CHAPTER 3

Methodology

3.1Water footprintassessment

3.1.1 Data requirement for WF calculation

The beginning of processing asses of water footprint could be started through a checklist illustrated by Hoekstra et al. (2009) (Appendix A).All of data was collected from MSCE Company staff and sugarcane's farmer in Mae Sot District, Tak Province.

Sugarcane fields about 23,966 rai in Mae Sot District were considered (Figure 3.1 beneath MSCECompany supported). And especially growing season of sugarcane cultivation since October 2011 to September 2012 were calculated WF. Collection of the data was carried out for green and blue WF calculation according to the checklist in CROPWAT 8.0 Model.

Table 3.1 The useful information for calculations of green and bluewater footprints in CROPWAT 8.0 model

No.	Parameters	results	unit	data source
	For evapotranspiration calculation* (ET_0; mm/day)	Table 4.1	°C	Data from meteorological station's MSCE
1)	Minimum and maximum temperature all of growing season			
2)	Humidity	Table 4.1	%	Data from meteorological station's MSCE

Table 3.1 The useful information for calculations of green and bluewater footprints in CROPWAT 8.0 model (Cont.)

No.	Parameters	results	unit	data source
3)	Wind	Table 4.1	m/s	Data from meteorological station's MSCE
4)	Sunshine hours	Table 4.1	hours	
After complete data by filling in No. 1 - 4, it could show the value in No. 5 - 6				
5)	Radiation	Table 4.1	MJ/m^2 /day	Outcome from CROPWAT 8.0
6)	Evapotranspiration (ET_0)	Table 4.1	mm/day	Outcome from CROPWAT 8.0
	For effective rainfall calculation (P_{eff})			
7)	Rainfall	Appendix B	mm	Data from meteorological station's MSCE
After complete data by filling in No. 7 , it could show the value in No. 8				
8)	Effective rainfall	Appendix B	mm	Outcome from CROPWAT 8.0
	Crop data			
9)	Name of crop	Sugarcane		Observation
10)	The date for beginning cultivation to harvesting	2011, Oct.-2012, Sep.		Interview and observation
11)	Crop coefficient (K_c)	$K_c$ini. 0.65 $K_c$mid. 1.27 $K_c$lat. 0.57		Royal Irrigation Department, Thailand (RID)

*Climate data were collect from October 2011-September 2012

Table 3.1 The useful information for calculations of green and bluewater footprints in CROPWAT 8.0 model (Cont.)

No.	Parameters	results	unit	data source
12)	Number of days for each stage		Days	InterviewMSCE Company's staff
	-initial	30		
	-development	60		
	-mid-season	180		
	- late-season	95		
	- total	365		
13)	Root depth	1-1.5	m	Interview and Allen *et al.*, 1998
14)	Critical depletion	0.65		Allen *et al.*, 1998 -The example of the use ofCROPWAT 8.0 by FAO (2012)
15)	Yield response factor (K_y)	1.2		(Allen *et al.*, 1998)
16)	Crop height	3	m	Observation
17)	Total of sugarcane yields	72.31	ton/ha	Interview MSCE Company's staff
	Soil data			
18)	Type of soil	Black clay soil		Observation andprovisional map of the soil and surface rock of kingdom of Thailand by Robert L. Pendleton, 1949
21)	Maximum rooting depth	2,000	cm	Allen *et al.*, 1998
22)	Initial soil moisture Depletion (as %TAM)	50	fraction	The example of the use ofCROPWAT 8.0 by FAO (2012)

Table 3.1 The useful information for calculations of green and bluewater footprints in CROPWAT 8.0 model(Cont.)

No.	Parameters	results	unit	data source
After complete data by filling in No. 18-22 , it could show the value in No. 23				
23)	Initial available soil moisture	100	%	Outcome from CROPWAT 8.0
24)	Fertilization data Formula and application rate of chemical fertilization	Table 4.5	kg/ha	Interview MSCE Company's staff

3.1.2Water footprint calculation

1)Green water footprint (WF)

The three kinds of WF are presented by the different colors as follows:Green WF (WF_{green}, m^3/ton) was calculated as the green component in crop water use (CWU_{green}, m^3/ha) divided by the crop yield (Y, ton/ha).

$$WF_{green} = \frac{CWU_{green}}{Y}$$

The green component in crop water use (CWU, m^3/ha)is calculated by CROPWAT 8.0 model.

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green}$$

Where,ET_{green} is the evapotranspiration of crop which wascalculated by accumulation of daily evapotranspiration (ET, mm/day). And,lgp is the length of growing period in days. Factor of 10 is applied to convert evapotranspiration (ET) of crop from millimeters (mm) into water volume per land surface area (m^3/ton) (Hoekstra *et al*., 2011)

The green WF assessment was done by using the climatic data from the meteorological station by MSCECompany, located near

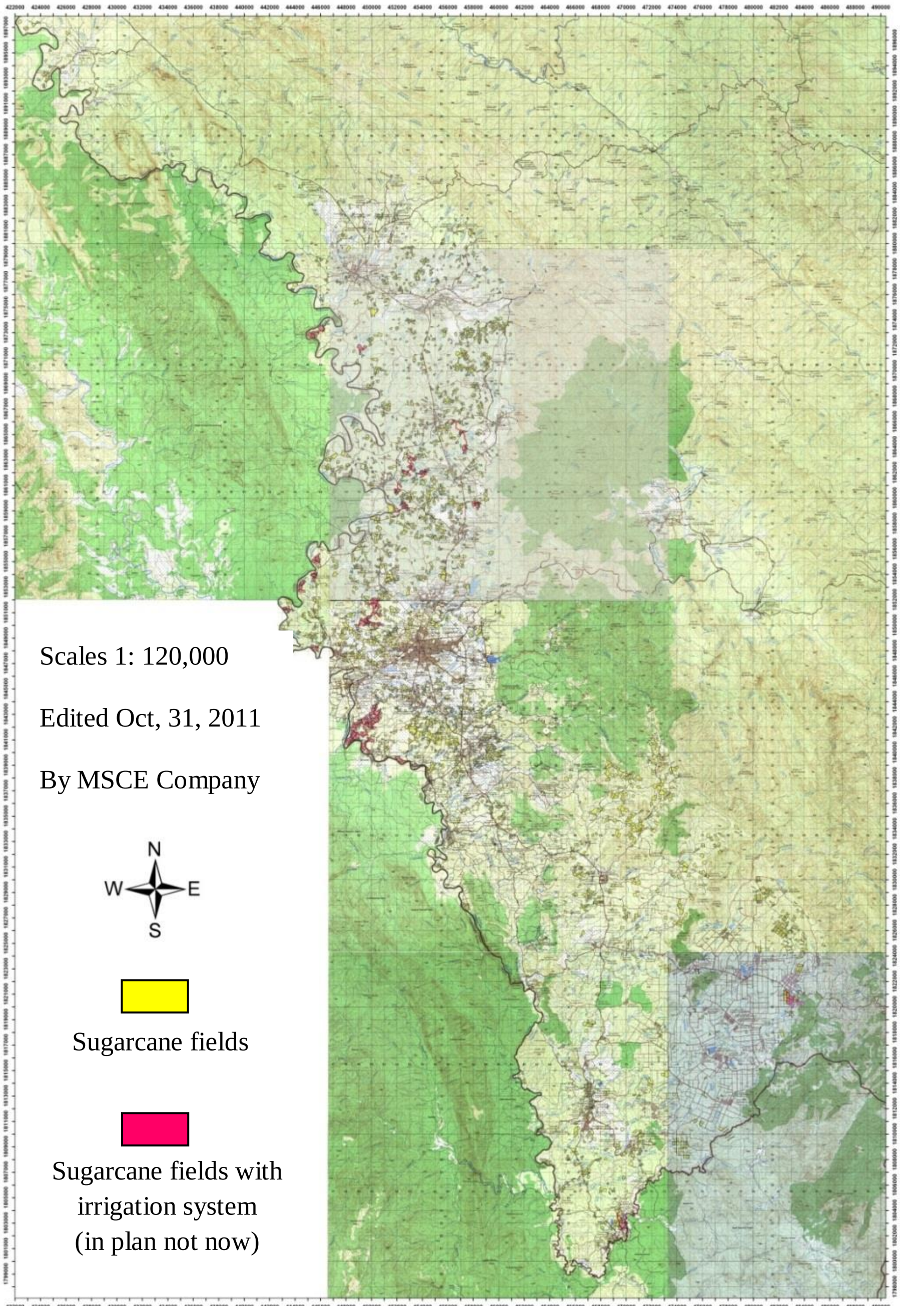

Figure 3.1 Sugarcane fields in Mae Sot District, Tak Province beneath MSCE Company supported

thesugarcane fields in Mae Sot District. The yield and harvested area of sugarcane in Mae Sot District were also obtained from MSCEC. The crop parameters from Allen *et al.* (1988) and Crop coefficient (K_c) for sugarcane wereobtained from Royal Irrigation Department of Thailand (RID, 2010). The growing period of sugarcane began early October, 2011 and ended late September, 2012 (12 month).

2)Blue water footprint (WF)

Blue WF (WF_{blue}, m^3/ton) is calculated in the similar way as green WF. However, in this study, the most of sugarcane fields (99%) in Mae Sot District have no irrigation system (rain-fed condition).

3)Grey water footprint (WF)

Many pollutantsgenerally consist of fertilizers such as nitrogen, phosphorus and so on; have been used to calculate the grey WF(WF_{gray}, m^3/ton). In this study, nitrogen is used as a fertilizer.

$$WF_{grey} = \frac{(\alpha \text{ x } AR) / (Cmax - Cnat)}{Y}$$

Where,C_{nat} is the natural concentration of pollutant in the receiving water body. In this study it was assumed to be zero (IFC, 2010; Hoekstra et al., 2011) because the receiving water is only precipitation. The Surface Water Quality Standards of Thailand recommended thatmaximum contaminant level or concentration (C_{max}) of nitrate nitrogen in surface water is 5.0 mg/L (PCD, 2013). 10% as a leaching rate was assumed to be a leaching run off fraction (α) of fertilizer application rate (AR, kg/ha) for all locations (Chapagain*et al.*, 2009) as recommended by Hoekstra and elsewhere (Kongboon and Sampattagul, 2012; Hoekstra et al, 2009; IFC, 2010; Hoekstra et al., 2011; Chapagain et al., 2006).

The total WF (m^3/ton) is calculated as the sum of the green, blue and grey WF.

$$WF_{proc} = WF_{green} + WF_{blue} + WF_{grey}$$

WF_{proc}(m^3/ton) is the total WF of an agricultural production process.

3.2Heavy metal analysis

3.2.1 Sampling sites and collection

Sampling sites were contaminated site and control site as follow basic information in Table 3.2:

Table 3.2 Site information

	Contaminated site	Control site
location	- Mae Tao Mai, Mae Tao Sub district, Mae Sot District, Tak Province	- Mae KuedLuang, Mae Kasa Sub district, Mae Sot District, Tak Province
GPS (Figure 3.2)	- 16°40'12.4"N 98°36'29.7"E - 229 m above sea level	- 16°49'25.0"N 98°33'37.2"E - 204 m above sea level
Site description	- Near Mae Tao Stream with inflow of heavy metals from Zn mine upstream	- Far from contaminated site about 25 kms and located at thecontrol site
Site description (Cont.)	- Sugarcane fields are in village, more shed by trees around filed and near road.	- Sugarcane fields are far from village and few shed of tree.
Soil characterization (Potichan*et al.*, 2004)	- Name of soil : Hang Chat Series (Hc) - Fine-loamy, mixed, isohyperthermicTypic (Kandic) Paleustults	Name of soil : Tub Kwang Series (Tw) - Fine, mixed, active, isohyperthermicTypicHaplustalfs.

Table 3.2 Site information (Cont.)

	Contaminated site	Control site
Soil characterization (Potichan*et al*., 2004)	- Dark brown or dark grayish brown sandy loam overlaying a yellowish red, reddish yellow or red clay loam - Reaction is moderately acid to very strongly acid that deceasing with depth. - Formed from alluvial deposits (mainly from granite) over residuum of granitic rock on coalescing fans or fan - Relief is gently undulating to rolling. - Slopes range 2-16 % - 1,100 – 1,800 mm average annual precipitation - Well drained. - Moderate permeability - Medium to rapid of runoff	- Dark brown or very dark grayish brown loam or clay loams A horizon overlaying brown and etc. - Reaction is medium acid to slightly acid at the surface and very strongly acid to strongly acid in the subsoil. - Same properties with Wang SaPhung(Ws) and Chatturut(Ct) Series. - Developed from residuum and/or colluvium of shale (sandy shale) and phyllite and occur on (dissected) erosion surface. - Relief is undulating to rolling with slope ranging from 2-8%. - 1,100 -1,400 mm average annual precipitation - Well drained. - Moderate permeability - Medium runoff

Sugarcane root and soil samplings werecarried out in August (2011) and February (2012) to compare the differences between dry and wet seasons as follow Table 3.3 (both of sites were planted sugarcane since March 2011 and harvest in February 2012). Three sampling, both sugarcane root and soil were collected randomly each area. Sugarcane roots were collected and cut to the length of 5-10 cms from the base of sugarcane stem. Soil samples were collected at10-20 cmsdepth in the sugarcane fields (IAEA, 2004; Ma *et a*l., 2012). In the laboratory, all the samples were washed with distilled water, dried at ca. 80C° for 24 hours, and grounded with a mortar for analysis.

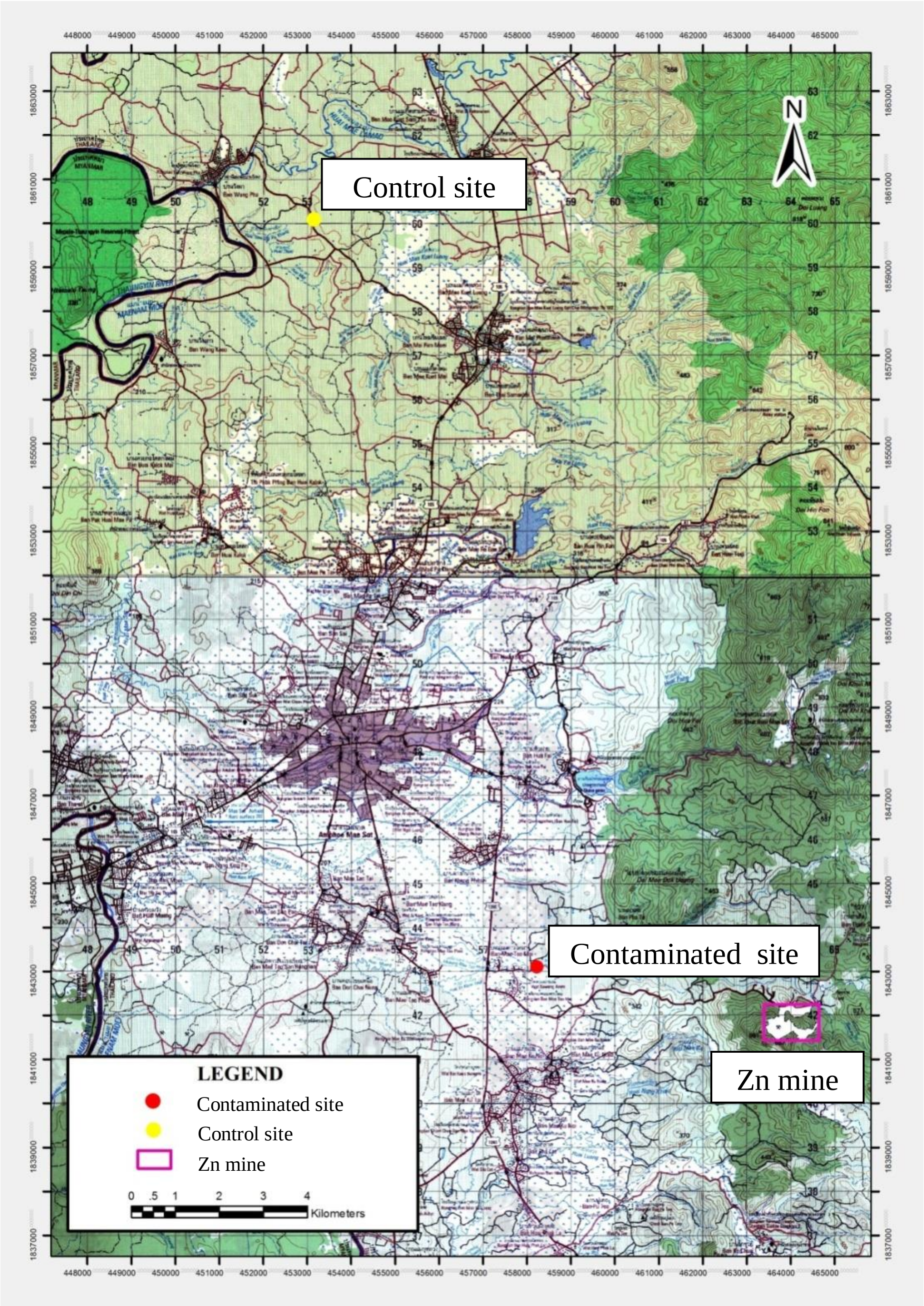

Figure 3.2 Sampling sites for samples in Mae Sot District, Tak province

Table 3.3 Number of sampling both soil and sugarcane root in study sites

Months	Type of sample	Age of sample	Contaminated site*	Control site*
August 2011	Soil	-	3	3
	Sugarcane root	1 yr.	3	3
		3 yr.	3	3
February 2012	Soil	-	3	3
	Sugarcane root	1 yr.	3	3
		3 yr.	3	3
	Total		18	18

*100 mg per 1 sample

3.2.2 Analysis of heavy metalsby ICP-OES

1)Materials, chemical reagents and equipment

- Balances
- Nitric acid pure and nitric acid 0.1 Molar
- Volumetric flask 10 ml
- Beaker
- Deionization water
- Polyethylene bottles size 30 ml
- Label
- Nylon filter 0.45 µm
- Syringes
- Micropipette
- Double layer Teflon digestion vessel
- Hot oven
- Inductively Couple Plasma-Optical Emission Spectrometer (ICP-OES)

2)Decomposition of samples and heavy metals analysis

The 100 mg of samples were digested by high purity concentrated nitric acid (1 ml) with double layer Teflon digestion vessel (modified from the method of Qiuquan*et al*. 2003). Al, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, and Znwere analyzed by ICP-OES based on Compendium Method IO-3.4 (USEPA. 1999) as shown by Figure 3.3 - 3.4.

Figure 3.3 Double layer Teflon digestion vessel (Qiuquan*et al*. 2003)

3)Quality Control for metal analysis

The certified reference materials (CRM) were digested by the same method as the samples, and heavy metals were measured by ICP-OES. Percent recoveries of Al, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, and Zn were calculated (Figure 3.4). For soil, CRM clay soil RTC 051 was used. And for plant, CRM pepperbush (*Clethrabarbinervis)* NIES 1 was used. The certificated values are shown in Table 3.4.

Table 3.4 Certificated values of CRMs Pepperbush NIES No.1 and clay soil RTC 051

Element	Certified value (mg/kg)	
	CRM Pepperbush NIES 1	CRM Clay soil RTC 051
Al	-	5530
Ba	165±10	-
Ca	13,800 ± 700	1,220
Cd	6.7±0.5	42.2
Cr	1.3	246
Cu	12±1	58.5
Fe	205±17	4,520
Mg	4,080±200	925
Mn	2,030±170	757
Zn	340±20	44

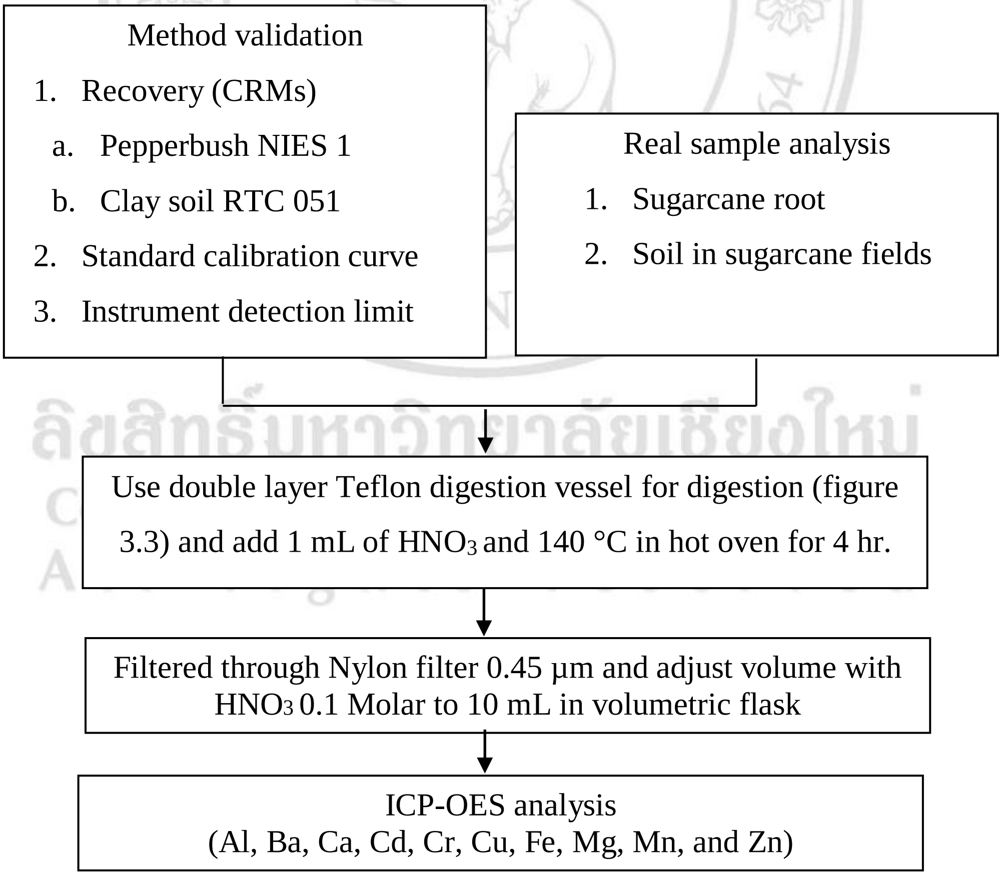

Figure 3.4 Diagram of analytical methods for elemental analysis