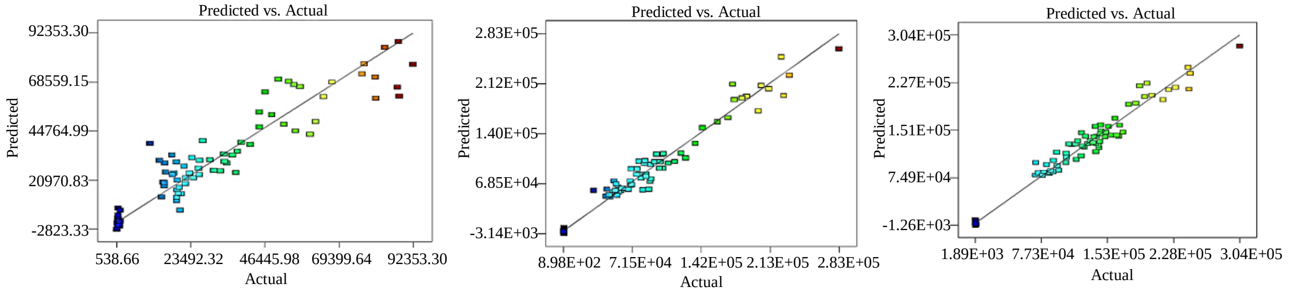
Locations	CWU$_{Paddy}$		CWU$_{Corn}$		CWU$_{Food}$		Sources
	m^3/ha	mm	m^3/ha	mm	m^3/ha	mm	
India	3,961.90	396.19	2,264.15	226.42	6,226.06	622.61	Amarasinghe et al. [26]
Bangladesh	4,995.32	499.53	1430.00	143.00	6,425	642.53	Amarasinghe et al. [27]
West Timor	4,504.75	450.48	3079.13	307.91	7,583.88	758.39	This study

3.3 Model development and evaluation

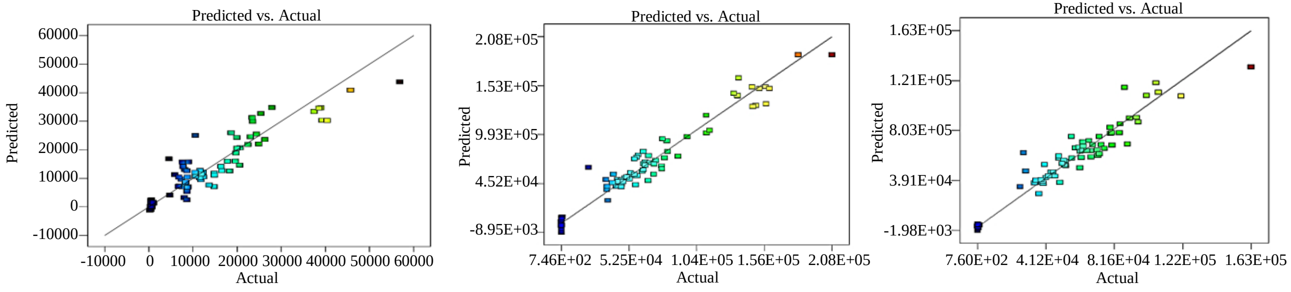
The model consists of six input variables and six responses variables. The model furthermore were developed and upgraded in three phases to select the best fitted to the observed values. The model upgrading was similar with the study by Rai et al. [28] that prefer to recommend the reduced quadratic model as the second order input-responses that proved better fit the data.

The result showed that the reduced quadratic response model performed better in terms of lowest standard deviation, coefficient of variance (CV) and PRESS; had the higher R^2, Adjusted R^2, Predicted R^2, adequate precision and the number of significant model terms. The model evaluation validated that the model provide an adequate representative to the observed data. The reliable model fitted to determine nonlinear relationships between response variables and independent variables that significant at 5% of confidence level (P values < 0.05).

The model had a considerable high multiple determinations (R^2, Adjusted R^2, and Predicted R^2). There were adequate signals to noise; the ratio was exceeding the desired value (Adequate precision > 4). In terms of the residual analysis, the Prediction Error of Sum Squares (PRESS) residual was acceptable. Moreover, predicted versus actual plot, as depicted in Figure 5a-5f, were apparent along a straight line which indicated that normality assumption are satisfied [7, 29].



5a. CWU$_{Paddy}$ 5b. CWU$_{Corn}$ 5c. CWU$_{Food}$



5d. Paddy-Production 5e. Corn - Production 5f. Food- Production

Figure 5 Model predicted versus actual plots

The value of the intercepts were lower compared to the accumulation values of other variables signified that given input variables dominant in explained the responses compared to other factors that not included in the model. Furthermore, in terms of actual factors model parameters are presented in Table 5.

Table 5 Model parameters in actual factors

Variables	$\text{CWU}_{\text{Paddy}}$	CWU_{Corn}	CWU_{Food}	Paddy - Prod	Corn-Prod	Food - Prod
Constant	17464953	2809434.74	47299543.29	14658781.36	7910667.778	2262462.924
Rainfall volume (Mm^3)	-1.014103	1.781	2051.440	-1.045$^{*)}$	1241.432	1295.021
Food cultivated areas (Tha)	-139230.861	10.07$^{*)}$	- 644618.363	- 678.35	-481389.963$^{*)}$	- 274363.904
HDI	1307.826$^{*)}$	2408.08$^{*)}$	30490.250	- 596.667	76003.305	1957.807
F. Expenditure (BIDR)	-2.173$^{*)}$	-27.29	-52.781	- 22.961	0.763	0.091$^{*)}$
Year	- 8665.425	-1513.53	-24525.448	- 7272.346	-4207.698	-1186.966
District	-2765623.93	58951.75	- 7953467.708	- 2946049.602$^{*)}$	86561.160$^{*)}$	8684.041$^{*)}$
Rain-Area						
Rain-HDI					1.118	
Rain-Expenditure			3.51E-05$^{*)}$			3.04E-05$^{*)}$
Rain-Year			-1.009$^{*)}$		-0.65	-0.65$^{*)}$
Rain-District			-5.791$^{*)}$		-2.61$^{*)}$	
Area-HDI	-121.722		-460.530		-348.76$^{*)}$	-97.42
Area- Expenditure						-3.55E-03$^{*)}$
Area-Year	72.349		333.284		252.15$^{*)}$	140.71
Area-District	524.798$^{*)}$		909.828$^{*)}$	213.851$^{*)}$		
HDI-Expenditure	0.038$^{*)}$	-0.03		0.011	-0.011	
HDI-Year						
HDI-District			-5233.008$^{*)}$			
Expenditure-Year		0.01	0.027$^{*)}$	0.011		
Expenditure-District				-0.048$^{*)}$		
Year-District	1342.857$^{*)}$		4149.895$^{*)}$	1458.063$^{*)}$		
Rain^2			-0.002$^{*)}$			
Area^2		27.91$^{*)}$	49.816			
HDI^2						
Expenditure^2	-4.67E-07		-8.90E-07$^{*)}$	-4.03E-07$^{*)}$		
Year^2						
District^2	6906.202$^{*)}$	-9694.647$^{*)}$	-11039.847$^{*)}$	3083.376$^{*)}$	-13808.543$^{*)}$	-2743.209

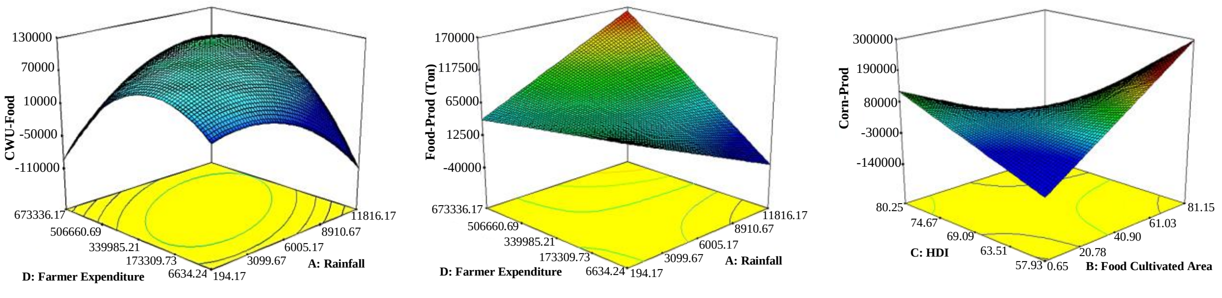
Remarks: Mm^3 = million meter cubic; Tha = thousand ha; BIDR = billion Indonesian Rupiah; ^{2} = a quadratic terms; $^{*)}$ = significant at 5% confidence level (P values < 0.05)

The effect of individual variables toward the responses showed a variation. The volume of rainfall in each district had a positive effect towards all responses except for $\text{CWU}_{\text{Paddy}}$ and Paddy–production. This variable was significant for Paddy-production. Food cultivated areas on the other hands had a negative effect towards the responses except for CWU_{Corn}. The cultivated area was a significant variable for both CWU_{Corn} and Corn-production. Social variable of HDI had the positive impacts on the responses excluded Paddy-production; it implied that farmers' quality was an important factor in the food production system. This variable was significant for $\text{CWU}_{\text{Paddy}}$ and CWU_{Corn}. Farmer expenditure had negative effects for the responses waive Corn-production and Food-production. This variable was significant for $\text{CWU}_{\text{Paddy}}$ and Food-production. Year variable had a negative effect on the responses while district variable had a positive outcome for CWU_{Corn}, Corn-production and Food-production. Moreover, the significant quadratic effects of single variables were included rainfall volume and farmer expenditure for CWU_{Food}; food cultivated area for CWU_{Corn}; and districts for all responses excluded food production. On the other hand, HDI and year variables were gravitated linear effects.

The interactions of rain with the expenditure and with year were significant for CWU_{Food} and food production. The interaction of rain with district was significant for corn production. The interaction of food cultivated area with other factors mostly notable affected productions and $\text{CWU}_{\text{Paddy}}$. While the interactions of HDI with other factors prominent affected CWUs. The interaction of farmer expenditure with year was the key influence for CWU_{Food}, and the interaction with district significant effect on paddy production. The year and district interaction was prominent factor for $\text{CWU}_{\text{Paddy}}$, CWU_{Food} and paddy production.

The notable curvatures of socio-economy-environment effects toward responses were various. The interaction of rainfall-farmer expenditure towards CWU_{Food} was a concave response which initially increased so that it reached its optimum point and decreased after that [7, 30]. The CWU_{Food} response was more quadratic then the food production response. The interaction of rainfall-farmer expenditure towards food production responses showed that the increasing of the interaction variables increase food production in ridge response. The interaction of food cultivated area-HDI towards food production responses and the interactions of HDI- Farmer expenditure towards CWU_{Corn} showed saddle responses.

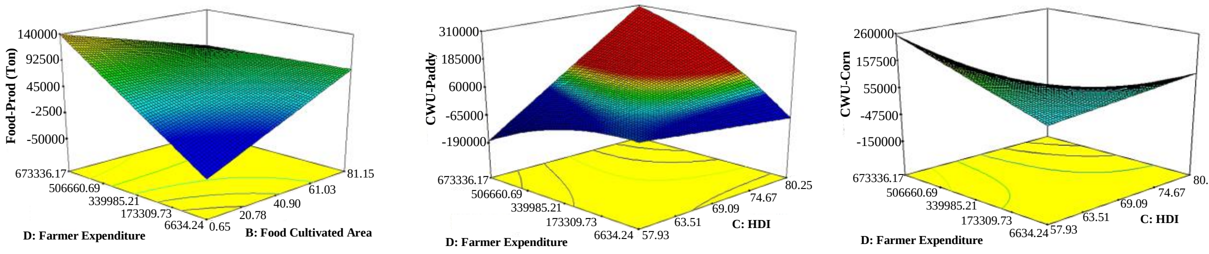
The interaction of food cultivated area - farmer expenditure that significant for food production response showed the increasing of cultivated area tend to increase the food production otherwise with farmer expenditure. The prominent effect of environment-social (food cultivated area-HDI) toward corn production showed a saddle response in which there was a maximum and minimum effect [7, 31]. Cultivated area more effected increased corn production compared to HDI, the maximum production gained when cultivated areas maximum and HDI was lower. The interaction of socio-economy (HDI-farmer expenditure) was a key effect on CWU_{Paddy} and CWU_{Corn}, the increased of HDI most positive effected CWU_{Paddy} than of CWU_{Corn}, and the increased of farmer expenditure was decreased more CWU_{Corn} than CWU_{Paddy}. The 3D plot of significant effects of socio-economy-environment on responses is depicted in Figure 6a-6f.



6a.Environment-economy interaction on CWU_{Food}

6b.Environment-economy interaction on Food production

6c.Environment-social interaction on Food production



6d. Environment-economy interaction on Corn production

6e. Social-economy interaction on CWU_{Paddy}

6f. Social-economy interaction on CWU_{Corn}

Figure 6 The 3D graphics of socio-economy-environment effects toward CWU and Crop Production

This study provided additional support for Rittenberg and Tregarthen [32] that claim labor, capital, and natural resources are the most important factors in agricultural production in the developing nations. Notwithstanding the interactions of socio-economy-environment variables were not prominent for Paddy-production, the interactions ware valuable for CWUs and crop-production. The interactions of socio-economy factors were necessary for CWUs; confirmed the importance of labor quality and expenditure to overcome the scarcity of water in a traditional food production system. In addition, this emphasize how important human and environment factors and the benefit of harmonizing the relationship between human and water as pointed out by Ding et al. [33].

3.4 Model optimization

Notable, it is difficult to solve multi-response optimization problem, one popular approached is by using the desirability function. The method introduced by Harrington in 1965 which entangle gauge the feature with response surface and using a transformation of a geometric mean function into a single performance with an ideal value is one while the value of zero considered entirely undesirable [34].

There were a hundred optimized results provided by the software with the desirability range of 0.734 to 0.816 to find a suitable result. The best solution that provided optimized result of 25% reduction of CWUs and the impact on crop production was solution number 56 with desirability of 0.777. The optimized result is presented in Ramps plot in Figure 7.

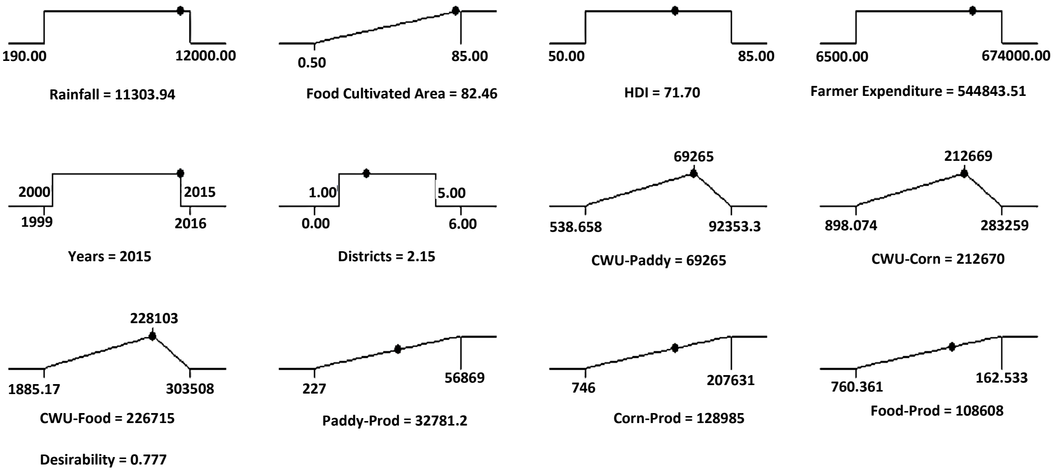
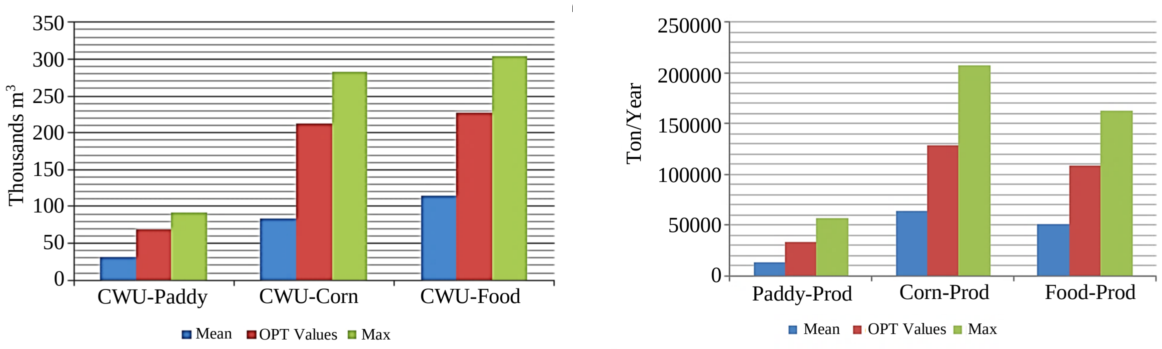


Figure 7 Ramps graph of optimization results

The optimum condition for socio-economy-environment variables was near maximum point; year was in maximum point while district was near minimum point. The optimum values of rainfall, food cultivated area, HDI and farmer expenditure was deducted 6%, 3%, 16% and 19% from maximum values respectively. That was signifying that input variables should be available on farmers hand near maximum point of the last 16 years so that the 25% saving of CWU could be reached. It is interesting to note that the optimal condition was achieved at South Central Timor (TTS) District in 2015.

Based on the difference values of maximum and optimal values, the one-fourth potential agricultural water saving from CWU_{Paddy}, CWU_{Corn}, and CWU_{Food} were 22.95 Mm^3, 124.56 Mm^3, and 75.40 Mm^3 respectively. Based on the difference percentage of optimal, maximum and minimum productions, the impacts of water saving on paddy production, corn production, and food production were the reduction of 42.36%, 37.88%, and 33.18% respectively from maximum production. Concerning the mean productions, there were an increasing of 142.48%, 100.58%, and 111.22% respectively. The comparison of optimized responses variables is presented in Figure 8a-8b.



8a. The comparison of CWU values

8b. The comparison of crop production values

Figure 8 The comparison of mean, optimum, and maximum values of the responses

Addressing food security and protecting natural resources is inevitable. However, the result denoted that the reduction of water impacted maximum crop production capacity that paddy production was more severe than of corn. The mitigation to the trade-off, Rosegrant et al. [35] point out that since agricultural system heavily depends on rain water the disruption of rainfall availability threatening crop production; therefore there should be an improvement in harvest index, biomass production and drought tolerance crop. Chang et al. [36] underline that the determinant factors are the improvement of agronomic-ecology interactions, resources endowments and economic development. Therefore, Tsinigo and Behrman [37] push forward the notion to secure effective input delivery, proper management not only conventional factors such as land, labor, capital, water, and chemical input but also non-conventional factors such as human capital, public and private investments, policy, and access to credit.

4. Conclusion

Staple food production system in the West Timor during 2000-2015 showed paddy cultivation was more intensive than dominated corn cultivation. The estimated CWU indicated an increasing and fluctuated trend. The average consumptive water use by staple food was 572 Mm^3/year with fluctuated rate among the districts. The staple food production depleted about 2.35% of total rainfall volume that total corn water use account for 73% compared to paddy water use of 23%.

The model consist of six independent variables that proxy the environmental, social and economic factors that affected six response variables of crop water use and staple food productions. The best fitted model to represent the observed data was a reduced quadratic response model. The significant effects of individual and interaction variables on response variables were showed a variation. The optimal solution for 25% water saving was impacted in the reduction of 22.95 Mm^3, 124.56 Mm^3, and 75.40 Mm^3 of CWU_{Paddy}, CWU_{Corn}, and CWU_{Food} respectively. Subsequently it impacted the reduction of paddy production, corn production, and food production of 42.36%, 37.88%, and 33.18% respectively from maximum production. This optimal condition was experienced in The TTS districts in 2015.

It is advisable to tackle the trade-off between water saving and food securities are with taking into consideration the dynamic interactions among environment, social and economic factors as well as to enhance not only agriculture conventional inputs but also non-conventional input.

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6. References

[1] Li R, Chai S, Chai Y, Li Y, Lan X, Ma J, et al. Mulching optimizes water consumption characteristics and improves crop water productivity on the semi-arid Loess Plateau of China 2021. Agric Water Manag. 2021;254:106965.

[2] Blaney HF, Criddle WD. Determining water requirements for settling water disputes. Nat Resour J. 1964;4(1):29-41

[3] Arayaa A, Prasada PVV, Gowdab PH, Afewerkc A, Abadid B, Foster AJ. Modeling irrigation and nitrogen management of wheat in Northern Ethiopia. Agric Water Manag. 2019;216:264-72.

[4] Usman M, Liedl R, Awan UK. Spatio-temporal estimation of consumptive water use for assessment of irrigation system performance and management of water resources in irrigated Indus Basin, Pakistan. J Hydrol. 2015;525:26-41.

[5] Sharma B, Molden D, Cook S. Water use efficiency in agriculture: Measurement, current situation and trends. In: Drechsel P, Heffer P, Magen H, Mikkelsen R, Wichelns D, editors. Managing water and fertilizer for sustainable agricultural intensification. Paris: International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI); 2015. p. 39-64.

[6] Laniak GF, Olchin G, Goodall J, Voinov A, Hill M, Glynn P, et al. Integrated environmental modeling: a vision and roadmap for the future. Environ Model Softw. 2013;39:3-23.

[7] Myers RH, Montgomery DC, Anderson-Cook CM. Response surface methodology: process and product optimization using designed experiments. 3rd ed. New Jersey: John Wiley & Sons; 2009.

[8] Kostić S, Stojković M, Prohaska S, Vasović N. Modeling of river flow rate as a function of rainfall and temperature using response surface methodology based on historical time series. J Hydroinform. 2016;18(4):651- 65.

[9] Graveline N. Economic calibrated models for water allocation in agricultural production: a review. Environ Model Softw. 2016;81:12-25.

[10] Molyneux N, da Cruz GR, Williams RL, Andersen R, Turner NC. Climate change and population growth in Timor Leste: implications for food security. Ambio. 2012;41(8):823-40.

[11] Piggin C. The role of Leucaena in swidden cropping and livestock production in Nusa Tenggara Timur province, Indonesia. In: da Costa H, Piggin C, da Cruz CJ, Fox JJ, editors. Agriculture: New Directions for a New Nation-East Timor (Timor-Leste). Canberra; ACIAR Proceedings; 2003. p. 115-129.

[12] WFP (World Food Programme). Food security and vulnerability Atlas/FSVA East Nusa Tenggara province 2015. Kupang: United Nations-World Food Programme (UN-WFP); 2015.

[13] Wikimedia. Map of West Timor-Districts and sub-districts [Internet]. 2023 [cited Feb 10]. Available from: https://upload.wikimedia.org/ wikipedia/comm ons/0/0b/Peta_Timor_Barat_-_Kabupaten _dan_Kecamatan.png. (In Indonesian)

[14] BPS (Statistical Bureau of NTT Province). NTT in figures years 2000-2015. Kupang: Statistical Bureau of NTT Province (BPS); 2016. (In Indonesian)

[15] Bambang T. Applied hydrology technique. Yogyakarta: Beta Offset; 2010. (In Indonesian)

[16] Ahmad NH, Deni SM. Homogeneity test on daily rainfall series for Malaysia. Matematika. 2013;29(1C):141-50.

[17] Runtunuwu E, Syahbuddin H, Ramadhani F, Apriyana Y, Sari K, Nugroho WT. Review of food crop planting time in Eastern Indonesia. Pangan. 2013;22(1):1-10. (In Indonesian)

[18] Directorate General of Water Resources. Irrigation planning standards: planning criteria section: planning irrigation network KP-01. Jakarta: Ministry of Public Works; 2013. (In Indonesian)

[19] Alauddin M, Sharma BR. Inter-district rice water productivity differences in Bangladesh: an empirical exploration and implications. Ecol Econ. 2013;93:210-8.

[20] Koehuan JE, Suharto B, Djoyowasito G, Wignyanto. Rice water total factor productivity growth of West Timor region, Indonesia 2000-2015: a novel parametric approach. AES Bioflux. 2020;12(2):110-22.

[21] Koehuan JE, Suharto B, Djoyowasito G, Susanawati LD. Water total factor productivity growth of rice and corn crops using data envelopment analysis-malmquist index (West Timor, Indonesia). AgricEngInt: CIGR Journal. 2020;22(4):20-30.

[22] Raes D. The ETo calculator; evapotranspiration from a reference surface; reference manual version 3.2. Rome: Food and Agriculture Organization of the United Nations Land and Water Division; 2012.

[23] Yan N, Wu B, Perry C, Zeng H. Assessing potential water savings in agriculture on the Hai Basin plain, China. Agric Water Manag. 2015;154:11-9.

[24] BPS (Statistical Bureau of NTT Province). Census of agriculture 2013: Nusa Tenggara Timur figures of paddy cultivation household, result of ST2013-subsector survey. Indonesia: Statistical Bureau of NTT Province (BPS); 2014. (In Indonesian)

[25] BPS (Statistical Bureau of NTT Province). Census of agriculture 2013: Nusa Tenggara Timur figures of secondary food crops household, result of ST2013-subsector survey. Indonesia: Statistical Bureau of NTT Province (BPS); 2014. (In Indonesian)

[26] Amarasinghe UA, Shah T, Singh OP. Changing consumption patterns: implications on food and water demand in India. Colombo: International Water Management Institute (IWMI); 2007. IWMI Research Report 119.

[27] Amarasinghe UA, Sharma BR, Muthuwatta L, Khan ZH. Water for food in Bangladesh: outlook to 2030. Colombo: International Water Management Institute (IWMI); 2014. IWMI Research Report 158.

[28] Rai A, Mohanty B, Bhargava R. Supercritical extraction of sunflower oil: a central composite design for extraction variables. Food Chem. 2016;192:647-59.

[29] Faleiro RMR, Velloso CM, de Castro LFA, Sampaio RS. Statistical modeling of charcoal consumption of blast furnaces based on historical data. J Mater Res Technol. 2013;2(4):303-7.

[30] Banerjee P, Karri RR, Mukhopadhyay A, Das P. Review of soft computing techniques for modeling, design, and prediction of wastewater removal performance. In: Karri RR, Ravindran G, Dehghani MH, editors. Soft computing techniques in solid waste and wastewater management. Amsterdam: Elsevier; 2021. p. 55-73.

[31] Chan KS, Greaves SJ, Rahardja S. Techniques for addressing saddle points in the response surface methodology (RSM). IEEE Access. 2019;7:85613-21.

[32] Rittenberg L, Tregarthen T. Principles of economics. Boston: Flat World Knowledge; 2011.

[33] Ding Y, Tang D, Dai H, Wei H. Human-water harmony index: a new approach to assess the human water relationship. Water Resour Manage. 2014;28:1061-77.

[34] Goethals PL, Cho BR. Extending the desirability function to account for variability measures in univariate and multivariate response experiments. Comput Ind Eng. 2012;62(2):457-68.

[35] Rosegrant MW, Ringler C, Zhu T. Water for agriculture: maintaining food security under growing scarcity. Annu Rev Environ Resour. 2009;34:205-12.

[36] Chang HS, Zepeda L. Agricultural productivity for sustainable food security in Asia and the Pacific: the role of investment. In: Zepeda L, editor. Agricultural investment and productivity in developing countries. Rome: FAO Department of Social Development Department; 2001. p. 75-92.

[37] Tsinigo E, Behrman JR. Technological priorities in rice production among smallholder farmers in Ghana. NJAS - Wagening J Life Sci. 2017;83:47-56.