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Integrated Optimization with 3D Variable Density Groundwater Flow and Solute Transport Model to Investigate an Efficient Groundwater Management Scheme in Bangkok Aquifers System

P. Arlai

***Abstract*—** *The study explores seven different groundwater management schemes for the best sustainable future groundwater restoration of the Bangkok aquifers system. The first three are "non-constructive" schemes. In a second part of this article, the study employs, for the first time, a highly complex groundwater management optimization tool, the GWM-model---which uses techniques of linear programming and nonlinear optimization---, to optimize various other recharge- and clean-up well configurations of the best integrated non-constructive and constructive schemes investigated earlier (Arlai et al., 2007) and, in addition, optimizes three new schemes that use a "water supply trade-off concept" for the in-lieu water supply cells of the recharge wells. Next, all seven schemes are re-simulated with the variable-density flow and solute transport model SEAWAT-2000 to see how their efficiency is impacted by saline density effects. Finally, the author is doing a very careful evaluation and comparison of the hydraulic- and the groundwater-quality efficiency and of the total financial costs of all schemes investigated and proposes one of them as the best alternative for realization.*

***Keywords*— Groundwater flow and solute transport, optimization technique, variable density effect, groundwater management.**

1. INTRODUCTION

Even though the simultaneously acting two cradles of the major saline pollution in the Bangkok aquifer system have already been clarified and some sustainable aquifer remediation concepts, consisting in both non-constructive and integrating policies & constructive measures have been proposed in Arlai et al., 2006b, the latter may globally not be optimal, neither in terms of hydraulics nor of economics, as they have exclusively been determined by human judgment or so-called "trial & error". Furthermore, the numerical method used there, i.e. MODFLOW-96&MT3DMS, did not yet take into account the density-dependent effects of the saline concentrations on the flow and solute transport. In the present article I will overcome these two limitations partly by

a) application of the groundwater management optimization module GWM (Ahlfeld et al., 2005), which embedded in MODFLOW-2000, to further optimize hydraulically and economically the number of recharge-, clean-up wells and three new water trade-off concepts for the given set of head targets,

b) use of the variable-density model SEAWAT-2000 to investigate the density effects on the optimized schemes proposed in a) and on the non-constructive schemes from a previous paper (Arlai et al., 2007).

It should be noted that this consecutive approach is, theoretically, not completely wishful, as neither the solute transport, nor the density-dependency of the groundwater flow are incorporated a priori in the GWM analysis. Nevertheless it is the best that can be achieved with the modeling resources available at the present time. Given these caveats, I will re-evaluate in the present article the three most efficient non-constructive schemes found earlier in Arlai et al., 2006b by means of the MODFLOW-96 & MT3DMS trial & error simulations and will examine, additionally, 4 more new optimal groundwater schemes, i.e. a total of 7 schemes. These 7 schemes are, namely, the

(1) 1st scheme - the sustainable yield scheme (Arlai et al., 2006a),

(2) 2nd scheme – a non-constructive scheme (the 19th scheme from Arlai et al., 2006b),

(3) 3rd scheme – another non-constructive scheme (the 10th scheme from Arlai et al., 2006b),

(4) 4th scheme–optimizing the number of recharge- and clean-up wells of the best integrated non- and constructive scheme (the 31st scheme from Arlai et al., 2006b),

(5) 5th scheme- applied "water trade-off concept" to the best non-and constructive 4th scheme (new scheme)

(6) 6th scheme– applying "water trade off concept" to the 2nd scheme (new scheme)

(7) 7th scheme– applying "water trade off concept" to the 3rd scheme (new scheme).

The first three schemes are only re-modeled using the variable-density model-SEAWAT-2000 in order to

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reflect more realistically the density-dependent effects on the groundwater movements and saline transport resulting from these schemes. The 4th scheme is directly obtained from applying GWM, to optimize the number of recharge-and clean-up wells which can attain the same head targets from the previous trial&error simulations. The 5th to 7th "water trade off concept" schemes are simulated with GWM to examine the least-cost effective means to raise the water levels along the front of the seawater intrusion up to zero meter (MSL)--- as the modeled 2032 water levels in the productive water bearing units of these previously simulated remediation schemes are below sea level---, either by shutting off the discharge wells or increasing freshwater injection close to the shoreline through in-lieu water supply, in order better restrain seawater intrusion or to reduce the polluted area of the "without scheme". This approach may particularly appeal to the Thai water authorities who are interested in a recharge concept for the Bangkok aquifers system, to prevent further saltwater encroachment. However, as the GWM-model cannot take into account the density-dependent solute transport into the optimization process, these; firstly, optimized schemes 4 to 7 are re-simulated by SEAWAT-2000. Eventually, the best remediation scenario for the Bangkok aquifer system will is extracted from a comparison of these 7 schemes, based on their effectiveness with respect to (1) the saline pollution reduction, (2) the groundwater-use policy to existing groundwater users and, (3) the scheme's implementation and operational costs.

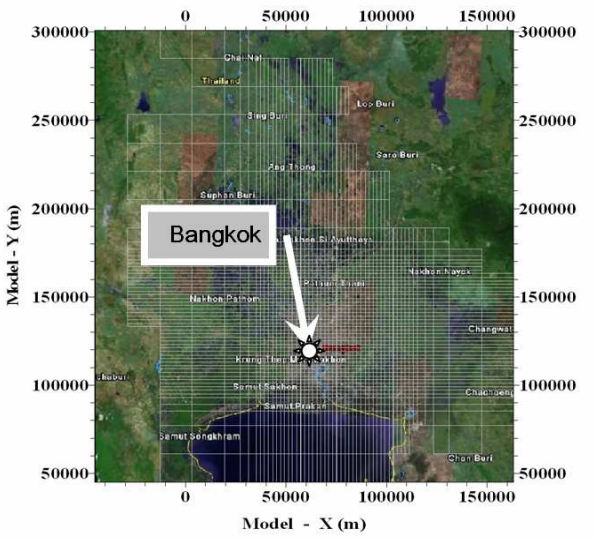
2. STUDY AREA AND MODEL IMPLEMENTATION

Flow Model:

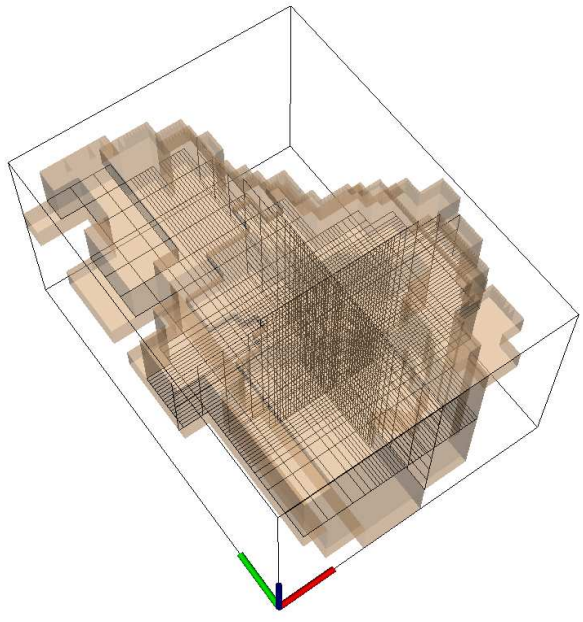
The Bangkok multi-aquifer system is located underneath the lower Chao Praya river basin which is bordered in the east, north and west by ridges of hills and mountains and in the south by the Gulf of Thailand. Hydrogeologically, the aquifers system is conceptualized as 9 layers, i.e., the topmost clay layer and eight lower principle confined aquifers (Arlai et al., 2006a). The groundwater flow model for the Bangkok multilayered aquifers is implemented by the 3D finite-difference model MODFLOW-96 and SEAWAT-2000, with 9 modeled layers whereby the topmost clay layer is treated as an unconfined aquifer and the 8 lower ones as confined aquifers. The model is divided into 55 rows and 52 columns with grid sizes varying from 2*2 km^2 to 16*16 km^2, following the approach of Arlai et al. (2006a) (Fig.1). The top boundary of the model is specified as constant head, representing the water table. The main recharges into the aquifer system are at the outcropping basin flanks and are simulated also as constant head that is set equal to the terrain altitude. Because the topmost clay layer has a thickness that varies from 15 to 30 meters, then recharge rate inside the basin is zero. The bottom of 9th layer is assigned as a NEUMAN boundary. All offshore cells in the uppermost layer are set as Dirichlet BC based on bathymetry is specified. Cells at the southern 55th row of the lower modeled layers that are connected to the Gulf of Thailand are treated as DIRICHLET boundary condition at sea level.

Solute transport model:

Dirichlet constant-concentration BC's for the saline concentrations are set at all active cells for the 1st layer reflecting the upper enriched saline clay layer that acts as a source of saline pollution inland over much of the extent of the model domain. Another intrusion source is the seawater offshore. Here some cells at the 55th row of the 2nd and 3rd layer which intersect the Gulf of Thailand have also been attributed a constant-concentration BC.



(a)



(b)

Fig.1. The FD grid in the 5th layer of the groundwater flow and solute transport model (a), and the 3D FD grid of the 9-multilayered model of Bangkok aquifers system (b).

3. THEORETICAL STATEMENT OF THE GROUNDWATER MANAGEMENT PROBLEM

Linear programming formulation

The ground-water management (GWM) problem is set into a form that can be solved using so-called linear programming techniques. As such the GWM problem consists of a (linear) objective function Z of the decision variables x that is either maximized or minimized, subject to constraints of these decision variables, i.e. (cf. Ahlfeld et al., 2005).

$$\text{Maximize (minimize)} \quad Z = cTx \tag{1}$$

subject to

$$Ax = b \tag{2}$$

and

$$0 < x < u \tag{3}$$

were Z is the value of the objective function; c is a transposed column vector of objective-function coefficients associated with the decision variables; x is a column vector of decision variables with upper bounds u; A is a matrix of coefficients defining the form of the constraints; and b is a column vector of right-hand-side coefficients associated with the constraints. The constrained linear programming problem (2) to (3) is solved by the well-known Simplex method.

Nonlinear constrained optimization approach

As the topmost modeled layer of the Bangkok aquifer system is fully convertible between a confined and an unconfined aquifer (setting the parameter LAYCON = 3 in MODFLOW), there will be a nonlinear relation between the position of the water table and the discharge- or injection stresses. Thus the constrained optimization problems become nonlinear which is more intricate to handle computationally. The usual approach consists then in linearizing the nonlinear objective function through a Taylor series expansion and to obtain a linear programming problem as above that can be solved as stated by the simplex method. This technique is also called sequential linear programming (SLP).

Formulation of the objective function and the constraints for the Bangkok aquifers GWM problem

According to the goals of the GWM optimization schemes for the Bangkok aquifers explained above, the constrained groundwater management optimization problem is formulated in two ways:

(1) For the optimization of the 4th scheme the objective function is to minimize the rates Q (or costs) of possibly 93 recharge and 93 clean-up well-candidates (Figure 8.1), subject to the constraints that (a) the maximum recharge and extraction well rates Q are less than 12000 CMD, (b) the total recharge rate cannot be greater than the extraction rate and, (c) the computed heads h at 42 spatially- fixed locations along the two lines of the proposed recharge wells and clean-up well barrier in layers 3 to 5 are not dropping below specified values H---- obtained from an earlier MODFLOW calibration of the "non-optimized" well scheme within the Bangkok Aquifers system (Arlai et al., 2006b)--- and that appears to be appropriate to repel future seawater intrusion (cf. Reichard et al., 2003). With these goals the GWM-problem is mathematically stated as follows:

$$Min\left(\sum_{n=1}^{31}\beta_n * (R_{3n} + Q_{3n} + R_{4n} + Q_{4n} + R_{5n} + Q_{5n}) * T_{Qw_n}\right) \tag{4}$$

subject to the constraints

$$\begin{pmatrix} 0 \le R_{kn} \le 12000; k = 3,4,5; n = 1,..,31 \\ 0 \le Q_{kn} \le 12000; k = 3,4,5; n = 1,..,31 \end{pmatrix} \tag{5}$$

$$\left(\sum_{k=3}^{k=5}.\sum_{n=1}^{n=31} R_{kn} \le \sum_{k=3}^{k=5}.\sum_{n=1}^{n=31} Q_{kn}\right) \tag{6}$$

and $h_{i,j,k,2} \ge H_{i,j,k,2}$ ($\sum$ i + j + k = 42) (7)

where R_{kn} is the recharge rate, Q_{kn} , the clean-up (discharge) rate in layer k and well site n (n = 31 is max. number of flux decision variables for layer k); β_n is the cost or benefit per unit volume of water withdrawn or recharged at well site n, (if only flow-rate is optimized, β_n is set to a dimensionless value of 1.0); T_{Qwn} is the total active duration of the flow-rate that is taken here as identical with T_{Qwn} = 7665 days (for the stress period 2 between year 2012 and 2032) at all well sites; is the modeled head at the 42 head constraint locations at col.= i, row = j, layer = k and stress period 2; and is the named head constraint acting as a flow barrier.

(2) For the optimization of the 5th to 7th scheme- the objective function is to minimize the monetary costs βQ of the "water trade-off concept" of possible 93 recharge wells and 123 in- lieu delivered water supply cells ---with the number of recharge wells and in-lieu-delivered water supply cells taken from those cells whose discharge wells have rates are greater than 500 CMD (Fig.2), subject to the constraints that, (a) the maximum recharge and extraction well rates Q are, in turn, equal or less than 12000 CMD, their existing pumping rates of selected discharged cells and, (b) the computed heads h at 42 spatially- head constraints along of the proposed recharge wells in layers 3 to 5 do not decline below specified values H = 0 meter (MSL) and that which appears to be appropriate to avert future seawater invasion (cf. Reichard et al., 2003). By that, the objective function and the constraints can be formulated mathematically as follows:

$$Min\left(\sum_{n_R=1;kn_W=1}^{N_R=31;3N_W=31;4N_W=60;5N_W=32}\left(\beta_R*\left[R_{3n_R}+R_{4n_R}+R_{5n_R}\right]+\beta_W*\left[Q_{3n_W}+Q_{4n_W}+Q_{5n_W}\right]\right)T_{QW_n}\right) \quad (8)$$

subject to the constraints

$$\begin{pmatrix}0\le R_{kn}\le 12000; k=3,4,5; n=1,..,31\\ 0\le Q_{kn}\le Q_{exn}; k=3,4,5; n=31,60,32\end{pmatrix} \quad (9)$$

$$h_{i,j,k,2}\ge 0 \quad (10)$$

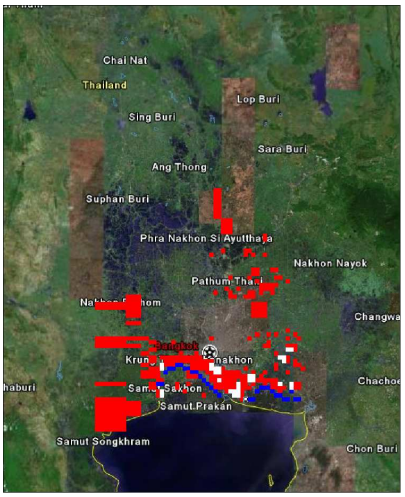
and $(\sum i + j + k = 42)$ (11)

where R_{kn} is the recharge rate, Q_{kn} , the in-lieu delivered water rate cell in layer k and well site n (n = 31 for Rkn and 31, 60, 32 for Q_{kn} are max. number of flux decision variables for layer k=3,4 and 5; βR and βW are the operational recharged- (approximate 0.43 USD; modified from Pyne, 1995) and in-lieu delivered water cost per CMD (approximate 0.4 USD; modified from the Bangkok Metropolitan Water Work Authority; assumed 40 Baht ~ 1 USD) at well site n; T_{Qwn} is the total active duration of the flow-rate that is taken here as identical with T_{Qwn} = 7665 days (for the stress period 2 between year 2012 and 2032) at all well sites; is the modeled head at the 42 head constraint locations at col.= i, row = j, layer = k and stress period 2.

As stated, the GWM problem for the present application is nonlinear, i.e. the hydraulic heads depend in a nonlinear manner on the well-pumping (recharge or discharge). Therefore the problem is solved through SLP, once the head constraints are linearized through 1st - order Taylor series expansion with respect to the flow-rate decision variables (R,Q) as follows:

$$h_{i,j,k,2}(R_{kn}andQ_{kn})=h^{\nu}_{i,j,k,2}(R^{\nu}_{kn}andQ^{\nu}_{kn})$$
$$+\sum_{n=1}^{N}\frac{\partial h^{\nu}_{i,j,k,2}}{\partial(R^{\nu}_{kn}andQ^{\nu}_{kn})}((R^{\nu}_{kn}andQ^{\nu}_{kn}))((R_{kn}orQ_{kn})-(R^{\nu}_{kn}andQ^{\nu}_{kn})) \quad (12)$$

where the superscript ν denotes the iteration level, $h_{i,j,k}$ is the head at col.= i, row = j, layer = k and stress period 2 obtained when the set of withdrawal and in lieu water supply rates $(R^{\nu}_{kn}andQ^{\nu}_{kn})$ is applied, $(R_{kn}andQ_{kn})$ is the new set of withdrawal and in lieu water supply rates and $\frac{\partial h^{\nu}_{i,j,k,2}}{\partial(R^{\nu}_{kn}andQ^{\nu}_{kn})}$ are the response coefficients. The SLP algorithm recalculates the response coefficient for the heads at each iteration ν from a new set of optimal withdrawal- and in-lieu water supply rates which are obtained from the linear programming solution of the previous iteration using the simplex algorithm.



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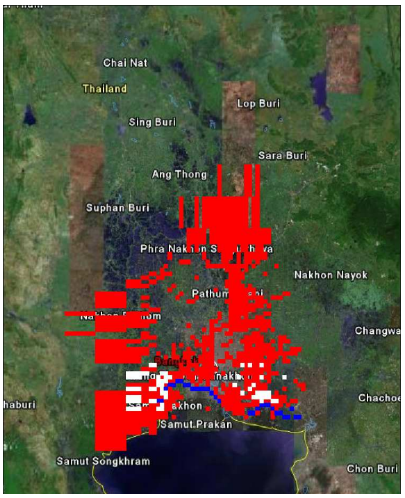

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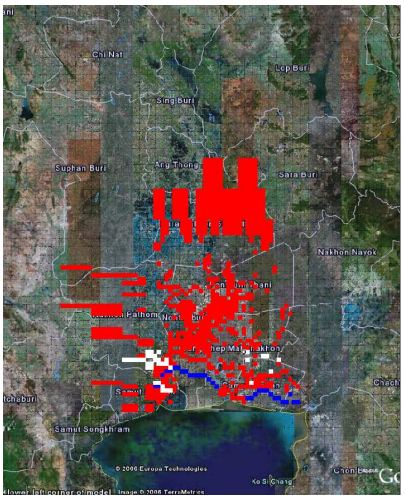


(c)

Fig. 2. An example of in lieu delivered water supply cell- (white cell), recharge well (blue cell) candidates and withdrawal cells (orange cell) in layer 3 (a), 4(b) and 5 (c) of the scheme 5 to 7.

4. DISCUSSION OF THE VARIOUS GROUND-WATER MANAGEMENT SCHEMES

As mentioned 7 schemes will be evaluated in this chapter, and for practical purposes, are to be compared to the reference scheme, the so-called "laissez-faire" scheme (Arlai et al., 2006b).

4.1 1st scheme - sustainable yield

The sustainable yield is defined as "the maximal groundwater yield that may be withdrawn so that the water levels in the third, forth and fifth layer do not decrease by more than 25% of their current water levels (Dec, 2002)". This scheme constrained pumping in the 6th to 9th aquifer by projecting into the future for the next 30 years (2003 to 2032) the acceleration rate of pumping from 1983 to 2002. Finally, the sustainability condition for the above conditions can be met if the pumping in layers 3, 4 and 5 is to be decreased at the rate of 1.2%, 1.2% and 1.9% per year, respectively (Arlai et al., 2006a).

4.2 2nd scheme -non-constructive scheme

It consists in keeping the present pump rate (2002) in each layer from 2012 to 2032, but decrease the pumping thereafter to 60% of today in low-sensitive zones and shut off completely the pumps in high-sensitive zones. This scheme is allowed to give 5 more years for law enactment.

4.3 3rd scheme - non-constructive scheme

It comprises maintaining the pump rates in layers 3 and 4 at the same rates than those of the WOS scheme from 2012 to 2032, as they are the main aquifer layers exploited, but completely stopping groundwater pumping in layers 5 to 9 which should retard vertical sinking mechanism of the salt plume from the upper source layers. This pump-shutoff in the lower layers will be executed from 2012 to 2032, leaving 5 more years for legal enactment.

4.4 4th scheme - optimized integrated non- and constructive scheme

The scheme is to minimize the least cost of "trial & error" integrated non- and constructive management scheme which combines recharge, clean-up wells and a cease of groundwater pumping in the 6th modeled layer. 31 recharge wells and 31 clean wells along the tongue of seawater intrusion in each layer are specified, resulting in a total of 93 recharge- and 93 clean-up wells (Figure 8.3) in order to attain the heads at the 42 head constraint locations with a complete cease of the groundwater withdrawal in layer 6, and keeping the extraction rates in layers 7 to 9 at the present-day rate (2002). The scheme will be operated from 2012 to 2032 leaving 5 years for realization.

4.5 5th scheme- applied "water trade-off concept" to the integrated non-and constructive scheme (4th scheme)

This scheme is to optimize the "water trade off concept": 93 recharge wells and 123 in-lieu delivered water supply cells candidates are applied (with no clean-up wells) and keeping the 21 head constraints equal to zero meter height (MSL) at the end of 2032. The in-lieu delivered water supply cells are selected from those pumping cells located closed to the shoreline (UTM Y: 694000 to 720000) that have the pump rates in a FD-cell 500 CMD---as the author has tested and found that if the existing pumping rates in a cell are specified to less than 500 CMD, the dimension of the optimized problem becomes too huge to be treated computationally in an acceptable time---. The GWM-optimization of this scheme is to ensure least costs for construction, operation and maintenance for its realization. This optimized scheme operates from 2012 to 2032, allowing 5 more years for governmental ruling (Fig.2.).

4.6 6th-scheme- applying "water trade off concept" to the 2nd scheme

It applies the "water trade off concept" as described in the 5th scheme with the 2nd scheme.

4.7 7th-scheme- appliying "water trade off concept" to the 3rd scheme

It applies the "water trade off concept" in 5th scheme with the 3rd scheme.

5. RESULTS

5.1 Optimization results for the 4th scheme

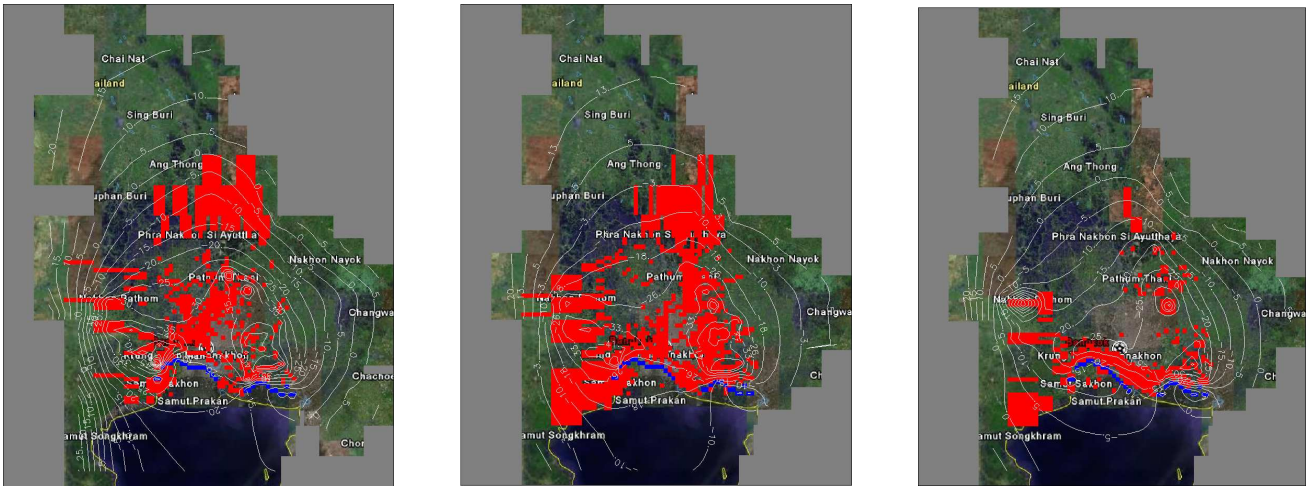
For the "trial & error" well scheme which combines recharge, clean-up wells and a cease of groundwater pumping in the 6th modeled layer, 31 recharge wells and 31 clean wells along the tongue of seawater intrusion in each layer are specified, resulting in a total of 93 recharge- and 93 clean-up wells (Fig.3). Each of these wells is operated at a rate of 7000 CMD. Hence the total water circulation rate in this scenario is $6.51*10^5$ CMD. On the other hand, using the MODFLOW-GWM optimization code to solve the GMW-objective function and constraints, results in a total of only 37 recharge-(15, 10, 12 wells in layer 3, 4 and 5) and 27 clean-up (16, 6, 5 wells in layer 3, 4 and 5) wells to control the heads at the 42 head constraint locations. And the water circulation rate is merely $3.17*10^5$ CMD. Hence, compared with the "trial & error" well scheme, the MODFLOW-GWM "optimized" scenario results in a significant reduction in both the number of wells and total water circulation rate (a 51% reduction), i.e., obviously a tremendous cost-saving, as discussed below.

Fig.4. illustrates that the modeled heads for year 2032 of the "trial & error"- and "optimized" well schemes coincide pretty well at the locations of the head constraints—but less so in the seaward zone where the named water circulation rate differences are prevalent, with the effect that the "trial & error"- computed heads in the gulf area are higher than those of the "optimized" one (Fig.4.). The minimum head recoveries in 2032 for

the two schemes are listed in Table 1. One notes that the head recovery for the "optimized" scenario is better than that of the "trial & error" one which is due to the fact that some of the, evidently redundant clean-up wells of this somewhat arbitrary scenario have a detrimental effect on the head recovery. Table 1 lists also the economic benefits of employing the "optimized" instead of the "trial & error" – scheme---the former being calculated by associating a unit price in the objective function (4)---. One clearly observes that, not only is the "optimized" well scheme cheaper by 154 million US Dollars for the project implementation, it results also in annual operation and maintenance cost savings of 76.7 million US Dollar compared to the latter scheme.

5.2 Optimization results for the 5th to 7th schemes

Table 2 lists the optimization results obtained for three new schemes (5^{th}-7^{th} scheme), namely, the cell candidates for the recharge-wells and the in-lieu delivered water supply wells which are able to recover the piezometric heads up to the constraints of zero meter (MSL), and the least costs achieved. The table illustrates that the 7th scheme is the most effective, at least with regard to the costs of installation and operation of the recharge wells, as both the number of recharge wells and the recharge rates are at a minimum while satisfying the zero meter (MSL) head constraint as a water barrier layers 3 to 5. However, at this current stage, it cannot be concluded that this is really best scheme, since, in principle, for each optimized recharge well and in-lieu delivered water supply cell configuration the models should be re-simulated using SEAWAT-2000 to check for possible solute density effects on the schemes' groundwater flow effectiveness, neglected so far.



(a) **(b)** **(c)**

Fig. 3. Trial-and error well scheme: Orange area shows the distribution of the present day pumps, blue area the line of recharge wells, with the clean-up wells located 4 cells northward of the former.

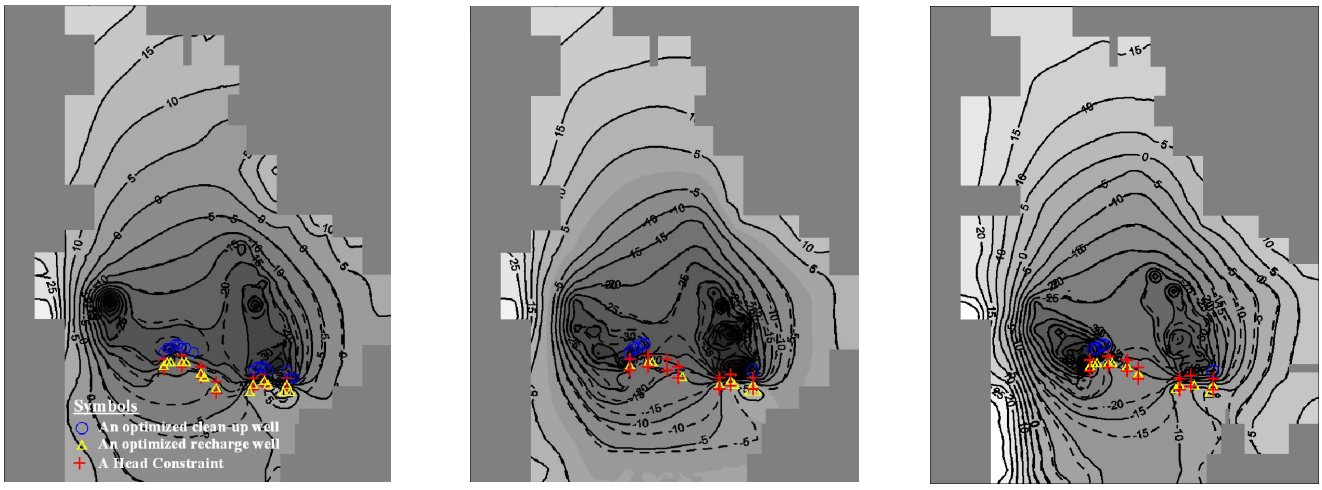


Fig. 4. 2032-heads for the "trial & error"- (solid lines) and "optimized" (dashed lines) well scheme in layers 3(a), 4(b) and 5(c); a blue circle is an optimized clean-up well, a yellow triangle is an optimized recharge well, a red plus is a head constraint.

Table 1. Comparison of head recovery and values of cost-function (hydraulic costs) and monetary costs for implementation and operational & maintenance for the two restoration schemes proposed.

Aspect	Original well scheme						Optimized well scheme						
	Layer3	Layer4	Layer5	Layer6	Layer7	Total	Layer3	Layer4	Layer5	Layer6	Layer7	Total	% Saving
1.Head recovery													
a.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
b.	-54.79	-64.82	-82.26	-31.19	-28.56	-82.26	-55.00	-59.66	-67.82	-31.61	-28.06	-67.82	
2.Cost													
a.	31	31	31			93	15	10	12			37	60
b.	31	31	31			93	16	6	5			27	71
c.	2.17	2.17	2.17			6.51	1.45	0.87	0.85			3.17	51
d.	2.17	2.17	2.17			6.51	1.85	0.72	0.60			3.17	51
e.	100	100	100			300	77	36	33			146	51
f.	49.90	49.90	49.90			149.70	36.37	18.94	17.69			73.00	51

Remark

Unit Cost of recharge project implementation	210	US Dollar/CMD, cf. Pyne, 1995
Unit Cost of clean-up project implementation	251	US Dollar/CMD,cf.Henthorne,2003
Unit Cost of O&M of recharge project	0.43	US Dollar/CMD,cf.Reichard et al., 2003
Unit Cost of O&M of clean-up project	0.2	US Dollar/CMD,cf.Henthorne,2003

1.Piezometric head recovery
- a.Similarity along the head constraints
- b.Minimum head (m. MSL)

2.Cost
- a.Number of recharge well
- b.Number of clean-up well
- c.Total recharge rate (10^5 CMD)
- d.Total clean-up rate (10^5 CMD)
- e.Project implementation cost (Million US$)
- f.Operational&Maintenance Cost/year (Million US$)

Table 2. Summary of optimization results for the 5th to 7th scheme

Scheme	Recharged well candidates	In lieu well cells candidates	Optimized recharged wells			Optimized in lieu delivered water supply		
			Number of wells	Total recharge rate (CMD)	Annual operational cost (10^6 USD)	Number of cells	Total in lieu delivered water supply rate (CMD)	Annual operational cost (10^6 USD)
5th	93	123	30	229035	36	123	2.42E5	38
6th	93	123	30	163612	26	123	2.42E5	38
7th	93	123	23	160570	25	123	2.42E5	38

5.3 Quantitative analysis of variable-density effect of all schemes

As the GWM-MODFLOW-2000 module could no simulate the density-dependent groundwater flow and solute transport, the WOS-scheme and all other schemes will be re-run using SEAWAT-2000. The most salient results obtained in this manner---with respect to those of the WOS-scheme---are summarized in terms of groundwater hydraulics, -quantity and –quality for layers 3 to 8 of the aquifer in Fig.5. The vertical saline plume pollution- and horizontal seawater intrusion extent in Fig.5. are, in turn, defined as that contaminated area where the salinity concentrations are higher than 250 and 4000 mg/l-locates nearby/closed to shoreline, with the reduction measured relative to original polluted area of the WOS-scheme. The % head recovery is specified by the ratio of the minimum head of each scheme to that of the WOS- scheme. The diagram shows that the 6th scheme is clearly the best one to reclaim both the piezometric heads and the groundwater quality, in as much as the average head recovery is 68%, and the area polluted by vertical saline plume intrusion is reduced by 9 % and that affected by horizontal seawater intrusion by 18%. Not surprisingly, all the 5th to 7th --- the “water trade off concept” schemes--- reduce both polluted areas better and result in better head recoveries than all other schemes.

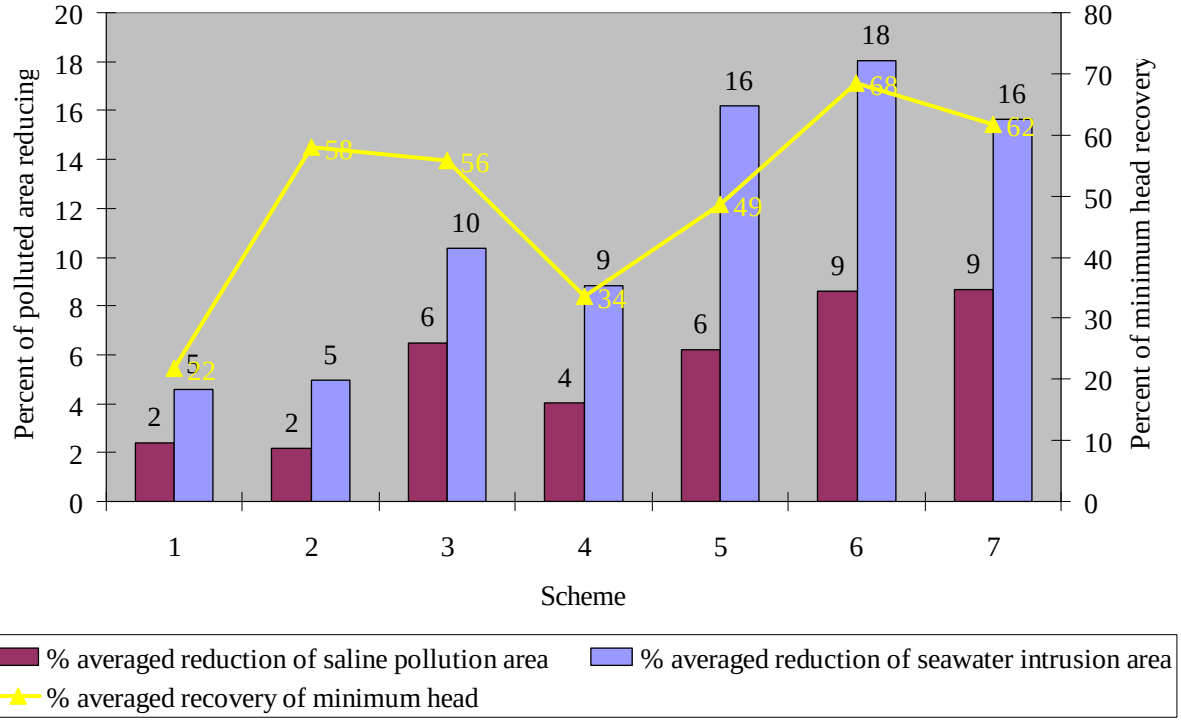


Fig.5. Summary of % averaged reduction of vertical saline plume pollution area, - seawater intrusion area and head recovery in layers 3 to 8 relative to the WOS scheme.

5.4 Detailed cost-analysis of the various schemes

The schemes discussed can be divided into three categories, namely, (a) non-constructive schemes- 1st to 3rd scheme, (b), optimized non-and constructive scheme- 4th scheme and (c) applied water trade off scheme-5th to 7th scheme. For the category (a) schemes, the unmet water demand (umd) and which is defined as the difference between the total withdrawal rate difference between the WOS-scheme and the pumping rate under the policy of that scheme is assumed to be served by surface water supply from Bangkok Metropolitan Water Authority (BMWA). Hence, the costs for the non-constructive scheme must be estimated by taking into account the construction costs of the delivering water supply pipe, connected to a water supply distributor station of BMWA, i.e. construction costs of a 8 inch diameter – pipe, 20 meters long are 5350 USD (including 7% VAT) which can provides water supply 934 CMD (assuming flow velocity in a pipe 1 m/s and operating 8 hrs/day), meanwhile the costs for the use of the additional water supplied are assumed to be covered by existing groundwater users there, namely 0.4 USD for a cubic meter of water supplied (BMWA- service rate and assuming 1 USD ~ 40 Baht).

These assumptions apply also for the unmet demand of the other two scheme-categories. The costs of scheme-category (b) are taken from Arlai et al. (2007). The costs of the scheme-category (c) are determined by calculating the implementation as well as the operational expenses for the recharge wells using the values of (Arlai et al., 2007), while the costs of the in-lieu water supply is taking into account only the costs of delivering water pipe construction as stated above. The total costs are then defined as the sum of the initial costs of implementation plus annual operational cost in the target year 2032. The cost summary of Table 3 unveils that the sustainable yield-scheme requires the smallest investment among all the other schemes, namely 2.22 million USD, while the investment costs of the 7th scheme are the lowest among the group of integrated non- and constructive schemes, i.e. 65 million USD. One an interesting point to mention is that the 6th scheme---which has been the best with respect to the efficiency in recovering the groundwater heads and the – quality--- requires only one million USD more than the 7th scheme. On the other hand, if the schemes's impact on the groundwater use policy is taken into account, one must consider also the unmet water demand (umd), since a higher umd would be more affecting existing groundwater users. From this point of view, the 4th scheme would be the least painful for them.

6. DISCUSSION

From the results obtained, it is difficult to give a clear "cut" for the best aquifer restoration scheme when considering the recovery of the groundwater quality, the costs of implementation & operation, and the impact of the groundwater use policy of each scheme on the existing groundwater users. As a trade-off and possible guidance to the water authorities of Thailand to choose among the various options proposed, these three relevant parameters, i.e. reduction of total pollution area, total cost and unmet water demand of each scheme are plotted in Fig.6.

Table 3. Summary of costs in each scheme.

Scheme	Unmet water Demand 10^6CMD	Cost of water supply implementation for unmet demand in 2032 Million USD	Cost of Recharge wells Implementation in 2032 Million USD	Annual Operational cost of Recharge well in 2032 Million USD	Total Cost in 2032 Million USD
1	0.39	2.22			2.22
2	0.86	4.91			4.91
3	0.88	5.02			5.02
4	0.16	0.94	146	73	220
5	0.72	4.14	48	36	88
6	1.00	5.74	34	26	66
7	1.00	5.73	34	25	65

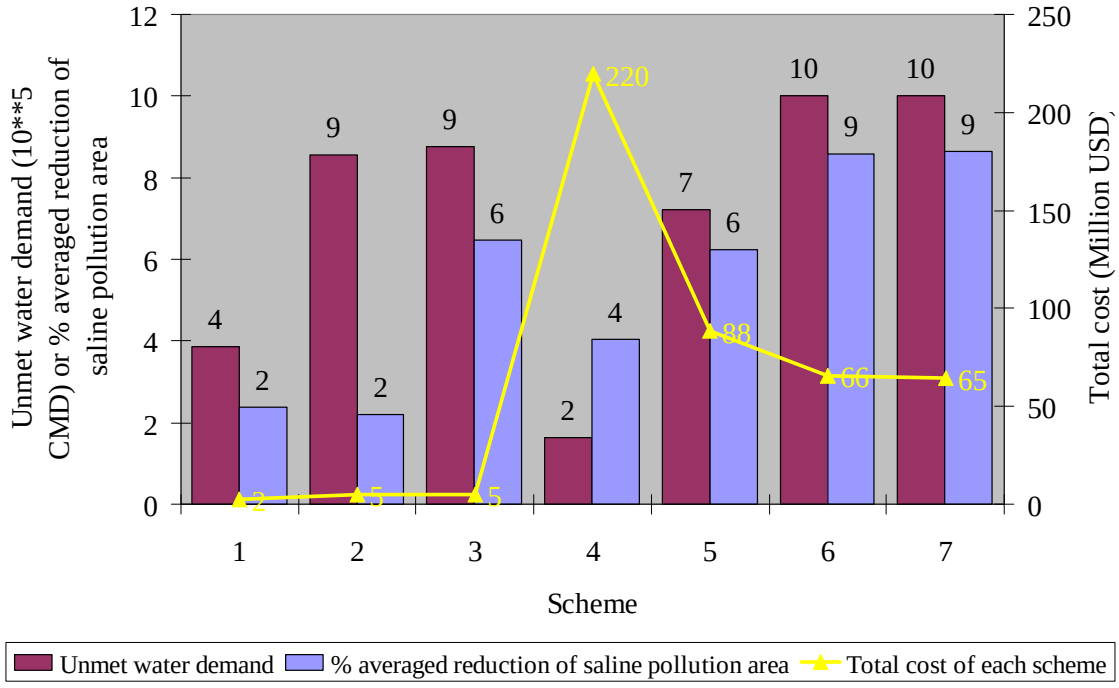
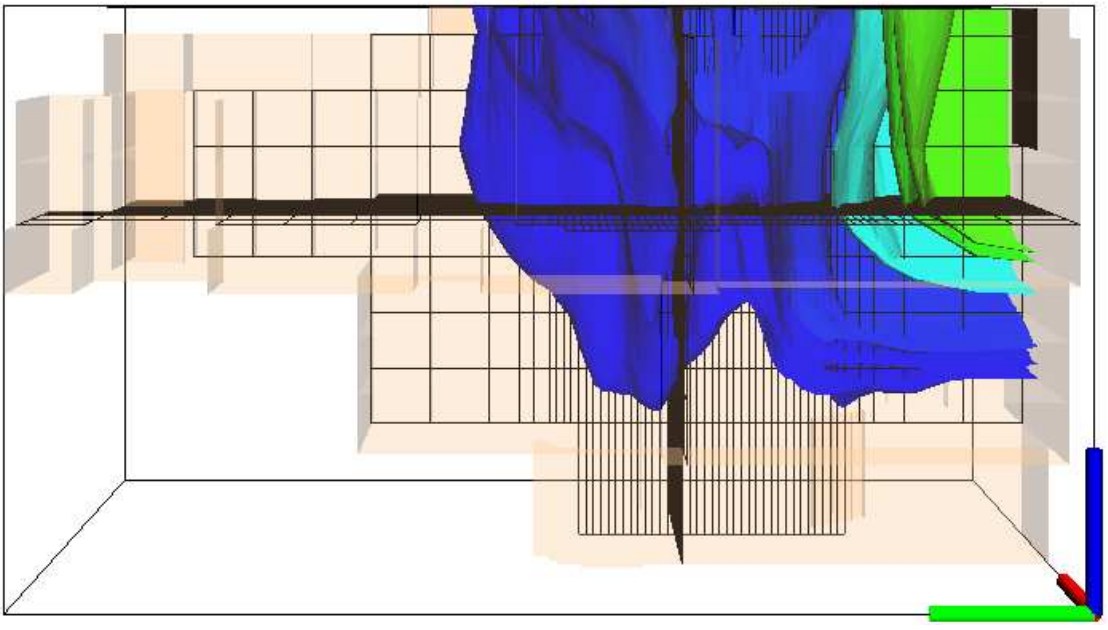
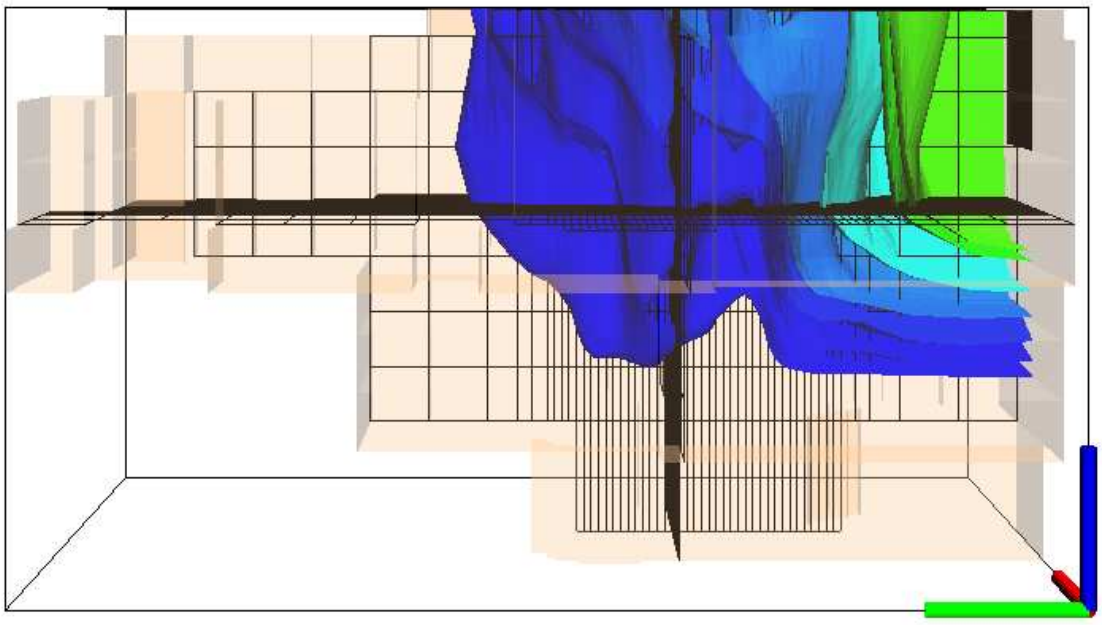


Fig.6. Comparison of unmet water demand, averaged reduction of saline pollution area and total costs of each scheme.

Fig.6. discloses that the 3rd scheme appears to be the optimal one for sustainable groundwater management and restoration of the Bangkok aquifers system. This is because the 3rd scheme can not only reclaim the total saline pollution area up to about two third of that of the best schemes---the 6th and 7th scheme--- and also retard the vertical sinking of the salinity plume from the upper marine clay layers (as shown in Fig.7), but it also requires also an investment of only 5.02 million USD for construction costs which is 92% cheaper than the total costs of the 6th and 7th scheme. Even this 3rd scheme may considerably impact the existing groundwater users, they latter may get a compensation from the construction costs saved of the water supply pipe connecting to the BMWA distributor and may thus pay only the unit costs of the water used.



(a)



(b)

Fig.7. Saline concentration profile (UTM-X = 662000 m.) of the WOS-scheme (a) and the 3rd scheme (b) located at the western side of the Chao Praya river, concentrations in kg/m^3.

7. SUMMARY

Seven different groundwater management schemes are investigated for the best sustainable future groundwater restoration of the Bangkok aquifers system. The first three non-constructive schemes that have been selected from a previous paper where they have been simulated only by the constant-density groundwater flow and solute transport model MODFLOW-96&MT3DMS (Arlai et al., 2006a and b) are re-run by the newest version of the variable density groundwater flow and solute transport model-SEAWAT-2000, allowing for a more realistic determination of the flow and saline transport due these schemes. The 4th scheme is set-up by applying GWM-optimized recharge- and clean-up wells to the best non-constructive scheme investigated earlier, and the 5th, 6th and 7th scheme uses also GWM to optimize "the water supply trade-off concept" with the 4th, 2nd and 3rd scheme, respectively. After optimizing the 4th to 7th scheme, the optimal non-and constructive- and the in-lieu water supply concept schemes are re-simulated with the variable-density flow and solute transport model SEAWAT-2000. Next, the hydraulic- and the groundwater-quality efficiency and the total financial

costs of all schemes are evaluated and compared. Eventually, the 3rd scheme appears to be the optimal scheme in all points of views and it is the one that may be recommended to the Thai water resources authorities for possible realization.

ACKNOWLEDGMENT

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An Approach to ICT Enabled Solution Architecture for Critical Social Security Issues and Challenges for e-Governance

W. Jeberson, Gurmit Singh and T. Mohanadhas

Abstract*— *Across the globe, countries have recognized Information and Communication Technology (ICT) as an effective tool in catalyzing the public services activity for efficient governance, and in developing human resources. There is a lot of growing recognition of the newer and wider possibilities that technology presents before society in the modern times. ICT has brought about unprecedented changes in the way people communicate; conduct business, pleasure and interact socially. The evolution of new technologies and e-Forms of applications makes the lives of the people better and more comfortable in several ways. With the emergence of ICT, technology is totally utilised as a tool for good governance, sustainable development, globalization of the economy and social empowerment. Information is also a key element of democracy. This paper attempts to provide a total solution architectural framework which enhances the potential for e-Governance in tackling some of the social security issues and challenges, which are hindering the growth process for extension of e-Governance activity, if not eliminate the entire present problems.

***Keywords*— ICT (Information and Communication Technologies), e-Governance, Security, Digital Divide.**

1. INTRODUCTION

With the advent of IT, it has become possible for the common person to access global information. Now, villagers can access information in their local language, thanks to Unicode, local language technologies, semantic technologies and related products and tools. The Internet has become the network for bridging the gap between citizens and governments while the Intranet bridges all central governmental organisations. However, the security of the Internet and Intranet based applications has not improved to reflect its use as a mission-critical infrastructure component. It is clear that Internet enabled applications are essential for delivering services to civil society with infrastructural capability even to tackle disaster and crises effectively.Various approaches are applied in support of privacy, security and trust in e-Governance for enhancing the G2C service delivery mechanism. These are public key cryptography (PKC) and public key infrastructure (PKI) including digital signatures developed for secure G2C transactions.

There are various reasons for the lack of e-Governance progress. To some extent, these may be due to technical issues, regulatory issues and economic issues that are very hard to eliminate. Lack of e-Learning tools and translation of contents affect the penetration of e-Governance to rural areas. Government departments have not fully attempted to computerize their back-offices to throw open the service deliveries to public. Many a times, departments are offering front-end services, which are more error-prone and problematic. Government Process Re-engineering and related reforms and regulatory frameworks are yet to mature enough to allow true e-Governance in place.

This paper discusses various issues pertaining to the hindering growth process of e-governance. Some of the issues discussed are related to e-government initiatives, organisational barriers, technological barriers, socio-cultural barriers, data and information barriers, privacy and security barriers, social security issues in e-government, identity theft and identity fraud, fraud in online payments and disparities in access of information systems.

2. ISSUES IN E-GOVERNMENT INITIATIVES

Almost all countries are facing lot of barriers [1] and security issues, which hinders the growth process of effective e-governance initiatives. Let us explore some of the areas where there are barriers.

2.1. Organisational Barriers

Since e-governance is a client-centered approach, it has to face lot of critical organizational challenges. The e-governance is purely for the citizens and government employees. It works in different way comparable to traditional service delivery mechanism by which the services are delivered to the citizens with the help of Information and Communication Technologies (ICT)[3].

The delivery of electronic services forces governments to change their organisation. The external objective of e-government is to satisfactorily fulfill the public's needs and expectations on the front office side, by simplifying their interaction with various on-line services. In the back-office, the objective of e-government is to facilitate a speedy, transparent, accountable, efficient and effective process for performing government administration activities. Real cost of the e-governance is only realised when there is a true integration between the front-end and the back office systems. Achieving this end-to-end

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integration requires administrative reforms, development of new skills, and redesign of traditional processes. Implementing the necessary changes is a complex process for governments with transparency.

2.2. Technological Barriers

To develop a technological infrastructure first there is a need to design and implement the technical components that are necessary to realise the architecture. In introducing an adequate technological infrastructure, governments should aim at a full ICT alignment to all the government entities, which integrate national level, state level and local level governments. Some of the technological divides are as follows:

- The environment of the government departments and private departments are heterogeneous.
  - Multiple operating systems such as Windows/Linux /Macintosh
  - RDBMS such as Oracle/Sybase/DB2/SQL Server
  - Front ends such as VB/FoxPro/VC++
- The environment in the State/Central data centers are unified architecture so not possible to integrate all the information systems from various state governments.
- Some government departments have legacy systems that are not in a situation to obey the Data center standards.
- Network systems are poor in the sense of performance and bandwidth to enable latest technology infrastructure to the entire public in the nuke and corner of the country.

Therefore, throughout the country all the governments should co-ordinate to have a unified technological architecture.

2.3. Socio-Cultural Barriers

Cultural resistance is the greatest obstacle to integrated on-line public services. There are bureaucratic procedures, which hinders the implementation process of e-Governance. Indeed the most perplexing problems are usually created because of the political affairs and customary restrictions in the country. If these issues get the kind of consideration among public, then implementing e-government programs will be a much-complicated exercise[8].

2.4. Data And Information Barriers

Citizens, employers and the employees tend to see the public sector as one single institution. However, this view changes when they have to provide different government institutions with the same information. E.g. For the case of passport and driving license, separate application forms with almost same information are to be given. This problem is caused by the fact that public institutions do not share their data to one another. Another case in point is the different databases created and used by Central Election Commission and State Election Commission.

All the state governments use their own languages for the user interfaces and the way they are stored in database. If there is a need of reference of this data by other state government, it is not easy to translate to the respective local languages. Citizens face difficulties like in the case of a Ration Card transfer from one state to another state with each state making it mandatory to have their data in respective local languages.

Therefore, there is a need of a new kind of infrastructure to integrate data, one that conforms less to existing government boundaries.

2.5. Privacy and Security Barriers

E-government will only succeed if the customers have full trust in all the backend processes of e-governance. Without trust, e-government will never reach its full potential.

The privacy and security issues are at the core of a trusting relationship between governments and citizens. This is understandable and known the importance and sensitivity of the information governments collect from citizens.

Privacy and security issues drive or drag the information economy. Without sufficient protections, there will be no consumer-confidence in e-government. Governments need to reassure the public that e-government is safe and secure for users. The credibility for e-government is certainly more if there is more consistency in violation of security and privacy policies by information systems.

3. SOCIAL SECURITY ISSUES IN E-GOVERNMENT

E-government changes the face of social security [1] in an immense way. Citizens and employers will receive information with confidence from the government if the new services delivery mechanism developed with reputation and credibility of the social security of an organisation[7]. That may of course increase the standard operations cost. It introduces radical changes in the processing of claims for benefits, the assessment of workers' entitlements and the payments of benefits, all of which will be administrated by the new information systems designed to strengthen the processes requiring client attention while, at the same time, reducing the paper work to complete these processes[8]. Few of the security issues discussed below

3.1. Identity Theft and Identity Fraud

Identity theft and identity fraud are emerging issues that arise both in the security and in the economic crime context. Identity theft and identity fraud have flourished in recent years. Public is in fear of economic and other risks prompted by this problem. A search for new security features on identification cards and other smartcards, which provide the basis for many commercial transactions and interactions with government. Identity and confidential information given to the governmental organizations by public oozes in the hands of frauds or criminals, which may leads to destructive effects to public and less confidence of government ICT based services among public.

3.2. Fraud in Online Payments

A troubling aspect is that ICT and electronic commerce now becoming viewed as increasingly susceptible to misuse, especially in the case of online payments over the Internet. There appear to be mounting risks associated with data confidentially, availability, integrity, and Consumer & merchant authentication. Problems not only give rise to direct costs for firms and individuals, but also indirect costs associated with loss of flexibility, goodwill, market positions, strategic opportunities, etc. To a major extent, the issue boils down to a need for ensuring privacy and security, that leads to lingering subtle values of trust among public. Addressing these concerns is likely to be of great importance for the ability of the world community to realise the potential virtues of ICT. However, the risks stretch further because the opportunities for on-line transactions gradually enter in more area, which may accumulate tremendous power in destructive hands, and may undercut confidence in legislation as well as prevailing market forces in non-digital spheres as well. A case in point is the use of 128-bit encryption by most of the payment gateways in the country when it is known that such encryptions have been broken long back [8].

4. DISPARITIES IN ACCESS OF INFORMATION SYSTEMS

Another challenge for e-government is disparities in computer access. This challenge includes two policy issues: the often-described "digital divide" and accessibility for people with disabilities. In the case of the digital divide, not all citizens [1] currently have equal access to computers, whether due to a lack of financial resources or necessary skills. While the placement of Internet-enabled computers in schools and public libraries is helping address this issue, these efforts are still progressing. Some observers point out that much of what governments do involves interactions with people least likely to have access: the poor, the elderly, language-limited persons, and the less educated. Similarly, supporter for the disabled observe that computers can present new obstacles for citizens such as the blind or physically impaired, which may require costly hardware or software for their computers, such as screen readers or oral controls, to be able to access online information and services. Such peoples require the resources in such a manner that makes them accessible using these tools.

5. PROPOSED SOLUTION ARCHITECTURE

Various approaches applied in support of privacy, security and trust in the digital world. In particular, public key cryptography (PKC) and public key infrastructure (PKI), including digital signatures [6], which developed for, secure Internet enabled transactions. There are various reasons for the lack of progress. To some extent, these may be due to technical nature, regulatory issues and economic issues, which are very hard to eliminate in this area.

There appears to be a need for new ways of gaining trust. Digital certification is one of those areas where many actors are busy to develop proprietary solutions. According to a survey made by Deloitte Touche recently, shows that 45 % of firms have some sort of PKI solution in place. Digital certificates can be provided for applications that are given in table .1 below to enhance the security level, if not eliminate the present problems

Table 1. Services with the potential to gain from use of Digital Certificates

e-Governance	Tax authorities, tax report, tax forms e-procurement e-Tenders e-Voting e-District
Bank Transactions	Internet Bank ATM Applications for sending payments Credit applications Recharge of Cash Cards e-trade/e-commerce Cross border Payments
Other	Secure Communication Health Care Education/Exams Knowledge transfer Invoice applications Legally valid certificate like birth certificate position to represent

To fulfill the requirement of "non-repudiation", agreements must be clear and indisputable from the outset. For achieving global reach, the legal framework within each country, and the legal interpretation, need to be addressed. Many certificates are in place today because of various public and private initiatives. In most cases, however, they are primarily national in scope, and have limited geographical as well as sector-based validity. Most of the leading ICT adapting countries have still not adopted the use of digital certificates on a wide scale. Some of countries in Mekong Subregion (GMS), even though topper in technology development among other nations, an understanding of how to develop and implement solutions that rely on digital certificates is not fully developed for adopting it in e-governance. For digital certificates to be truly effective, they should work similar to a driver's license or passport, which is accepted wherever the person go. The certificate should be valid and easy to use.

A generalized multi purpose national framework for a national infrastructure that will enable strong authentication of users involved in electronic transactions [3]. A common bridge to enable the digital

certificate infrastructure to the entire country to link all central government organizations even to the global extent developed will satisfy one of the security requirements of "non-repudiation" in G2C service delivery models. Today, the issues are clearly a global one. The national infrastructure developed with highly available secured digital certificate management servers to serve the national framework throughout the country.

6. PROPOSED APPROACH TO ESTABLISH SECURITY INFRASTRUCTURE FOR E-GOVERNANCE

- All State government should follow a Common Security Infrastructure (CSI). Current State Wide Area Networks (SWAN) should be modernised of not to be developed to maintain the common security standards to satisfy the minimum needs of CSI.
- Digital Certificates are maintained and controlled within the National Cyber Security Authority (NCSA), which is a body formed for national security under ministry of defense. Other country and third party participation duly avoided in case of digital certificate.
- Public Key Infrastructure (PKI) should be implemented from the top level to the lower level of freedom in the e-Governance system infrastructure. The digital certificates should have adequate length to avoid frauds
- Unicode concept implemented using firewall protected Unicode servers, which should bridge in between national and state level infrastructure.
- National and state level datacenter enabled with digital signature, firewall and 24x7 availability with distributed database facility.
- Information superhighway (backbone network channel) for national level network should be developed for the communication of information with future ready large capacity bandwidth, which should support to at least next 100 years. (Statistical principles should be applied to find out future demand of bandwidth)
- Security priority levels developed by identifying the sectors with high-level risk to low-level risk and classified as higher, medium and low level. i.e. Defense, police, finance, will be classified under higher level. Business, Universities, Hospitals will come under medium level. Library, warehouse etc. will come under lower level. Based on the classification contingency planes should be developed for disaster management.
- Smart card should be given to citizens with integrated biometric identity (Technology should be developed to minimize the expense). Smart card issued to citizens in co-ordination with NCSA and the database should be centralised.
- NCSA appoints a high power rapid-action research and development group to analyse every day security threat and to take the contingency plan quickly to resolve the problem.
- NCSA develop an independent certification authority for the interoperability of PKI and facility developed for every department and agency to entertain the PKI facility.
- The proposed model of security infrastructure will interconnects all the critical infrastructure services at international, national, state level and local level through the security infrastructure enabled by authorization policy and security technologies.

7. SOLUTION ARCHITECTURE MODEL FOR E-GOVERNANCE IN GREATER MEKONG SUBREGION (GMS)

The solution architecture is a generalized architecture provides all the basic information about how the Information and Communication Technologies (ICT) utilised to enable the technology framework for e-Governance integrating all the levels for Governance to provide services to citizens with security. Fig. 1.0 explains the solution architecture for secured e-Governance. All the state governments are insisted strictly follow the norms of generalized architecture and standards to make the integration of state government with central government to fill the gap of information divide so that the services to the citizens can be delivered to their doorsteps without any inconvenience.

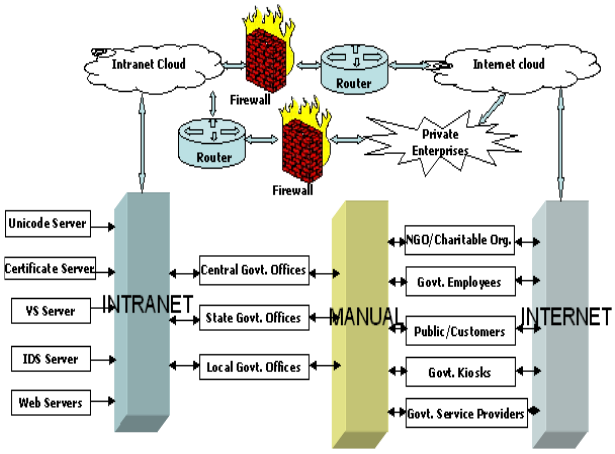
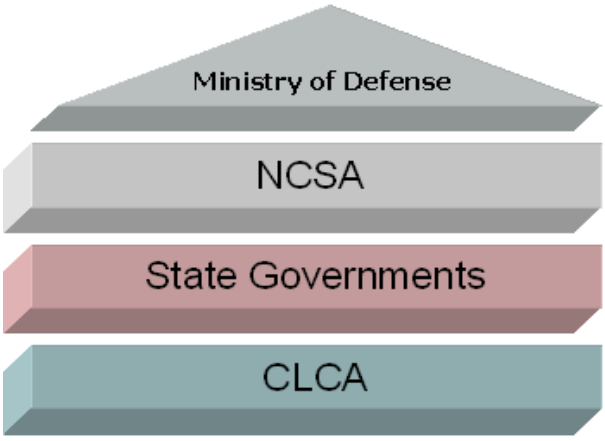


Fig.1.0 Solution architecture for e-Governance

- Central, State government offices and organizations were interlinked [3] by an intranet through security layer which will act as the backbone information superhighway for the entire Thailand.
- Central, State and Local government may do some activities manually or partial electronically e.g. Electricity, water spot billing. Data collected during manual operations are transferred to the Local Area Network (LAN) based systems, which are directly stored in remote databases under intranet framework for further processing. Some of the services were delivered to the customers/Government employees / public manually by the government offices (e.g. Universities send the mark list, degree through post) but at the same time services were available through internet also e.g. Result, marks of exams were available in internet or by voice response system or VOIP through telephone system.

- The intranet backbone network linked with Local, Central and District level datacenter through security layer will work with 24x7 architecture.
- For exchange of data from state government to central government with multilingual compatibility Unicode server should be maintained for the interchange official language to any other desired language. Central government should form an authority for regulation of linguistics as Central Linguistics Control Authority (CLCA). All state level governments should take initiative steps to develop Unicode for their own language with the guidance from the CLCA.
- Storage Area Networks (SAN) developed with generalized security architecture to store centralized data are enabled with Intrusion Detection System. Data from State, Central and Local governments will be stored in various levels of datacenters. The datacenter should include security layer to protect intrusion of hackers and unauthorized users to access data. Certified and authenticated users only allowed fetching data. PKI implemented in SAN datacenters.
- For online financial transactions, digital certificate based security is enabled to have a smooth hassle free transactions.

The above said architecture hierarchy is pictorially explained in figure 3.



NCSA- National Cyber Security Authority
CLCA- Central Linguistics Control Authority

Fig. 3. National security flow hierarchy diagram

- For Disparities in access of information systems, there is a need of initiating awareness among the public by the joint effort with NGOs and education based governmental bodies. Improving the literacy rate will thrive lot of changes among public. Indeed this process is a time consuming process to implement. For peoples with disabilities government can initiate the respective welfare organisations (e.g. Blind Federation, Deaf Federation) by funding to start training programs to train such disabled peoples with special electronic accessibility devices specially designed to access the information systems for that types of peoples that may be enabled with voice recognition etc. for their need. Thus the gap of the digital divide can be reduced drastically to have a better future.

8. SECURITY INFRASTRUCTURE FRAMEWORK FOR GREATER MEKONG SUBREGION (GMS)

To enable improved security and privacy there is a need to secure the entire network of e-Governance with multilayered security model. This approach will cover the entire system, which provides security for every layer in OSI model so that consistency in security of entire network of e-Governance from physical layer to presentation layer is applied. To enable this multilayered security [2], the layers logically organized into three levels by grouping some of the layers in each logical group, which are named as follows:

The Network Security Layer provides security functions at OSI layers 1 to 3 (physical to network layers)[2].

The Network-Assisted Security Layer provides security functions at OSI layers 4 to 7 (transport to application layers) [2]

The Application Security Layer provides security in layer 7 of the OSI model [2]

Security functions such as VPN, VLAN (Virtual LANs), port security, IP security, encryption and secure dynamic routing operate purely at the Network Security Layer. Others such as fire walling, intrusion detection, SSL encryption, content filtering and virus scanning operate at either the Application security layer or Network-Assisted Security Layer. Thus by enabling the multilayered security in a structured fashion the security can be tightened overall in the e-Governance communication networks and in service delivery mechanisms.

The following general principles are to be followed to enable the security infrastructure for e-Governance in Greater Mekong Subregion (GMS) countries:

- Use a uniform access management system for entire network that enabled in central, state and local government level with the appropriate level of authentication and resource access authorization to meet the basic security standards.
- Use of e-Governance standards
- Use of Standards like Web 2.0, e-Forms etc.
- Use a **centralized authentication** mechanism to facilitate administration and remove the need for locally stored passwords. Figure 2 explains the model of centralized authentication system.

Authentication systems are used to ascertain identity. There are various types of authentication in present scenario they are (i) Single-factor authentication uses user ID /password combinations to prove identity.(ii) Two-factor authentication requires two components, usually a combination of something the user knows (such as a password) and something the user possesses (such as a physical token Secure ID card). (iii) Three-factor authentication adds a biometric, a measurement of a human body characteristic [4].

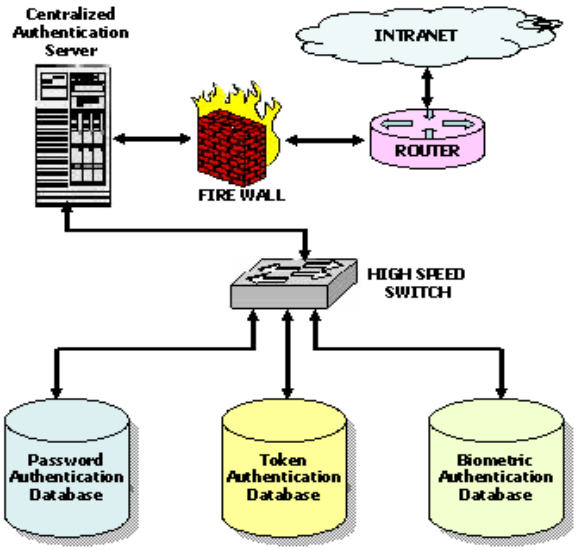


Fig. 2. Model of centralized authentication system

• Use a **centralized authorization system**, tightly coupled with authentication system, with appropriate granularity for the enterprise [3].

Once authenticated, authorization mechanisms control user access to appropriate system resources. Authorization can be categorized according to the granularity of control. Authorization is often "role based" whereby access to system resources is based on a person's assigned role in an organization. The System Administrator role may have highly privileged access to all system resources whereas the General User role would only have access to a subset of these resources. Authorization may also be "rules based" whereby access to system resources is based on specific rules associated with each user, independent of their role in the organization. For example, rules may be set up to allow Read Only access or Read/Write access all or certain files within a system, or access only during certain times or from certain devices.

• Enforce strong, complex rules for all passwords.

The Single Strong Password system enforces strict password rules. For example, passwords must contain at least eight characters, both upper and lowercase letters, and at least one number or symbol. Additionally, passwords must not contain dictionary words of four characters or longer, a previously used password, a password that matches an account name, contain a date or year, keyboard patterns, or repeating characters. Users are required to change passwords at predefined intervals.

• Securely store all passwords in encrypted standard format.

• Securely log or record authentication and authorization events for audit purposes.

9. CONCLUSION

The New approach and solutions would enable the true empowerment of both government employees and public of Greater Mekong Subregion (GMS) Countries best practices and the guidelines given will improve the credibility and reliability of the e-Governance service delivery mechanisms among the public. No system connected to the Internet is safe from attack but the solution architecture provided will reduce drastically the frequency of attacks in the network if not eliminate the entire attack and increase the confidentiality among the public. This paper gives a practical approach providing coverage for the multi-dimensional facets of e-Governance in terms of social security and challenges of Mekong Subregion (GMS) based countries. The solution architecture along with appropriate e-Governance standards for Meta Data, Security, Systems Development, language technologies, etc. would pave the way for new generation e-Governance practices.

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Development of Excellent Entrepreneurs in Small and Medium Enterprises in Laos and Cambodia

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Abstract— *Laos and Cambodia share many similarities: both struggled against the French colonists and the United States in the Vietnam War, and both also started driving national development through a market-oriented economy in the 1980s. To strengthen economic growth and poverty reduction objectives, the enhancement of Small and Medium Enterprises (SMEs) was used as a critical engine to boost the success of socio-economic growth. With the administrative and financial support of government, Non Governmental Organisations (NGOs) and international organizations, the number of SME entrepreneurs was increased in various businesses, including food processing, garments, construction materials, wooden furniture, tourism, trading, transportation and so on in both countries. This contributed to more job opportunities and higher national income, and reduced the unemployment rate of the countries. The competition amongst the SMEs became intensified, and challenged the entrepreneurs in terms of accessing modern technology, limited capital and management skills. This study uses evidence from in-depth interviews to explore the similarities and differences of the SMEs' entrepreneurial characteristics, business experiences, problems and supporting requirements in Laos and Cambodia. The findings lead to recommendation aimed at upgrading effective entrepreneurial skills, as well as proposing some alternative considerations for the policy makers for excellent entrepreneurial capacity advancement.*

***Keywords*— Cambodia, Laos, Entrepreneur Development, SMEs.**

1. INTRODUCTION

Laos and Cambodia share many similarities: both struggled against the French colonists and the United States in the Vietnam War. Both Laos and Cambodia also started driving national development towards the same goal of a market-oriented economy in the 1980s. To strengthen economic growth and poverty reduction objectives as requested by the Asian Development Bank (ADB), the enhancement of Small and Medium Enterprises (SMEs) are particularly recognized as a critical engine to boost the success of socio-economic growth. Just a few years ago, due to the administrative and financial support of governments, Non Governmental Organisations (NGOs), and international organizations, the number of SMEs in Laos and Cambodia has increased. These ventures have played a significant role in employment generation in handicrafts, small-scale agricultural processing, timber production, textiles manufacturing and trading; reduced the unemployment rate of the countries; and contributed to national income as a whole. However, SME development was not easy as several constraints have been encountered by the entrepreneurs as a consequence of many substitute products/services and many competitors existing in the market, lack of access to modern technology, and inconsistent macro-policies for SME development. This study uses evidence from in-depth interviews of SME entrepreneurs in Laos and Cambodia to investigate the nature of the SMEs, the constraints faced by the entrepreneurs, and how those challenges were tackled. The characteristics of the entrepreneurs, and supporting requirements in the SMEs of Laos and Cambodia were explored. Afterwards, the findings were compared and discussed in order to address the lessons learnt and to draw up recommendations aiming at fortifying SME development and promotion in these two countries. All these key elements are dicussed in this study.

2. LITERATURE REVIEW

Concepts of Entrepreneurs and SMEs

An entrepreneur is someone who is always bursting with new ideas, highly enthusiastic, hyperactive and insatiably curious [1]. To make a success of a business, an entrepreneur has to (1) hold a lot of commitment and hard work, (2) accept uncertainty to minimize risk by calling up more information, (3) have good health to plug any gaps caused by other people's sickness, (4) be self-confident to make the venture succeed, and (5) have innovative skills do old things in new ways [1]. There are four main forms that a business can take such as sole trader, partnership, limited company, and public limited company (PLC or plc). A sole trader normally relies on loans from banks or individuals and other non-equity sources of finance. Partnership is for two or more people to agree to carry on a business together, intending to share the profits. The limited company is formed by two shareholders, one of whom must be a director, the company's assets are separate from the people who own it. PLC is formed by anyone to back a venture with a country-specific value of nominal shares. Besides these four, a co-operative is an alternative registered form in

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which shareholders can share profits and control, where each member has only one vote.

In research [2], the definition of SMEs employed by the Australian Bureau of Statistics is that a small firm employs between 5-19 workers and a medium firm has between 20-199 employees. However, in the Lao context SMEs are viewed differently. According to the Decree on the Promotion and Development of Small and Medium Sized Enterprises (No. 42/PM), SMEs are defined as dependent enterprises that are legally registered and operate according to the prevailing laws of the Lao PDR [3]. A small enterprise normally has an annual average number of employees not exceeding 19 persons or total assets not exceeding US$25,000 or an annual turnover not exceeding US$40,000. A medium sized enterprise has an annual average number of employees not exceeding 99 persons or total assets not exceeding US$210,000, or an annual turnover not exceeding US$100,000. However, the SME classification determines the nature of the support measures available, according to the actual situation of the social and economic development in each stage.

Cambodia is at the crossroads of economic development. Development is taking place in an increasingly competitive regional and international marketplace, making it imperative that SME issues and challenges are successfully identified and addressed. However, Cambodia does not have a legal definition of what constitutes an SME. The problem with defining a small industry on the basis of the size capital is that the cut off point needs to be revised over time in order to allow for inflation. However, because not all firms revalue their capital in a uniform manner, inconsistencies can also arise. An additional problem with defining SMEs is that any definition must serve several purposes. According to the Ministry of Industry, Mines and Energy [4], one definition could be based on employment and the other on size of capital in real terms. SMEs in Cambodia are divided into three sectors (1) Production sector including agricultural processing, manufacturing and mining; (2) Service sector; and (3) Trading sector including wholesale and retail. There are four types of enterprises which are defined according to the number of employees and the value of fixed assets (excluding land), such as micro enterprises, small enterprises, medium enterprises and large enterperises. Micro enterprises employ less than 10 people and have fixed asset values less than US$50,000; small enterprises consist of not more than 11-50 employees and fixed assets value between US$50,000-250,000; medium enterprises have between 51-100 employees with the value of fixed asset around US$250,000-500,000; and finally large enterprises employ over 100 people and have fixed assets value of more than US$500,000 [4].

Previous Study of SME Development in Laos and Cambodia

The World Bank is one inportant participant that argued that fostering economic growth through free and open markets was the better way to alleviate poverty [5], while the ADB supported an investment of around $5million in the Mekong Enterprise Fund (MEF) to support SME enhancement for Cambodia (25%), Laos (10%) and Vietnam (25%) [6]. To meet the commitment of investment in a sustainable development way, the entrepreneurs are required to differentiate products/services and segment markets, as specified by the Law [7]. The study on Generating Employment through Micro and Small Enterprise and Cooperative Development in Lao PDR confirmed that SME enhancement did not only contribute to the creation of employment, but also contributed to mobilization of the country's resource with less external dependency, and help family members to utilize their available talents and resources to operate single or multiple enterprises. Around 259,000 full-time workers were employed in small enterprises - 10 times the employment created by large enterprises in 1996 [8]. The promotion and development of small business operations furthermore provided alternative opportunities for farmers and senior governmental employees to obtain jobs upon their retirement. The study showed that 43% of former farmers and 30% of retired governmental employees were occupying a career in small business, mainly engaged in the commerce and manufacturing sectors. A further 6.8% or 162,420 persons with disabilities (mostly resulting from accidents with unexploded ordnance in the North of Xieng Khoung and the South of Savannakhet), were investigated by the National Committee for Handicapped Persons. Based on that problem assessment, government agencies and international donors organized rehabilitation and other technical training courses to improve and enhance their skills and performance to help them into employment until they are able to run a micro business or become SME entrepreneurs.

Key international agencies of business developments in Laos are JICA, ADB and UNIDO which support through mainly providing rural access roads, power generation, and distribution. With cooperative support from goverment, NGOs and international organizations, the number of SMEs in Laos significantly increased from 10,735 units in 1995 to 25,993 in 2005 [9]. Nevertheless, it was found that there were unfair practices in accessing finance, credit unions, and raw materials as the larger enterprises got more support whereas the smaller enterprises faced complicated and lengthy administrative procedures and corrupt practices by officials. Even though small ventures existed; they were still less competitive in terms of price, quality and distribution. The small enterprise owners often have limited knowledge of business law and taxation. A study by ADB on SME development in Vietnam, Laos and Cambodia also showed that SME operation in these three countries still encountered many constraints such as the lack of capital, limited demand in the market, too similar competitors, lack of access to modern technology and inconsistent macro-policies for SME development [10]. To enhance SME development and promotion sustainably it is necessary to obtain considerable assistance in terms of infrastructure development, accessible credit unions, marketing study, and development of transparent macro-policies as SMEs had different target markets, faced different challenges and

required alternative support, as argued by Thikeo [11]. The development of small enterprises of Laos is confronted with many challenges, mainly the lack of awareness of skill deficits, low competition in terms of quality, implications of modern technologies for business management and communication, productivity enhancement and marketing. Medium ventures are still challenged by products/service quality improvement, scale of production, unit and transaction costs. To deal with these challenges, medium enterprises urgently need to improve the business environment, acquirea deep understanding of accounting and finance management and the implications of Total Quality Management (TQM), Balanced Score Card (BSC), and obtain on-going updated market information [12]. These issues are explored in the following sections.

3. METHODOLOGY

To explore the context of entrepreneur development of SMEs in Laos and Cambodia, 28 key informants were interviewed face to face. Thirtheen individuals were randomly selected in SMEs in Vientiane Municipality and Savannakhet Province of Laos and 15 entrepreneurs of SMEs in Phnom Penh, the capital city of Cambodia. The entrepreneurs are involved in a variety of activities such as hairdressing, construction services, construction material retail, grocery retail and others were randomly selected by using convenience and snowball techniques. These approaches were considered to be useful and suitable for this empirical study since, by interviewing unknown entrepreneurs in the private business sector, it was assumed that they would be hesitant to share information, opinions or experiences of their business fields. Consequently, convenience and snowball approaches were chosen as it was believed that this would provide accurate and reliable information. Interview agendas were designed to identify the characteristics of entrepreneurs in SMEs, the problems facing SMEs in the globalization era, assistance and support from government and other relevant agencies. Further, this research is a qualitative study, aiming to explore naturally the concurrent practice of SME entrepreneur development in Laos and Cambodia. During interviews, the researchers made records in compliance with direct observation, and used the content analysis method to analyse the obtained information. Content analysis, a tool for measuring the semantic content of a communication [13], was used to diagnose the findings of the primary and secondary data.

4. RESULTS AND DISCUSSION

4.1 Case Study of Laos

The promotion and development of SMEs in Laos is chiefly administered by the SME Promotion and Development Office, in accordance with the Decree on the Promotion and Development of Small and Medium Sized Enterprises (No. 42/PM), which is aimed at expanding commercial goods production, trading and service business activities as well as contributing to employment creation, the raising of living standards of people, and gradual industrialization and modernization to contribute to the sustainable growth of the national economy. SMEs in Laos are categorized into three groups (1) SMEs operating in the commercial goods sector, (2) SMEs operating in the trade sector, and (3) SMEs operating in the service sector. The mandate of SME Promotion and Development Organizations at the national level consists of (1) the National SME Promotion and Development Committee (NSMEPDC), which will operate and advise the Government of Laos (GoL) on policies and SME promotion and development projects and programs, (2) The Standing Committee of the National SME Promotion and Development Office (SCSMEPDO)— not more than nine members of the National SME Promotion and Development Committee shall be appointed as the members to assist the NSMEPDC, and (3) the National SME Promotion and Development Office (NSMEPDO), to administer the practical operation of SMEs. The goals, however, would never be achieved without the contribution and high efforts of the individual entrepreneurs themselves. Consequently, the next session will address the entrepreneurs of SMEs in practice.

Profiles of Entrepreneurs and Attributes of Expected Employees

All 13 interviewees were of Lao nationality and Buddhists (6 in Savannakhet and 7 in Vientiane Municipality). Eleven of them were female entrepreneurs, and 11 were married, one was single, and one was widowed. Five of them were 21-30 years old; three were between 31-40 years old; three were between 51-60 years; and the other two were 51-60 years old. Five of them held bachelors degrees majoring in business administration or engineering; and the rest had various educational backgrounds, such as Lower-Secondary School, High School and Vocational School in electricity and teaching skills. All of the SMEs had been officially registered before starting operations. In practice, several of them had registered capital of less than US$10,000 and a few had registered capital of around US$10,00-50,000, which means most of the key informants interviewed had small rather than medium enterprises. Most SMEs were under the family ownership and control, meaning that businesses have family members as employees, influence in decision-making, and exist with a particular intent to transfer the family firm from one generation to the next generation. Other business ownership structures also existed, including a business registered as a limited company but still owned by a family. Interviews revealed that SME business ventures have been continuously established from 1991 until 2007. As start-up businesses, the number of employees employed ranged from 2-4 and 5-8 persons; eight employees represented the highest number hired including the owner, family members and others; females were more likely to be employed than males were (25 female employees and 10 male employees at 13 SMEs); the capital for start-up investment was certainly dependent on the nature of the business and ranged from US$1,000-8,000; US$8,000-13,000; and US$13,000-200,000 as a maximum. The businesses that initially

invested around US$1,000-8,000 and US$8,000-13,000 mostly appeared to be commodity grocery shops, copying and office equipment, bicycle shops, gift shops, clothes boutiques, and so on; meanwhile the businesses which invested higher capital (around US$8,000-200,000) were in wooden furniture, schools, tourism and car retailing and food manufacturing. The 13 entrepreneurs revealed average annual revenues of US$1,000-3,000; US$3,001-7,000; and maximum US$7,001-54,000. These figures show some businesses were loss-maing and others profitable. However, it was common for many businesses to sustain losses for the first or early years of investment as investors had to pay several operating costs, especially for fixed assets. Nevertheless, a few of them still obtained higher revenues in comparison to capital invested in the first year, showing that it was not always true that the businesses suffer losses as a start-up business. As an on-going operating or existing enterprise, most of the business owners accepted that they kept increasing the capital on operating cost annually, based on social and economic circumstances (ranging from US$500-11,000; US$11,000-42,000; and US$42,000-56,000); and the number of hired employees also increased, ranging from 2-8, and 9-18 employees. Again, the facts showed that more women were required (29 females and 13 males within 13 SMEs). These figures indicate that the performance of SMEs develops as the size of their businesses grow and are required to employ more employees to facilitate/provide services for customers. In addition to operating their own businesses, some of them are also worked for the government sector or other private companies.

According to the interviews, most of the entrepreneurs said that they initially preferred to hire employees who have good interpersonal skills and ability to interact well with customers, are honest and offer sincere opinions towards a particular situation, as well as having a high level of responsibility in dealing with their duties. Besides, potential employees should be cheerful, friendly and good looking to attract new customers as well as maintaining existing ones, and be able to speak other languages such as Vietnamese, Chinese and, principally, English. Females were preferable for most SMEs as entrepreneurs believed that women were hardworking, tolerant and worked well with clients. Family membership was another critical attribute to which business owners gave first priority in employment decisions. It emerged that educational levels were not very important in recruitment decision-making as long as applicants have working experience related to the available jobs. In addition, several entrepreneurs had moderate intent to hire relatives before considering employing other people like neighbours and friends who are already known. The main reasons that the entrepreneurs opted to invest in such business areas mentioned above are (1) the entrepreneurs firstly would like to be their own boss and manage the business with their own management style, (2) then pursue their personal interest such as inventing wooden objects which illustrated their abilities, talents and experiences in a particular ventures, (3) to seize advantages where there was high customer demand in the market; and (4) some of them saw their friends doing good business and they viewed it as something which was not difficult to manage. The products which are currently available in the market included domestic and imported products. The domestic products were largely related to Lao cigarettes, Lao plastic bags, Lao soft drinks (Mirinda, Pepsi, Coca-cola), Lao beers, sweets, papers, garments, powder and others. For imported products, most of them were imported from Thailand (food commodities, office equipment, bicycles and clothes), China, Vietnam (books and some food commodities), Hong Kong (clothes), Japan and Italy (cars) respectively. From the interviews, it was clear that most investment capital was owned jointly or shared by family members, as it was common for family members to help or lend to each other to contribute to business investment even if they feared tgat they would lose capital early in the business venture. Another important source of capital was self-contribution. It is very important for business initiators to have their own money before borrowing from other sources to start-up a business; otherwise it would be uncertain whether they would be able to repay their creditors. Very few of the interviewed entrepreneurs intended to borrow money from other lenders as it was difficult to convince the informal lenders if they did not already know one another well. Approaching formal creditors was even more complicated and difficult since they had to prepare many official documents, property certificates and many steps to be processed.

Successful Traits for SMEs Entrepreneurs

The number one characteristic of successful entrepreneurs was to be highly educated and have both conceptualized skills to form ideas and direct their thinking, and technical skills in terms of marketing, finance, business administration and practical experience. Secondly, it was important to obtain the involvement of employees. Thirdly, they should be initiators to introduce new ideas, have competitive endeavour to accomplish objectives, be confident and certain of what will happen and that it will follow a defined direction, and be passionate that the business will positively influence people's lives and bring financial rewards to the enterprise, as well as dealing with problems openly and honestly in order to create organizational trust and make employees feel that they are of value to the firms. Fourthly, the interviewees also observed that the entrepreneurs were to be clear about what they expected to do, be ready to take immediate decisions and take risks in the event of either pleasant or unpleasant unexpected events. Listening to the customers certainly helped the entrepreneurs to adapt their service to satisfy customers' needs too. However, surprisingly, even though it is largely known that the business operation would not be able to achieve its goals without the contribution of employees, entrepreneurs neither prioritized skill development of employees nor planned to reward employees for their performance enhancement appropriately.

Benefits, Constraints of SMEs and Problems Solving

Several entrepreneurs observed that they obtained many benefits from their businesses operations. Primarily, they absolutely held the entire decision making themselves, while the earnings gained from these ventures helped generate household income for family members and also contributed to an increase in national employment. Operating their own businesses was more enjoyable and they felt relaxed and flexible enough to change quickly or adapt to different circumstances and develop new skills at the same time. Besides, some interviewees pointed out that they had an independent life style to deal with their own businesses and had more opportunities to meet and get to know other people. However, even though it was acknowledged that starting a new venture was expensive, these ventures more or less helped entrepreneurs to gain moderately satisfying returns. The entrenepreneurs' skills and abilities furthermore improved, and they undoubtedly had time to stay with thier families and directly communicate with customers and suppliers. Not only did entrepreneurs acquired these advantages, but the SMEs also contributed to poverty alleviation in terms of unemployment rate reduction, household income generation and national income contribution through taxation and other supporting fee payments as defined by the law. Hence, if the GoL attempted to boost the performance of the SMEs, they should facilitate and strengthen the competence of entrepreneurs. To gain high return or sustain the business was not an easy exercise as a number of recurrent constraints were confronted, in particular many substitute products/service and plenty of competitors, which gave customers more bargaining power. The technology development and economic dimensions were further constraints to business growth, while the inflation and exchange rates had strong influences on product/service prices. Social and geographic phenomena are also important, including the climate and the fact that 80% of the population live in the countryside, which have negative business effects because the number of customers is reduced (the customers in these SMEs are chiefly regular customers). In brief, these constraints possibly made some businesses close down after a few years of operation. Apart from these constraints, other restrictions included inadequate capital for business expansion and development, lack of management skills and limited experience, as well as unfair support from relevant authorities, for instance, slow processing of documents.

In terms of dealing with these problems, many entrepreneurs chose just to let things be, while others preferred cautiously to study the customers' needs and provide a variety of products or offer more choices to meet demand, as well as continually adjusting the business strategies in response to the market environment. Some ventures used strategies of price discounting, sales promotions and giving extra gifts, coupons etc. In the education business, for example, the business owners opted to recruit skillful and qualified teachers, adapt the teaching curriculum, set appropriate rules and regulations, and facilitate targeted customers to ensure the quality of products/services. Providing a variety of products/services and expanding new branches to different markets in combination with suitable location selection were other techniques that had been applied to develop business performance. It is not surprising that very few ventures planned to go to international markets such as Europe, Japan, Vietnam markets and others because the products to be exported were required to meet international standards. Additionally, most of the products available in Lao market are imported from neighbouring countries and suffer from the limitation of logistic channels, knowledge and capital capacity as well as high labour cost in other countries; it is difficult to expand the business in regional/international markets. The new potential entrepreneurs of SMEs were initially suggested to be clear first of all about what their target market would be, obtain adequate capital and be ready to cope with potential challenges. Shop decoration and convenience-focus organization of stores was observed in almost every venture. In addition, new entrants were also advised to be tolerant and brave to invest and take risks, to love their jobs, and have good connections with others in society. These attributes were required for success because experience alone was insufficient.

Briefly, Lao SME performance is highly associated with the assistance of GoL agencies, NGOs and international organizations, and predominantly to the strong endeavour and capacity of venture owners. The entrepreneurs, therefore, are required to understand precisely what they are doing and where they are for the moment in order to bring their own capacity to bear and to minimise risks.

4.2 Case Study of Cambodia

Entrepreneurs Profile and Issues Challenging SMEs

Fifteen Cambodian interviewees from Phnom Penh agreed to give interviews in regards to this project. All of them are Buddhists. Two-third of the interviewees are male; 8 are single; 10 are between 21 to 30 years old; 3 are in early middle age (31-40) and the remaining 2 are between 41 and 50. Among the 15 interviewees, 1 used to study in primary school, 1 in lower-secondary school, 3 in high school, 1 in vocational school, 5 in university and the remaining 4 are pursuing Masters' degrees in the field of management and business administration. Six of the businesses were home-based business, 2 were family businesses, 2 were sole proprietorships and 5 were partnerships. Partnerships were important because most of the relevant interviewees were young university graduates and they did not have enough capital, skills and experience to set up business alone. Eight of them said that, at first, they had the idea to run a sole proprietorship business but it seemed very risky for them to invest their entire capital alone. They decided to ask their close friends and relatives to share part of the business. To do this, they made sure that many people can help each other to make decisions concerning the investment in this or that type of business activities. It is true that partnership provides a lot of benefits such as sharing the risk, providing a larger pool of capital and complementary skills [14]. For the young university

graduates to start SMEs, partnership would be the best choice for them. In regard to the financial source, one third used their own money, one third from the family and the remaining third from other partnership members.

Owing to business secrecy, six interviewees preferred not to reveal the source of their investment capital when starting their business or even the revenue earned per year. Others claimed that their investment started from US$3,000 up to US$40,000 for starting up the business and the capital was keeping growing because they tried to expand their business by adding more products and other modern equipment. Most of the businesses in this study were created during the early 2000s, when the economy of Cambodia was starting to grow. According to the National Institute of Statistics, the GDP in 1999 grew by 11.9% and the rate of growth declined to 6.5% in 2002 and then started growing again to 13.5% in 2006 [15]. This shows that economic growth has a strong impact on business. The majority of the interviewees strongly agreed that the political situation, economic situation, technology, social and geographical issues represent direct constraints for their businesses. Examples of this included the following: during the election, where political stability was uncertain, buyers tended to save more money, thus spending less because they were afraid that they would not have enough reserves for their family, since things can changed in just a blink of the eye. This is part of the trauma suffered by the people of Cambodia. Another issue related to technology, interviewees who operated business activities needing new technology to produce products claimed that the customers' buying decisions were also related to what type of technology they were using to produce the product. For example, in the construction service business, the customers would look at what type of new technological equipment or machine that the service providers used because they considered that new technology could build higher quality buildings or houses in a shorter period of time. This issue shows that customers nowadays have high bargaining power due to strong competition in the market. It is one of the challenges that SMEs in Cambodia now face. According to the interviews, the difficulties that the SMEs face in this globalized and competitive world are price fluctuations caused by inflation, which generates low profits, competitive pricing, cutomers' bargaining power, high technology, time and human resource management. In order to solve the aforementioned problems, interviewees declared that they have to be patient, follow up market pricing, make good relationships with customers aiming to keep a good image and lifelong relationships, provide good quality product and on time delivery and finally satisfy the needs of cutomers.

In order to obtain a slice of the market, SMEs have to compete with domestic and international competitors. The majority of domestic SMEs fail to perform well due to high costs and uncertain business environment [16]. The annual report of SME Sub-Committee[1] [16] classified the reasons for failure into four categories: (1) High regulatory compliance costs. The cost of establishing a business is about three times higher and takes more than 15 times longer than in Australia; (2) Lack of clear and market-oriented framework for SME development. Despite the importance of the SME sector, the government has been unable to develop a framework for its development. As a consequence, various agencies and line Ministries are developing their own SMEs programs, which are at times redundant and even contradictory; (3) Limited Access to Finance. Local banks provide only 1% of working capital and 1.7% of investment capital overall. Despite the liquidity of the banking system, it is difficult for banks to lend due to weak fiancial infrastructure, which makes the loan and collateral system uncertain. This is due to the lack of financial information resulting from the weak accounting standards and absence of a credit information sharing system; and (4) Poor market access infrastructure and information. It is difficult for local producers to meet both domestic and foreign market demand due to poor road conditions, limited internet and other telecommunication services and a lack of associations to assist in gathering information about quality and design requirements.

Successful Characteristics of Entrepreneurs in SMEs and Some Suggestions

The majority of the interviewees strongly agreed that entrepreneurs should, firstly, have clear vision and specific goals and objectives in doing business because if they do not know what they are going to do, they would not be successful in their businesses as well as in their lives. Secondly, they should have at least some educational background, experience, some management skills such as marketing, accounting, finance and talent for the business activities that they are exercising. This means that if they sell books, they should at least know how to read the title of the books (in Khmer, English, French or Japanese languages). If they are not able to read, they will not know which books they should buy to keep in their stores or which books will appeal to customers. The respondents suggested to potential new entrepreneurs to take into consideration what they are going to sell and they should know in detail about those things in advance before starting the business. Thirdly, entrepreneurs have to be initiators, innovators and not followers because the environment can change at any time without notice. Since it is impossible to escape these changes, it is recommended to keep changing product/service quality, price and design, as well as including other innovative ideas about products or services in order to create value added. Fourthly, entrepreneurs should be decisive decision-makers and

[1] The SME Sub-Committee was created in August 2004 and is composed of eight Ministries (Ministry of Industry, Mines and Energy as chair, Ministry of Commerce as vice chair, Ministry of Agriculture, Forestry and Fisheries, Ministry of Economy and Finance, Ministry of Tourism, Ministry of Women's Affairs, Ministry of Labour and Ministry of Rural Development as members) working with the Phnom Penh Chamber of Commerce and other private sector representatives with the responsibility of implementing the SME Development Framework.

risk takers. Nine interviewees agreed that it is important that the investment decision should be made quickly when the opportunity emerges and not wait in case the opportunity disappears. Sometimes, they know that the investment comprises many risks but the competitive situation urges them to take those risks in order to keep updated with changes.

Additionally, hiring the right person for the right job is very crucial for the success of entrepreneurs. Most of them preferred to hire people whom they already knew such as their relatives, friends and neighbours. The people concerned have to be honest, have good interpersonal skills and abilities, high levels of responsibility and be creative, although experience and skills are viewed as less important because most SMEs employees work in less skillful jobs which required them to use basic labour only. Business activities such as book shops, grocery shops, car spare part supply and hairdressing, are more likely to employ women rather than men since those jobs do not required physical strength to perform the needed duties. By contrast, in construction materials selling, construction, repair and maintenance service providers, male employees are preferred. Seven respondents noted that they gave rewards to employees who have achieved and performed well in their jobs. Most rewards were in the form of cash, materials and holidays. Finally, successful entrepreneurs have to be competitive, confident and passionate about what they are doing, as well as being good listeners to both customers and employees.

In brief, existing entrepreneurs recommended to new entrepreneurs to study supply and demand in the market, find good locations, employ new technology, provide good services and products at reasonable prices (as well as respecting quotations given) in order to build trust and long-term relationships and, finally, create a good image and keep monitoring and responding to changes made by competitors.

They mentioned that their success could not stand alone without the support of the goverment. Some suggestions were made during the interviews to the governement. The majority of them pointed out the importance of access to credit in order to help them establish their business. This means that some of them have plans to expand their business to other markets or to extend their branches to many other provinces but their wishes could not be realized due to the lack of finance. If the government can help to set up some policies which allow them to obtain loans, their future plan could be realized. Other suggestions referred to support requests in building basic infrastructure such as water supply, electricity, road installations and others. Nowadays, some SMEs are located in rural areas producing agricultural products and they could not bring their product to sell in the centre of the city because of the bad road conditions and transportation systems. They can only sell their product in nearby villages. The profit is very low compared to those people who can bring their products to sell in the city. Furthermore, they need some training and development courses such as marketing, accounting and decision making, in order to improve their skills and knowledge in doing business in a competitive environment. They even suggested that these skills should be included in the formal education curriculum. Some people could not continue their studies the family businesses need their help. They suggested that some vocational skills in the lower secondary school curriculum should be included. Twelve of the interviewees gave the importance to government policy and law reinforcement in SME promotion and development because it seems that there is no clear framework, rules or regulations for SMEs. However, the remaining interviewees said that the law was already issued but the ones who implemented it do not exercise their duties properly. They used those laws and regulations to obtain bribes because most SME entrepreneurs do not have knowledge about legal issues.

SME Contributions to the Economy and Poverty Reduction

Cambodia has a population of approximately 13.5 million people. Over 80% of the population lives in rural areas and agriculture, which accounts for over 70% of employment [17], is where most poverty is found. Over five million people or 36% of the population live below the poverty line[2] with 90% of these were found in the rural sector [18]. 99% of the firms, and 45% of total employment are dominated by the SME sector in Cambodia's economy [16]. They playing various critical roles not only in enhancing regional development but also in boosting the free market economy. The important roles of SMEs are summarized as following: (1) Generate employment opportunities, raise income levels and living standards, especially in the regions, poverty reduction; (2) Create an entrepreneur class, which is so necessary for industrial development; (3) Increase raw material supplies, especially to manufactured exports, which boost economic growth; and (4) Create self-employment, which would enable people to live and work with dignity.

Small-scale enterprises dominate economic activities and account for a substantial part of employment[3]. In 2005, the Ministry of Industry, Mines and Energy (MIME) [4] determined that there were 29,297 small industrial establishments with fewer than 50 employees[4]. This represents an approximate 21% growth in the number of establishments since 1999. Food, beverages and tobacco manufacture represent the largest number of small industrial establishments. Among these, approximately 90% are rice milling enterprises.

[2] The definition of the poverty line is based on the cash value of what it take to consume 2,100 calories and 58 grams of protein per day per person and to cover basic items like clothing and shelter. This is equivalent to US$0.45 per day.

[3] Accurate figures are not available. The dominance by small-scale enterprises incorporates economic activities in all three sectors-agricultures, industry and services, and includes enterprises based on the household and micro-enterprises.

[4] Data on small industrial establishments is provided by the Ministry of Industry, Mines and Energy. The Ministry, through its municipal-provincial departments, gathers information on small industrial establishments nationwide, including the number of establishments, capital investments, capital investment, labour, permit status and output.

Registered private enterprises constitute what is referred to as the formal private sector and number approximately 12,000. These enterprises acquire legal status as companies and sole proprietors through registration with the Ministry of Commerce (MoC) and are required to pay profit tax based on the real regime system, which relies on the submission of financial statements.

It is difficult to estimate the exact number of small enterprises, because there are so many unlicensed industrial establishments. According to MIME [4], there were a total of 21,516 small rice-milling enterprises of which over 10,000 had not obtained operating permits and were operating informally. These small rice milling enterprises accounted for 73% of all small industrial establishments and employed over 47,500 people. Food processors accounted for 81% of all small enterprises or 23,727 in number. Almost 12,000 of them did not have operating permits.

Regarding the interviews, the respondents answered the question of how can they contribute to the poverty reduction policy of the government by pointing to three major issues: firstly, SMEs provided employment opportunities to people who had little experience and skills and had low educational backgrounds, which resulted in household income generation for each employee; Secondly, they paid income tax and Value Added Tax (VAT) of 10% to the government, so the latter generated the revenue to pay national expenses such as civil servant salary payments. Some interviewees claimed that they had contributed to charities such as the Cambodian Red Cross and some orphanages as well. The entrepreneurs in the study were optimistic about their contribution to the economic growth and the poverty reduction policy of the government.

5. CONCLUSION

To conclude, the performances of SMEs in both Laos and Cambodia have gradually improved due to the fact that the number of SME entrepreneurs keeps increasing yearly. However, the main challenges that SME development in these two developing countries face are the unclear legal framework, the uncertain rules and regulations for SME establishments, lack of accessible credit, shortage of entrepreneurial and managerial vocational training centres, competition in terms of price and quality and the need for other support from the government and relevant agencies. To be successful entrepreneurs, they should be knowledgeable and tolerant, have experience, obtain adequate capital, and of course they should precisely understand the nature of the market and their target customers. However, it appeared that very few entrepreneurs had a focus on developing and strengthening employees' skills and performance even they recognized that the employees are the ones who most closely work with customers. To sustain the development of business, both entrepreneurs and government agencies are the main stakeholders to intervene and contribute support in all capital investment efforts and regulation reinforcements.

Apart from these similarities, some differences between the entrepreneurs of SMEs of Laos and Cambodia have been identified; they are summarized as in Table 1.

Laos retains the monolithic state mentality that means rules and regulations are created and enforced for all kinds of economic activities, even though technical capacity of state agencies often tends to be very limited in practice. Cambodia, on the other hand, has been more exposed to capitalist society and Cambodian entrepreneurs seem to have a more intuitive understanding of the needs that entrepreneurs must manage, while at the same time operating in something of a vacuum in terms of government support and, indeed, regulation.

6. RECOMMENDATIONS

To enhance the promotion and development of SME entrepreneurs of Laos and Cambodia, government agencies and other relevant stakeholders are suggested to (1) put strong effort into organizing a systematic training course for SME entrepreneurs in either management skills or rules and regulations enforcement; (2) support basic infrastructure such as water supply, electricity and roads improvement, together with convincing donors to contribute to SME development; and reinforce the regulations to avoid a special connection/biased treatment for particular operators; (3) develop the educational curriculum to meet the international standards and compete with other neighboring countries and encourage female entrepreneurs; (4) support accessible credit for business start-up; and finally (5) inspire entrepreneurs with disabilities to come forward to demonstrate their skills and even to establish their own businesses. Moreover, the tax rates should be decreased as their daily revenue was very low in comparison with annual capital investment; everyone should get an equal chance to access the credit unions; and the process for credit accessibility should consist of fewer steps; while government should urgently intervene in these issues and solve the disputes.

The recommendations explained above are strongly proposed for either entrepreneurs themselves or the relevant agencies in both countries. However, each country still acquires distinctive attention to improve its SMEs performance, as addressed in Table 2.

Laos already has certain institutions which might be used to help transmit necessary skills and competencies to entrepreneurs, perhaps in cooperation with NGOs. Cambodia, on the other hand, has very little institutional support and will need to rely, therefore, much more strongly on market-based provision of services. Managing these two different systems requires different types of skills and resources from the government systems in place and will be influential in structuring the relationships between government and entrepreneurs. More research is required into the issue of how, when and to what extent increased revenues will result from provision of the proposed services to entrepreneurs and whether government expenditure can be clawed back accordingly.

Table 1: Differences of SMEs Entrepreneurs in Laos and Cambodia

Nature of SMEs Entrepreneurs in Laos	Nature of SMEs Entrepreneurs in Cam
- The definition of SMEs in Laos prevailing in the Decree on the Promotion and Development of Small and Medium Sized Enterprises (No. 42/PM), the small and medium enterprises are defined according to the an annual average number of employees, total assets and annual turnover.	- Cambodia does not have a legal definition of what constitutes an SME. But according to Ministry of Industry, Mines and Energy, the definition could be based on employment and size of fixed asset values.
- Some attempts of the Lao government and other agencies towards the development of the SMEs entrepreneurs have been emergent among the SMEs entrepreneurs as some of them accepted that they had been invited to join some of the training programs in accordance to the interviews.	- None of the respondents claimed that they received technical support and advice from government agencies, which demonstrated the shortcomings of the governmental agencies.
- But surprisingly, the entrepreneurs in SMEs of Laos have not yet attempted either to enhance their employees' skills or plan appropriately to reward employees for their performance enhancement.	- Many respondents had recognized important roles of their employees by rewarding them, especially, in terms of cash, materials and holidays, aiming at motivating their employees to achieve and perform well in their job. Most of the rewards were given in term of cash, materials and holidays.

Table 2: Different Recommendations for SMEs Entrepreneurs' Improvement in Laos and Cambodia

Recommendations for Laos	Recommendations for Cambodia
- Initially, the venture entrepreneurs themselves are suggested to be self-enthusiastic in innovation of their skills and acquisition of continuous-learning attitudes in order to diversify new products according to the market needs as well as satisfying the customers' needs.	- It is necessary for entrepreneurs to have basic knowledge and skills about the products and services provided management skills such as basic accounting, finance, human resource management, quality control management, decision making analysis and to register their business in order to get some rights to access government support.
- Women should be encouraged to join as members of the Lao Business Women's Association (LBWA) as this association tries to unite all Lao women and to collect their wisdom and creative ideas to improve and promote Lao business women and their products and services.	- Additionally, entrepreneurs need to have clear vision, goals and plans for their business; to know what they are doing and encourage and reward employees for good performance and contributions; to employ new technology, and finally entrepreneurs must be risk takers, immediately decisive, patient, passionate and good listeners to customers as well as employees.
- For both small and medium enterprises, entrepreneurs urgently need to have a clear understanding of what they are doing, where they are now, and what they expect to achieve. At the same time, they provide specific needed skills of: accounting and finance management, marketing, implication of Total Quality Management (TQM), Balance Score Card (BSC), Innovation and Development, and have on-going update market information if they expect to sustain their business where there are high rates of new entrants, substitute products, and high bargaining power of the customers [12].	- As strong competition arose domestically and internationally, SMEs are recommended to build up good brand names supporting high quality products. This issue could not be done without the technical and advisory support from the SME Secretariat committees and the related civil society working in the field.
- It would be great if an e-commerce platform for products and services of SMEs group were introduced in order to develop the Lao product and services directory, and link them to the GMS region to support for the regional transactions through GMS e-commerce portal but based on the basic rules of each individual country. It would be even more beneficial if the logistic, supply chains and payment system (through e-finance and banking) for each professional business association of Laos are officially and securely developed and linked with other GMS countries.	- Last but not least, to respond to the foreign competitors, the local producers and the service providers who have the same or substitute products to work in team by set up an association in order to reduce domestic competition and to concentrate the power. Thus associated members have stronger bargaining power over the suppliers as well as customers.

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Economic Integration and Adaptive Strategies of Farmers: How Garlic Farmers in Chiangmai Coped with FTA

Narumol Nirathron

Abstract— The paper examines the effects free trade, a second degree of economic integration, on the livelihood of farmers who grow garlic in Chiangmai, a northern province of Thailand. It also describes different strategies adopted among farmers in order to survive fierce competition and limited alternatives. The concepts of adaptive strategies and stakeholder analysis form the major theoretical framework. The areas studied include Chaiprakarn, Fang, and Mae Ai - major areas for garlic production. Stakeholders interviewed were garlic farmers, local merchants, government officials, academics and representatives of NGOs.

The study found that small-scale farmers are ill-equipped to cope with risks arising due to economic integration. The adaptive strategies in which the farmers engage depend largely on their economic, social and cultural capital. The study recommends that alleviation of negative impacts of economic integration should take a two-pronged approach: (1) Chronic problems in the agricultural sector such as oversupplies of produce and excessive use of chemical substances must be addressed; and (2) appropriate adaptive strategies are needed both for farmers who want to keep their occupation and for those who decide otherwise.

***Keywords*— Free trade agreement, agricultural workers, adaptive strategies and sufficiency economy.**

1. INTRODUCTION

The free trade agreement between Thailand and China, under the framework of the Asean-China FTA, took effect on October 1, 2003. Tariffs on vegetable and fruit products were eliminated, subject to HS 07-08, under the Early Harvest Programme of the Framework Agreement. Theoretically, free trade aims at cutting tariffs between countries. The basic reason for Thailand's active engagement in these trade liberalization efforts is the opportunity to enhance economic growth and development. Nonetheless, as Stiglitz [1] has observed, trade liberalization brings enormous benefits when there is full employment and the economy is mature. With full employment, a worker who loses his job can quickly find another. Where these important conditions are not met however, liberalization can expose developing countries to enormous risks. In particular, the less-privileged people in poor countries are ill equipped to cope with the attendant hazards.

This paper was part of a study on the effects of the FTA on farmers in the northern region of Thailand. The focus here is on farmers who grow garlic in Chiangmai province. An overview of the situation of garlic production in Chiangmai is followed by a brief outline of theoretical framework and methodology, and a discussion of the research findings. The paper concludes with a recommendation which takes into consideration the alternatives of adopting coping strategies in time of economic integration.

2. THEORETICAL FRAMEWORK

Free trade is based on liberal theories of international trade. The most oft-cited theories are the Principle of Comparative Advantage and The Heckscher-Ohlin or Factors Endowments Approach. Both theories emphasize cost-effectiveness due to expertise, efficiency and availability of resources as factors determining which commodities should be produced. There are also costs associated with free trade itself. The most frequently cited negative consequences are social repercussions affecting the livelihood of farmers who are major stakeholders. Theoretically, these negative ramifications can be effectively dealt with through proper preparation and adjustment, but joint efforts are required from the parties concerned.

The theoretical framework employed by this research consists of stakeholder analysis and adaptive strategy. In this analysis [2], stakeholders are in the value chain, i.e. farmers, casual workers, and garlic merchants, as well as those persons with the expertise to intervene and to control the intervention. According to Bennett [3] adaptation refers to ways of dealing with resources and people in order to solve problems and attain goals in time of change. Adaptation should include preserving the environment. Sustained adaptation implies goal attainment by individuals or groups and an on-going need for environmental preservation. Balancing calls for economic benefits with the duty to preserve the environment is vital to the sustained livelihood of farmers.

Farmers in the context of globalization have to manage

This paper is part of a 2006 research project funded by the Office of Agricultural Economics of the Ministry of Agriculture and Cooperatives. The author was in charge of a Post-FTA Assessment of the situation of local producers of selected agricultural products, namely garlic, onion, tea, fruit and vegetables, silk worms, and dairy and beef cattle.

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internal and external conditions in order to obtain the resources they need to survive. They must maintain relationships with fellow farmers, cooperatives, middlemen, and government agencies. Farmers are also exposed to various temptations which affect their consumption and way of life. Proper adjustments depend on factors such as understanding challenges, having good social networks and sufficient time to prepare, and being supported by enabling policy. In order to be surmounted, challenges must not be too complicated. The ability to adapt of individual farmers varies considerably.

A study of impacts of NAFTA in 2003 [4] reports that 6 years after the trade agreement came into effect, people in more than 100,000 farm households were jobless. In Mexico alone, the number of poor households increased from 36 percent to 52.4 percent. The study also found that capital intensive, commercialized farming and farmers who had larger operations, extended social networks, and were more in favor of the FTA were able to capitalize from the free trade agreement. For the most part, small farmers did not benefit from FTA because of their lack of resources. Some were able to form cooperatives and increase productivity, but others had to leave for big cities to find work. Interestingly enough, more labor intensive, subsistence farming with less use of chemical substances allowed farmers a better chance to adjust. These 'independents' formed small cooperatives or bargained for better access to markets. They also engaged in alternative occupations which enabled them to offset many of the risks imposed by free trade. Farmers were also found to be making good use of waste, which in some instances provided them with a higher income. This study recommended a close follow-up on adaptation. In 2005 [5], a subsequent study confirmed that subsistence farming tends to create resilience among farmers.

In the case of Thai farmers, another 2005 study [6] brought more news of the negative impacts of the FTA. This study suggests that Thailand's more lenient examination process facilitates the influx of produce from China. The same study found that Thai farmers use a number of different adaptive strategies. For example, they participate in the Royal Project to reduce risk, adjust their farming system, invest in more expensive equipment to upgrade the quality of their own production, and learn to act as middlemen. They also receive assistance from the government and seek help from the Bank of Agriculture and Agricultural Cooperatives. This study recommends that any assessment of FTA impact take into consideration contextual factors such as the socio-economic and cultural characteristics of the community.

3. METHODOLOGY

This study takes a qualitative approach, focusing on group discussion and in-depth interviews. The use of a qualitative method enables the researcher to witness the process of adaptation, in addition to analyzing the role of other stakeholders.

The areas studied included Chaiprakarn, Fang and Mae Ai districts in Chiangmai province, which produce the highest yield of garlic. Fifteen farmers were interviewed. Among them were members of agricultural cooperatives and landless farmers. Other stakeholders interviewed included two middlemen, seven government officials, two academics and two NGO staff.

4. GARLIC FARMING IN CHIANGMAI

More than 90% of the garlic plantations in Thailand are in the northern region, but statistics from the year 2003 indicated a continuing decrease in garlic farming. The planting season in Chaiprakarn, Fang and Mae Ai runs from October to November and the harvest takes place from January to February. Fresh garlic is plentiful in January and dried garlic begins to appear on the market about two weeks later. Generally, farmers sell both fresh and dried garlic. Dried garlic keeps well for six months. Most farmers rotate crops of rice, garlic, sweet corn, baby corn and other vegetables. Garlic requires approximately 100-120 days from planting to maturity. Before harvesting the garlic, chili peppers are planted in order to make the most of fertilizer still left in the field.

The value chain of unprocessed garlic starts with farmers who sell their crop to local middlemen. These entrepreneurs transfer produce to provincial wholesale merchants. The important markets in Chiengmai are in Sanpatong, Hang Dong and Chom Thong. The produce is then distributed to the Talad Tai and Si Moom Muang Markets in Rangsit before being passed on to retailers.

5. IMPORTED GARLIC

Statistics from the Customs Department confirm a sharp increase in garlic imports since 2003, as shown in Table 1.

The highest volume of imports comes from China, Myanmar and Laos, respectively. The volume of imported garlic from China increases in the third and fourth quarters of the year, while imports from Myanmar surge in May and June, periods during which local garlic has already been distributed (Table 2). By contrast, imported garlic from Laos floods the market from January to March. The major export markets are Malaysia, Indonesia, Japan and Taiwan.

Prices on imported garlic from China are relatively low, compared to local production. Since 2004, the average price, per kilogram, of garlic from China has been less than 6 baht. The price of this import, which arrives on the market at the same time as the locally grown, tends to undercut local prices in other periods as well. Furthermore, the cost of production of Thai garlic has tended to increase every year, as shown in Table 3.

6. FARMERS AND THE FTA : IMPACTS, ADAPTIVE STRATEGIES AND GOVERNMENT MEASURES

In all three areas of this study, only farmers who were members of cooperatives understood that the falling price of garlic was a consequence of the Asean- China Free Trade Agreement. The more well-informed asserted

Table 1. Volume (in%) and price of garlic imported from China

Volume of import (in % of total volume) Unit : 1,000 Tons

Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
2002	0.12	0.80	4.43	7.03	6.41	12.49	15.50	11.31	11.86	6.87	10.32	12.86	15.07
2003	4.06	5.32	8.65	5.81	6.90	7.12	12.78	11.76	5.05	8.40	11.75	12.19	41.16
2004	8.13	7.89	7.75	4.42	10.72	7.24	10.80	8.89	9.25	4.98	8.29	11.62	50.52
2005	7.62	5.09	8.10	8.23	6.99	7.62	11.95	11.98	7.83	6.20	11.76	6.53	43.79
2006	16.99	15.83	13.66	7.38	7.21	5.73	10.19	8.94	4.64	4.42	2.97	1.84	26.08

Price of garlic Unit : Baht/kilogram

Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
2002	6.97	9.16	6.93	6.50	6.74	6.91	6.10	6.26	6.11	5.74	6.44	6.52	6.42
2003	6.44	5.86	5.69	6.89	6.64	6.79	6.39	5.69	5.64	5.26	5.03	4.61	5.79
2004	4.59	4.82	4.37	4.31	4.12	4.70	4.42	4.58	5.10	4.91	6.08	5.18	4.77
2005	4.85	3.80	6.07	5.00	4.17	4.74	6.05	4.82	5.38	4.73	6.54	3.74	5.15
2006	3.28	3.34	3.49	3.93	9.21	9.45	11.48	9.03	8.49	7.78	8.68	8.97	6.21

Source : Customs Department

Table 2. Production of Garlic and Other Crops in Chaiprakarn, and Imports of Garlic from Selected Countries

Garlic	1	2	3	4	5	6	7	8	9	10	11	12
Local												
Fresh	●	●										
Dried		●	●	●	●	●						
Imported												
China						◆	◆	◆	◆	◆	◆	◆
Myanmar					◆	◆						
Laos	◆	◆	◆									
Others												
Rice						◆	◆	◆	◆	◆	◆	
Corn and Rhubarb					◆	◆						

that most farmers did not know about the FTA. These better informed individuals expressed anger toward the government [1]. The farmers said they had neither been informed nor consulted about the FTA. They asserted that only a select few were benefiting from the agreement, and that the government's action was a 'short term solution' which showed no consideration for the long term survival of Thai farmers.

Garlic generally earns farmers higher returns, compared with other crops such as soy beans or corn. Though much more investment is required, returns are also higher. Farmers would rather assume some risk rather than switch to other crops. Though the price of garlic has continued to fall, many farmers have preferred to keep on adjusting rather than begin planting a different crop. For many farmers, garlic farming is their way of life and their culture. One village headman lamented, "We have been in garlic farming for more than 60 years. Garlic has been our way of life since the days of my parents." Another village headman said "We grew up with garlic. It is our livelihood."

Farmers are engaging in various adaptive strategies, as follows:

1. By reducing his area for garlic farming, a farmer can receive a 12,000 baht per rai [2] subsidy. However, this option is open only to farmers who own their land or rent land under a written contract.

[1] At the time of the study, Thaksin Shinawatra was the Prime Minister of Thailand.

[2] 1 rai is equivalent to 0.4 acre.

Table 3. Areas of Garlic Plantation, Volume of Production, and Prices on Local and Selected Imported Garlic

Year	2002	2003	2004	2005	2006
Area (rai)	7,192	5,842	5,205	2,508	-
Volume (ton)	25,172	20,447	18,217	8,778	-
Volume/rai (kg.)	3,500	3,500	3,500	3,500	-
Cost/kg. (baht)					
Fresh	5.11	6.18	6.43	6.76	-
Dried	6.11	7.18	7.43	7.76	-
Price/kg.					
Local					
Fresh	6	4-5	5	7-8	-
Dried	25	22	13	34	-

2. Farmers can switch to other crops such as potatoes or sweet corn under a contract farming system recommended by the government. But for farmers, this is not a good alternative, as they have no bargaining power. Furthermore, returns on corn tend to be very low. The investment is not interesting, since profits tend to hover around just 2,000 baht per rai.
3. Some farmers are considering planting rubber trees as the government is urging them to do. Rubber is a valuable economic crop, though the investment takes 6-7 years to turn a profit.
4. Some farmers have tried to reduce their dependence on expensive chemical fertilizer by producing their own organic fertilizer on a trial and error basis.
5. Few farmers have become middlemen. Such a course is possible only for farmers who accumulate sufficient capital. Being a middleman also requires another set of knowledge and skills, beyond those developed in farming.
6. Some farmers who own land have stopped farming, offering their lands for rent.
7. Farmers without capital may hire themselves out for manual labor. Unskilled or semi-skilled male laborers receive 120 baht per day, female laborers, 100 baht.
8. Some farmers have migrated to the city.
9. One landless farmer said, "I really had no idea….How can we possibly cope with this? I wish the government would help us more."

Farmers were not impressed by the government's initiatives in coping with the impact of the FTA. They have felt that official the measures do not go far enough in solving their problems. Many are resentful about not being informed about a policy that has so negatively affected their livelihood. Most farmers want to retain their occupation. They expect the government to listen to them and to be more sincere with them, for they are major stakeholders. They expect the government to be more assertive about reducing the price of fertilizer and chemical substances, promoting off-season farming and contract farming, and providing marketing information. They also hope that the government will be more serious about strengthening agricultural cooperatives.

Officials in the Agricultural Promotion Department explained that the government has had a clear policy to reduce areas of garlic farming since 2003. Compensation for farmers who stopped farming garlic was raised from 1,500-2,000 baht in 2003 to 12,000 baht in 2005. To substitute for garlic farming, the government introduced a rubber plantation scheme requiring an investment of approximately 30,000 baht for 10 rai. But 6-7 years are needed till the investment pays off, and not every area is suitable for growing rubber.

Officials said that measures to counter the impact of the FTA should take into consideration the need to upgrade the quality of garlic, to cut production costs, and to preserve the environment, particularly the quality of the soil. They recommended the following measures:

1. Enforce zoning.
2. Promote a contract farming system that is just and fair to provide more alternatives for farmers. Any such system should take into consideration the interests of the farmers and enterprises concerned.
3. Encourage cutting production cost through the reduction (not the elimination) of chemical substances and the promotion of organic fertilizers. Farmers should also learn more about the importance of caring properly for the soil.
4. Agricultural cooperatives need to be stronger so that farmers will have more bargaining power.
5. Intensive campaigning should promote the use of Thai garlic.

These suggestions are supported by some academics and NGOs who have reaffirmed that the government still lags far behind in alleviating problems which threaten the livelihood of farmers. Academics recommend that the government obtain more reliable information about farmers and their organizations. Farmers are a diverse group in terms of mode of production, size of land-holding and access to resources. Measures to alleviate problems must take this diversity into consideration, it has also been suggested that farmers make use of cultural capital by seeking out niche markets and by creating a new identity for their goods and services. Farmers who have potential should be encouraged to enter new markets. They should have sufficient knowledge to exercise their economic rights. Given the many kinds of interventions possible, academics emphasize the importance of cooperation among the agencies concerned.

NGO staff sees the FTA as damaging the country's food security. They stress that remedial action is needed at the structural level – a reorientation of agricultural policy which emphasizes the balance between subsistence and export-oriented farming. Organic farming, alternative markets and a sufficiency economy all grow in importance in this view. The government should promote self-reliance in production and consider

the possibility of subsidies. Green markets should be established in all provinces along with a global network of organic farmers.

7. CASE STUDY

7.1 A Local Merchant

The subject of the study, a small-scale, local merchant, was formerly a farmer. He became a merchant after garlic prices fell in 2003-2004. This enterprising individual collects garlic on a round-the-clock basis from farmers in the village to sell to buyers.

The merchant owns his own land and continues to cultivate rice and peas for family consumption. Part of his land has been rented to other farmers. In 2005, he decided to take advantage of the compensation scheme offered to garlic farmers by the government. The money he obtained from that was used as start-up capital for his new venture as a middleman. This farmer-turned-businessman also borrowed from the Bank of Agriculture and Agricultural Cooperatives.

The decision to become a merchant came after he made his own 'cost - benefit analysis,' in which he compared what was to be gained from continuing as a garlic farmer with the perceived benefits of becoming a garlic merchant. This turning point occurred after he had been unable, for 2 consecutive years, to turn a profit as a garlic farmer. The investment he needed was between four and five hundred thousand baht per year. The merchant told how he started his new career as a small businessman. In 1991, he married and received 5,000 baht as a wedding present from the parents of his bride. The young couple began selling vegetables in the market as well as cultivating garlic on rented land. After 7-8 years they were able to save enough to buy more land and a pick-up truck.

Emphasizing the importance of frugality, the merchant said that they started from a small purchase and learned the trade gradually. In his view, most farmers were not well prepared for the impact of the free trade agreement. To offset the hardships it caused, farmers have to be frugal and practice good financial planning while they await some helpful intervention by the government.

7.2 A Farmer

This landless farmer was 40 years old. Before 1990, he farmed his parents' land. As he explained, his parents were so poor that their children had no clothes to put on. They farmed garlic and occasionally hired out as manual laborers. In hopes he might escape poverty, his parents asked him to ordain as a novice when he was eleven years old.

He left the monkhood in 1988 and married in 1993. His wife died when their daughter was only eight months old. The child is now 11.

In the year that he left the monkhood, the farmer went to Japan, where he worked as a manual laborer for 2 years. When he returned to Thailand, he started growing garlic on rented land. After the harvest, he went to work in Japan again. This was before his marriage in 1993.

According to this farmer, the price of garlic fluctuates every 2-5 years. His volume of production also fluctuates. At the time of this interview, he was planting only 10 percent of his land to garlic and was taking advantage of the state's compensation scheme.

The land where he once cultivated garlic is currently given over to eggplant, chilies and sweet corn. He currently works as an independent farmer and also on a contractual basis. He understands that imported garlic is coming in, not only from China, but also from Myanmar, Cambodia and Vietnam. He believes that the free trade agreement benefits only the industrial sector and not the agricultural sector. He suggested that the government find ways to slow the influx of imported garlic. They should encourage cooperatives to buy garlic from local farmers as storage is expensive. Citing his experience and his observations in Japan, the farmer said he had no confidence in his own government because Thai politicians have too many vested interests.

This farmer's ambition is to be a broker in the contract farming system. He noted that agricultural cooperatives could also act as brokers, but the cooperative system here is not strong, and the interests of the farmers are not well protected.

8. ANALYSIS

Analysis of the interviews and previous research confirms that measures to facilitate adaptive strategies of farmers should consider the following:

1. Cooperation among stakeholders, i.e. farmers, government officials, NGOs and academics. Facilitating adaptive strategies is not the sole responsibility of any single Ministry. It is imperative that the parties concerned be aware of their roles. The Ministry of Labor, the Ministry of Education and the Ministry of Social Development and Human Security, for instance, should be cooperating to reduce the vulnerability of farmers and to create a social safety net for the farm sector.
2. Respect for the economic rights of farmers includes ensuring they have good access to the information which affects their livelihood.
3. Small scale farmers also have a role in ensuring the nation's food security.
4. More reliable data on the diversity of farmers in terms of size, mode of production and access to resources is needed.
5. Strengthening farmers' organizations will help sustain the strength of farmers themselves. Good access to information and occupational skills contribute to the formation of strong groups.

9. CONCLUSION AND RECOMMENDATION

Economic Integration puts farmers in a more vulnerable situation. The free trade agreement is having multiple damaging impacts on farmers. For example, it exacerbates the farmers' already chronic problems of

high debts[4] and overuse of chemicals, and increases imbalances between demand and supply. These farmers are not prepared to compete in a free trade environment, particularly with the enormous influx of cheaper produce from China. Even the most basic requirements of readiness are not in place among most Thai farmers, who are the major stakeholders in this scenario. The FTA has taken them more or less completely unawares. Adaptive strategies of individual farmers depend on their economic, social and cultural capital. In general, Thai farmers are using strategies similar to those employed by farmers in other countries. Nor do the adaptive strategies of farmers reflect concerns for environment. The use of organic fertilizer emerges from the need to reduce cost rather than from a desire to protect the environment. Government interventions do not seem to recognize diversity among farmers.

This study recommends that alleviation of negative impacts of the FTA should be two-fold.

(1) Basic and chronic problems in the agricultural sector such as the oversupply of produce, the excessive use of chemical substances and need to empower floundering agricultural cooperatives must be seriously addressed. (2) Dealing with FTA-related problems will require that farmers who want to remain in their occupation be introduced to appropriate adaptive strategies, as should those who decide otherwise. It is imperative that the government acknowledge the diversity of farmers and those they collect and provide more reliable statistics for research. Farmers need access to appropriate technology and plenty of social capital as well, etc. Cooperation among concerned agencies such as the Ministry of Labor, the Ministry of Social Development and Human Security, and the Ministry of Education is also recommended.

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Greenhouse Gas and Aerosol Emissions from Rice Field and Forest in the Mekong River Basin Sub-Region

Sirintornthep Towprayoon, Sebastien Bonnet, Savitri Garivait and Amnat Chidthaisong

Abstract— *GHG Emission in term of methane and nitrous oxide were estimated using IPCC method with specific emission factor derived from the experimental site in Thailand. The estimation covered rain fed and irrigation rice fields both first and second cultivation in a year and the typical forest types in Thailand and Cambodia. GIS emission map of two land use were established for Mekong River Basin Sub-region using the information from each country. Identification of high emission and sensitive area are at the northeast region of Thailand and around TonleSap area in Cambodia. Carbon monoxide and particulate matter from rice field residue burning and forest fire were also estimated using method developed from IPCC. Data from remote sensing was used to compare the result of GIS map established from the studies. Hot spot of forest fire and biomass burning in Mekong River Basin Sub-region were identified. Both forest fires and paddy field burning activities are observed to peak during the first and last few months of the year from January to April and October to December. This seasonality pattern corresponds to the dry season, period during which there is a lack of rainfall and vegetation fires are therefore detected to take place. Considering biomass burning and biogenic GHG emission, forests in GMS are sources of CO and TPM from biomass burning as well as less significant amount of N_2O from forest soil but are the sink of methane form forest soil. Rice fields with the high contribution for methane emission are likely to emphasize in terms of CO and TPM for local emission problems, while emission from forest should be concerned for the regional or trans-boundary problems.*

Keywords— **GHG emission, biomass burning, Mekong river basin, soil forest, rice field.**

1. INTRODUCTION

South East Asia covers an area of 410 million hectares with forest and agricultural land representing respectively about 77% and 20% of the total area. The agricultural land use in South East Asia has expanded only slightly from 16.8% of total land area in 1975 to 19.6% in 1992, but for the period of 1990-1995, the Asia Pacific forests observed a reduction by 17 million hectares, with the fastest rate in the Mekong region (1.6% per year) and in South East Asia (1.3% per year). Deforestation via burning and intensive agricultural activities results in the increase of GHG and aerosol emissions in the region, which are of main concern for their impacts on the regional air quality and global climate change. To ensure the sustainable development of the region, GHG and aerosols emission inventories need to be established to provide scientific information relevant for the formulation of appropriate control and mitigation strategies. In this study, we generated GIS maps of vegetation land use and corresponding emissions for the Mekong River Basin Sub-region (GMS), the calculation methodologies and data required to perform those emissions calculations were identified.

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2. CLASSIFICATION OF VEGETATION LAND USE IN GMS

To classify the vegetation land use of the GMS, we developed a Geographic Information System (GIS), incorporating a database of digital maps of the 4 countries included in the paper, i.e. Cambodia, Lao PDR, Thailand and Vietnam. Geographic data and their associated attributes, such as vegetation types, secondary data collected from literature review, from governmental agencies in charge of land development or land use management, e.g. Land Development Department in the case of Thailand, and from field surveys.

Two types of vegetation land use are considered in this study: forest and paddy fields. Regarding forest, 6 types were identified in Thailand including, mixed deciduous forest, dry evergreen forest, dry dipterocarp forest, moist evergreen forest and hill evergreen forest. These 6 types were selected on the basis of the calculation method established to estimate biogenic emissions from forest, since emission factors to be used are specific to the type of vegetation. Likewise, for biogenic emissions from rice fields, the emission factors are function of the water management system used for rice cultivation, and hence the classification of paddy fields was categorized in two major classes, i.e. rained and irrigated areas.

From the developed general GIS, the 1:250,000 scale map of vegetation land use including only forest and paddy fields was created, in order to serve as the base layer for locating emission areas.

The land use of the 4 countries of the GMS part of this study is classified in 3 major categories and is reported in Table 1. The corresponding GIS map is displayed in

Figure 1. According to this land use classification, it results that Thailand, with 170,157 km^2, has the largest forest area, followed by Lao PDR, Cambodia and Vietnam. However, with regards to the ratio of forest to total land, Cambodia and Lao PDR, , are largely ahead in the region with about 60% of the country covered with this forest. Concerning paddy fields, Thailand and Vietnam possess the highest numbers. This reflects the position of these two countries as major world producers of rice.

Table 1: Land surface of forest and paddy fields (km^2)

Type	Thailand	Cambodia	Lao PDR	Vietnam
Forest	170,157 (33%)	108,990 (61%)	142,602 (60%)	58,613 (18%)
Paddy fields	105,754 (21%)	17,024 (9%)	2,556 (1%)	48,611 (15%)
Others	237,450 (46%)	55,021 (30%)	91,642 (39%)	223,809 (67%)
Total	514,361	181,035	236,800	331,033

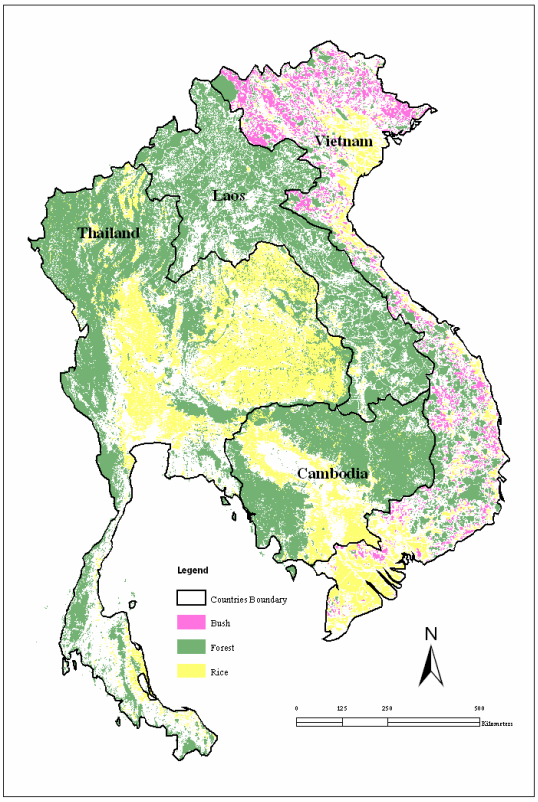

Fig. 1 Land use of GMS

3. ESTIMATE EMISSION

In this study, we estimate amount of greenhouse gases in term of methane and nitrous oxide from two major sources, Forest and rice field. The soil forests are differentiating by forest types and rice fields are differentiate by water management regimes. While aerosol emission, we estimate CO and TPM (total particulate matter) from biomass burns in the forest and agricultural residue (rice straw) burning in the rice field. Emission of these studied GHG and aerosol were expressed in GIS map to show the area of emission for four countries in the Great Mekong Sub-basin namely: Thailand, Laos, Cambodia and Vietnam.

Emissions from biomass burning activities [1]

a) Estimation of amount of biomass burned:

In order to estimate the amount of biomass burned per year as a result of vegetation fires the following general equation is used:

$$M = A \times B \times \alpha \quad (1)$$

M is the amount of biomass burned per year, (kg/year), A is the area of land cleared (burned) per year (m^2 per year), B is the above ground biomass density (kg/ m^2), and α is the Fraction of above ground biomass burned.

In the case of crop residues burning, the amount of biomass burned is determined using a modified version of the expression given in the IPCC revised guidelines (1996)[2] and also used in works of Hao and Liu (1994) [3] or Streets *et al*., (2003)[4]. It is as follows:

$$M = P \times D \times B \times F \times \alpha \quad (2)$$

M is the total mass of crop residue burned in field (kg), P is the crop production (kg), D is the crop specific residue to product ratio, B is the dry matter fraction (or biomass load if P is expressed in unit of surface instead of unit of mass), F is the percentage of dry matter residues burned in field, and α is the burning efficiency

Table 2: Data for estimation of amount of tropical forest and crop residues burned in Asia [2] [3] [4] [5], [6] [7]

Tropical Forest	Biomass load range (kg/m^2)		Burning efficiency	
	10[a]		0.2[b]	
Crops	Residue-to-crop ratio	Dry matter fraction	Dry matter burned in field**	Dry matter burned in field***
Rice	1.76[c]	0.85[d,e,f]	25%[d,e]	17%[d,e]

[a]IPPC (1996); [b]Levine (2000); [c]Koopmans and Koppejan (1997) [d]Hao and Liu (1994); [e]Streets et al., (2003); [f]OEPP, Thailand (1990)

b) Estimation of emissions from biomass burning:

The amount of atmospheric emissions generated annually by biomass burning can be estimated by the product of the amount of dry biomass burned (*Equation 1* or *2*) and the emission factor of a specific pollutant, as follows:

$$E_x = M \times EF_x \quad (3)$$

E is the emission of the compound x (g/year), M is the mass of dry matter burned (kg dm/year), and EF the emission factor of the compound x (g/kg dm burned).

A comprehensive study from Andrea and Merlet (2001) [1] provides emission factor for various types of biomass burning including tropical forest fires and crop residues burning. These are reported in Table 4.

Table 3: emissions factors [1]. [6]

	Tropical Forest	Crop residues
Compounds	Emission Factors (g/kg)[a]	
CO_2	1580 ± 90	1515 ± 177
CO	104 ± 20	92 ± 84
CH_4	6.8 ± 2.0	2.7
N_2O	0.20	0.07
NOx	1.6 ± 0.7	2.5 ± 1.0
TPM*	20[b]	10[b]

[a]Andrea and Merlet (2001); [b]Levine (2000)

Emissions from biogenic activities

Biogenic emissions from forest can be estimated using the following equation:

$$E = A \times EF \quad (4)$$

E is the emission of the compound x (mg/year), A is the land area of the forest vegetation (m^2), and EF is emission factors (mg m^{-2} d^{-1})

In order to perform these biogenic emissions calculations the type of forest considered is to be identified as the emissions factors to be applied are vegetation (soil) specific. Emission factors are reported in Table 4.

Table 4: Emissions factors for major types of forest found in the GMS [8]

	Emission Factors	
Types of forest	CH_4	N_2O
Mixed deciduous forest	-0.8	0.3
Dry evergreen forest	-1.5	0.4
Dry dipterocarp forest	-0.8	0.3
Moist evergreen forest	-1.4	0.1
Hill evergreen forest	-2.4	0.3

Vanitchang and Chidthaisong (unpublished data)

Biogenic emissions from paddy fields can be estimated using the following equation:

$$CH4 = Area \times EFw \times t \quad (5)$$

EFw is the emission factor (kg CH_4 ha^{-1} day^{-1}), t is the cultivation period of rice (day), and A is the harvested area of rice (ha)

The emissions factor indicated in Equation 2 accounts for the differences in water regime during the rice cultivation period. Values are reported in Table 2.

Table 5: Emission factor of water management system for rice fields [9]

Water management	Emission Factor (mg CH_4 m^{-2} d^{-1})	
	CH_4	N_2O
Irrigated (Single aeration)	97.2	0.29
Rain fed	45.7	0.29

** Towprayoon et al 2005 and personal communication*

*** t = average 120 day*

4. GREENHOUSE GASES AND AEROSOL EMISSION FROM FOREST

Greenhouse gases emission in term of CH4 and N_2O was estimated from forest soil using 6 types of forest as representative of GMS forest type. However there are limitation of data accessibility from Laos and Vietnam therefore the estimate focused only for Thailand and Cambodia. Emission factors derived from the experiment in Thailand which showed the negative emission of methane. Total methane emission sink of the two countries was -173.22 ton as seen in Table 5. Mixed deciduous was the major contribution of negative methane emission in both Thailand and Cambodia. Emission of nitrous oxide from soil forest, although the global warming potential was 310, was relatively small.

Aerosol in terms of CO and TSP from biomass burning activity in GMS was estimated. The biomass burning activities observed by ANDES for the 4 countries included in this paper are reported and converted burning area from the fire counts using the resolution of the satellite sensor, which was quite coarse in this case since it was of 2.7 km x 2.7 km. Consequently, each detected fire count was assumed to correspond to a 2.7 km x 2.7 km burned area. It was found that the peak season of forest fires in Thailand, Cambodia, Lao PDR, and Vietnam runs from January to April. Indeed forest fires are significantly detected from October onward, i.e. starting month of the dry season in the region. Result of emission of CO and TMP showed in Table 6. In general fires occurring in dipterocarp and mixed deciduous forest, are generally surface or ground fires, consuming only biomass accumulated on the ground surface or litter. These underline the important influence of local conditions or specificity on the emissions, especially those related to area of land and type of biomass burned. It is therefore of most importance to continue setting up field experiments and surveys to determine and monitor these parameters in the GMS, so as to be able to improve the mission inventory and its assessment. Highest emission of CO and TPM were from Thailand.

Table 6. Emissions from forest fires and forest soil

	Aerosol Emission		GHG Emission from soil	
	CO (ton/year)	TPM (ton/year)	CH_4 (ton/year)	N_2O (ton/year)
Thailand	*6,123,520.00*	*1,177,600.00*	*-144.2*	*39.6*
Cambodia	*2,860,416.00*	*550,080.00*	*-29.022*	*12.030*
Vietnam	*1,323,920.00*	*254,600.00*	*NE*	*NE*
Lao PDR	*2,116,192.00*	*406,960.00*	*NE*	*NE*
Total	*12,424,048.00*	*2,389,240.00*	*-173.222*	*51.6*

Table 7. Emissions from rice field

	Aerosol Emission from burning		Greenhouse Gas Emission from cultivation	
	CO (ton/year)	TPM (ton/year)	CH_4 (ton/year)	N_2O (ton/year)
Thailand	*79,705.85*	*8,663.68*	*1,059,330.17*	*5,630.82*
Cambodia	*7,944.40*	*863.52*	*147,328.60*	*827.13*
Vietnam	*37,303.55*	*4,054.73*	*NE*	*NE*
Lao PDR	*1,205.78*	*13.,06*	*NE*	*NE*
Total	*126,159.58*	*13,581.93*	*1,206,658.77*	*6,457.95*

5. GREENHOUSE GASES AND AEROSOL EMISSION FROM RICE FIELD

Using the emission factors obtained from measurement in Thailand, emission of CH_4 and N_2O from rice field of the whole country was estimated, based on the total area and land use classification. Estimation is only possible in these two countries because the information on land use classification in other countries is not available. Estimates were divided into irrigated and non-irrigated rice. Irrigated rice accounted for about 32% of the total CH_4 emission because rice is usually grown twice a year and emission per unit area for irrigated rice is about twice that of the rain-fed. On the other hand, although rain-fed rice area accounts for about 80% of total growing area, it contributed around 68% of total CH_4 emission (1.1 ×106 tons). However, only about 18% of total N_2O emission was from irrigated rice. Amount of CO and TMP estimate from rice field burning were lower than emission from forest due to the lower amount of residue burn. Major emission from rice field comes from cultivation.

Figure 2 illustrates that methane is contribute largely in the northeast of Thailand and around Tonle Sap of Cambodia. Figure 3 shows distribution of CO and TPM in GMS area.

6. CONCLUSION

Comparing two major emission sources, forest and rice field in GMS, rice fields act as the GHG source in term of methane while forest soil likely to become the sink. Although the forest area is larger than rice field the magnitude of sink and source cannot be comparable. However it is interested to study more on soil respiration where GHG sink can be interpreted as CO2 to increase capacity of sink by tropical forest. It is also noted that the EF of negative methane emission in the paper is in the early step of study. Both forest and rice field are source of nitrous oxide but not in the significant emission. On the contrary to GHG emission, aerosol shows greater contribution from forest which is due to the large burning area as well as control and management system in each country. CO from forest fire is quite large when compare to rice field. Although small amount of CO come from rice field burning but this source is closer to large community. The magnitude of aerosol emission can help confirm that emission from forest is likely to involve in regional problem than rice field which contribute more or less on local problem.

ACKNOWLEDGEMENT

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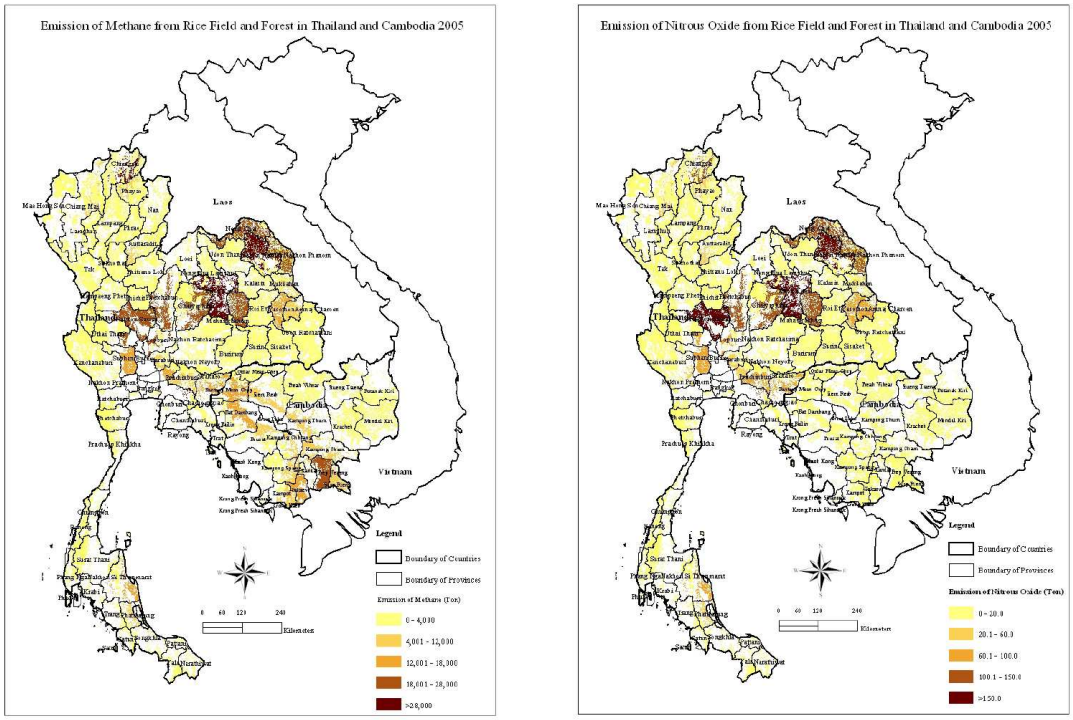

Fig. 2. Total CH_4 and N_2O emission from rice field and forest in Thailand and Cambodia

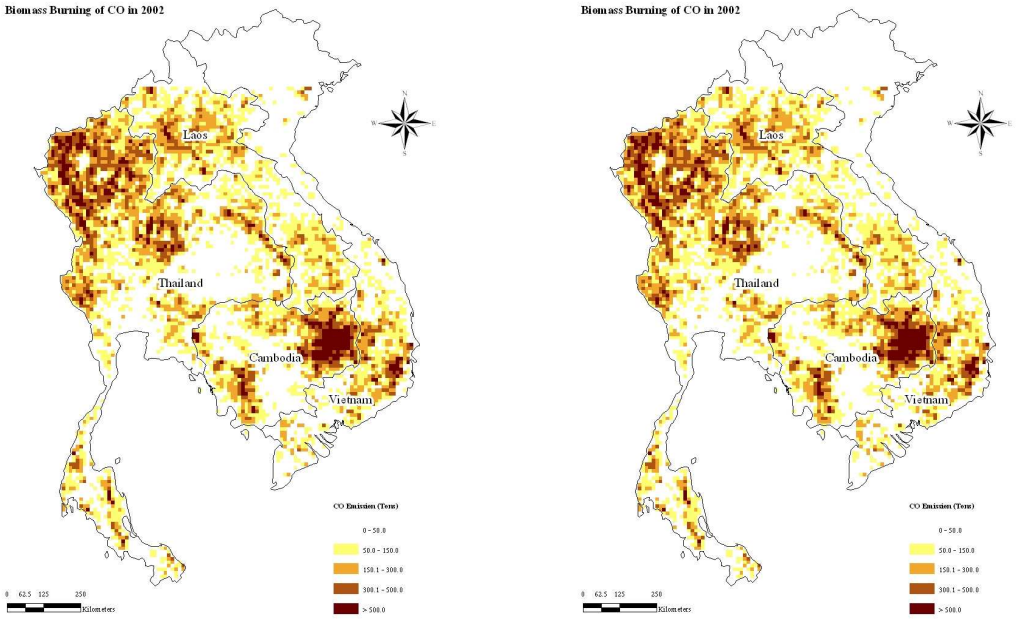

Figure 3. Total Emission of CO and TMP from GMS countries.

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Air Pollutant Emissions from Paddy Residues Open Burning and their Potential for Bioenergy in the Greater Mekong Sub-Region (Cambodia, Lao PDR, Thailand and Vietnam)

Savitri Garivait, Sébastien Bonnet and Orachorn Kamnoed

***Abstract*—** *An inventory of emission and emission factors of carbon monoxide (CO) and total particulate matter or aerosol (TPM) from biomass open burning in the Greater Mekong Sub-Region (GMS) was developed, in order to document the characteristics of this significant source of air pollutants in the region. This was conducted using remote sensing data in combination with ground-based observations, and vegetation land-use in each country. First, we prepared monthly gridded emission maps, to identify vegetation types subjected to open burning, and to investigate its spatial and temporal distribution. Preliminary results indicate that the major types of vegetation land use subjected to open burning in the GMS are forests and paddy fields. For the latter, the amount of rice straw and stubbles available for open burning in the GMS countries is estimated and converted to the energy equivalent in order to assess their potential as renewable energy resource at the national and regional scale. Results obtained in the case of Thailand show that about 48 million tons of rice straw and stubbles are available to open burning annually. Considering their calorific values for heat production, rice straw and stubbles may give rise to about 680 PJ.*

***Keywords*— Bioenergy, Emissions Inventory, Open Burning, Paddy Field Residues, Greater Mekong Sub-Region.**

1. INTRODUCTION

Biomass open burning is defined as the combustion of the world's living and dead vegetation, including grasslands, forests and agricultural lands after harvest for land clearing and land-use change. It has been recognized as a key driver for global change, since it constitutes one of the major sources of gaseous and particulate emissions to the atmosphere. These latter contribute to global environmental change by affecting local, regional, and global air quality as well as by disrupting rainfall patterns. In the ASEAN region, they lead to an air quality problem named transboundary haze, especially during the dry season in both hemispheres [1-2]. In the northern hemisphere the peak period is observed during January to March in the region including Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, and in the southern hemisphere during August to October, with a transport of haze from Indonesia up to the southern part of Thailand. To remediate this regional air quality issue, which was the origin of high number of patients among the population suffering of respiratory diseases, the ASEAN approved to set up the ASEAN Agreement on Transboundary Haze on a voluntary basis of participation and ratification. Once a member country accepted to ratify, the National Master Plan on Open Burning Control and the Open Burning Control Plan of Implementation should be developed and implemented. However, there is still a lack of reliable and up-to-date information on the spatial and temporal distribution of biomass open burning emissions in Asia, and more particularly in the Greater Mekong Sub-Region (GMS) including Cambodia, Lao PDR, Thailand and Vietnam, which could support the regional air quality modeling and monitoring in order to better evaluate their impacts on regional air quality and climate.

As part of this process, this research study focused on a spatial and temporal inventory of biomass open burning in the GMS, using remote sensing data in combination with ground-based observations, in order to develop a database of emissions and appropriate emission factors of carbon monoxide (CO) and total particulate matter or aerosol (TPM). Preliminary results indicate that the major types of vegetation land use subjected to open burning in the GMS are forests and paddy fields. Rice is the major economic crop in the GMS countries; the burning of rice residues, i.e. straw and stubbles, may affect not only local and regional air quality, but also national economy through the impacts of these burning activities on the soil structure, and so on the production yield.

In this study, a monthly 12 km x 12 km gridded emission maps of CO and TPM associated to open burning of paddy fields in the GMS was developed, in order to investigate spatial and temporal distribution. The obtained results are analyzed and discussed, with a focus on emission characteristics of this type of air pollutants source. Their contributions to the formulation of control strategies and mitigation policy measures, in order to support the ASEAN Transboundary Haze Agreement, are also evaluated. The amounts of rice straw and stubbles available for open burning in the GMS countries are also estimated and converted into energy equivalent in order to assess their potential, at the national and regional scale, for renewable energy.

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2. METHODOLOGY

Vegetation coverage of GMS

To classify the vegetation coverage of the GMS, a Geographic Information System (GIS) was developed incorporating a database of digital detailed land-use maps of Thailand, Cambodia, Lao PDR and Vietnam. Geographic data and their associated attributes were collected for the base year 2000 from governmental agencies in charge of land development, land use management, national statistics. The two main types of vegetation being accounted in this study are forest and paddy fields, and a 1:250,000 scale map including only 3 types of land-use (forest, paddy, and others comprising vegetation, constructed area, etc.) was created for each country of the region, in order to serve as a base GIS layer for classifying emission areas (Fig. 1). In the case of Vietnam, bush was also included to better account for vegetation frequently subjected to open burning.

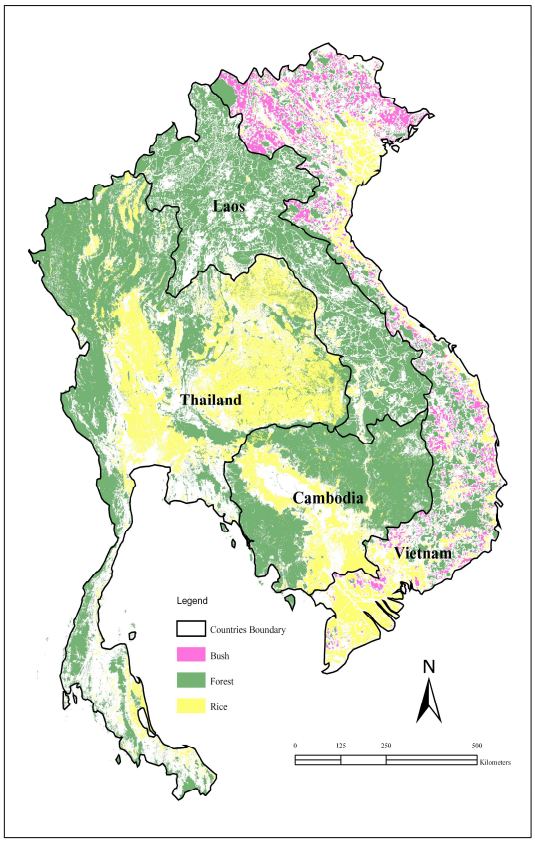

Fig.1. GMS vegetation map – Base year 2000

Figure 1 indicates that paddy fields are mostly located in the central part of Cambodia, in the central and northeastern part of Thailand, and in the northern part along the border with China and in the southern part of Vietnam. In the case of Lao PDR, the main vegetation of the country is forest, and lands dedicated to paddy are still limited and spread throughout the country. A summary of land surface of each type of vegetation is reported in Table 1.

Table 1. Land surface of forest and paddy fields in GMS

Type	Thailand	Cambodia	Lao PDR	Vietnam	Total in GMS
Forest					
km^2	170,157	108,990	142,602	58,613	480,362
Mha	17.02	10.90	14.26	5.86	48.04
(% NL)	(33%)	(61%)	(60%)	(18%)	
Paddy					
km^2	105,754	17,024	2,556	48,611	173,945
Mha	10.58	1.70	0.26	4.86	17.39
(% NL)	(21%)	(9%)	(1%)	(15%)	
NL*					
km^2	514,361	181,035	236,80	331,033	1,263,229
Mha	51.44	18.10	23.68	33.10	126.32

**NL : National Land*

From Table 1, Cambodia and Lao PDR are observed to be the two countries of the region to be mainly covered by forest, i.e. about 60% of the total national land, while Thailand and Vietnam dedicate 15-20% of their national land for rice cultivation.

Assessment of biomass burning activities using satellite data

Biomass burning activity was assessed using remote sensing data. This method provides an overview of geographic positions and temporal changes of biomass burning areas. The satellite data used in this study are fire hotspots retrieved from satellite launched under the Asia-Pacific Network for Disaster Mitigation Using Earth Observation Satellite (ANDES) research program. The DMSP-OLS sensor enables to detect areas where a temperature higher than a threshold, qualified as reference temperature of an open burning (>150 $^{\circ}$C), is observed and named as hotspots. The resolution of the detection instrument is 2.7 km x 2.7 km, which is considered as a coarse resolution for satellite detection; however it is sufficiently fine for geographically indicating the position of biomass burning area, and for calculation of the associated emissions. Based on this resolution, the size of a hotspot is assumed to be equal to 2.7 km x 2.7 km. The ANDES hotspots data were available daily from 1998-2004. The base year of hotspots' data collection for this study was the year 2002, since for this year no major interruption of satellite data collection was noticed; hotspots had been collected for the whole year enabling to document the temporal changes of open burning activity in the region.

The daily data were first processed into monthly data of fire hotspots in the form of a GIS map, in order to investigate the seasonal variability over a year. An example of monthly hotspots map is given in Figure 2. Each hotspot was classified according to the vegetation in which it occurred, by overlaying the monthly hotspots

map to the vegetation coverage map, in order to qualitatively and quantitatively assesses the type of biomass subjected to open burning.

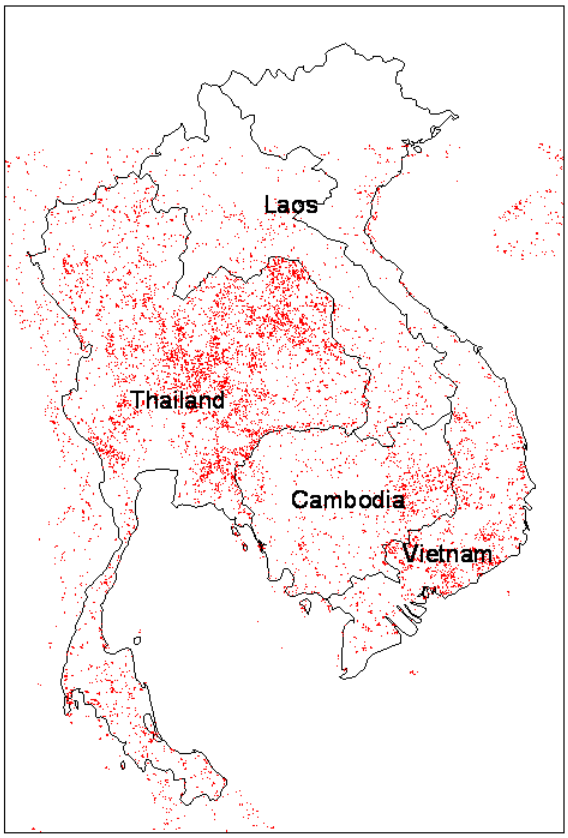

Fig.2. An example of monthly hotspots map - 2002

In order to systematically geo-reference the position of the hotspots, a grid map with a resolution of 12 km x 12 km was developed.

Estimation of air pollutants emission from biomass open burning – Calculation method

The emissions of air pollutants from biomass open burning on a yearly basis can be estimated using the equations, initially developed by Seiler and Crutzen [3], based on the basic chemical reaction of combustion, which represents the relationship between the combustion process and its emission as follows.

$$E_x = M \times EF_x \quad (1)$$

where, E_x is the emission of the pollutant x (g/year), M is the mass of dry matter burned (kg dm/year), and EF_x the emission factor of the pollutant x (g/kg dm burned).

From Equation 1, it is evident that before estimating the emission, M and EF_x should be first quantified.

a) Estimation of dry matter biomass burned:

- *Forest*

In order to estimate the amount of biomass burned per year as a result of forest fires the following general equation is used:

$$M = A \times B \times \alpha \quad (2)$$

where, M is the amount of biomass burned per year, (kg/year), A is the area of forest burned per year (m^2 per year), B is the above ground biomass density (kg/m^2), and α is the fraction of above ground biomass burned.

- *Agricultural crop*

In the case of crop residues burning, the amount of biomass burned is determined using a modified version of the equation given in the IPCC revised guidelines (1996) and also used in works of Hao and Liu (1994) or Streets et al. (2003) as follows.

$$M = P \times D \times B \times F \times \alpha \quad (3)$$

where, M is the total mass of crop residue burned in field (kg/year), P is the crop production (kg/ m^2.year), D is the crop specific residue to product ratio, B is the dry matter fraction (or biomass load if P is expressed in unit of surface instead of unit of mass), F is the percentage of dry matter residues burned in field, and α is the burning efficiency.

The data used in this study and their sources both for forest fires and rice residues burning, are reported in Table 2.

Table 2. Estimates of tropical forest biomass and crop residues burned in Asia

	Biomass load range (kg/m^2)		Burning efficiency	
Tropical Forest	10[a]		0.2[b]	
Crops	Residue-to-crop ratio	Dry matter fraction	Dry matter burned in field	Burning efficiency
Rice	1.76[c]	0.85[d,e,f]	25%[d,e]	89%[e]

[a]IPPC (1996) [4]; [b]Levine (2000)[5]; [c]Koopmans and Koppejan (1997)[6], [d]Hao and Liu (1994)[7]; [e]Streets et al., (2003)[8]; [f]OEPP, Thailand (1990)[9]

b) Estimation of emission factors of air pollutants of interest

A comprehensive study by Andreae and Merlet (2001) provides emission factors for various types of biomass burning including tropical forest and crop residues. The emission factors reported by Andreae and Merlet [10] come from an updated review of practically all research works performed over the last 30 years on emission factors measurements worldwide. The emission factors of air pollutants of interest are reported in Table 3. For Total Particulate Matter (TPM) or aerosols, the emission factors used are from Levine (2000), since they have been obtained from experiments representative of burning conditions occurred in Asia (Table 3).

In order to systematically assess the open burning emissions of a given pollutant, a grid map with a resolution of 12 km x 12 km, identical to the map used

for evaluating open burning activities, was set by incorporating the equations and data required to calculate air pollutant emissions, as inputs into the GIS database. Monthly emission maps were prepared for each of the pollutants considered in this research study.

Table 3. Emission Factors of air pollutants of interest

Compounds	Tropical Forest	Crop residues
	Emission Factors (g/kg)[a]	
CO_2	1580 ± 90	1515 ± 177
CO	104 ± 20	92 ± 84
CH_4	6.8 ± 2.0	2.7
N_2O	0.20	0.07
NOx	1.6 ± 0.7	2.5 ± 1.0
TPM*	20[b]	10[b]

[a]*Andrea and Merlet (2001)[10];* [b]*Levine (2000)*

Estimation of amount of straw and stubbles consumed and corresponding energy released by open burning

Stubble corresponds to the lower part of the plant next to the root, which generally stays on the ground after harvest. Straw constitutes the part coming with the grain during harvesting. Based on field surveys in Thailand and Cambodia, it is to underline that in the past, straw was moved out of the fields to be used as animal fodder, and stubbles served as additional fodder for cattle and buffalo labors as well as supplement organic matter to be incorporated back into the soil during land preparation for the new plantation. At present, with intensification of rice farming, animal labors are replaced by machines, and straw and stubbles are being more extensively burned in the field, especially in the region where water resources are sufficient to enable the plantation of secondary rice. In addition, the length of straw and stubbles varies greatly with species and harvesting methods. A paddy field harvested mechanically leaves in the field stubbles of 20-30 cm height, while when manually collected leaves stubbles of over 50 cm height. Also, long-lived (about 180 days) species planted in some parts of northeastern region of Thailand may provide straw of 1.5-2.0 m in length, while short-lived species (90-120 days) would have a length of less than 1.2 m.

The amount of straw and stubbles consumed by open burning can be estimated using the residues-to-product ratio (RPR) or D in the calculation of emission estimates based on the following equation.

$$M_{res} = A \times P \times RPR_{res} \quad (4)$$

where, M_{res} is the total mass of considered crop residue after harvest (Mt), A is the cultivated area (Mha), P is the crop production (t/ha), RPR_{res} is the specific considered residue-to-product ratio.

In this study, A and P are collected from Food and Agriculture Organization (FAO) statistics (FAOSTAT) for the year 2002. For RPR, the calculations were conducted using two values: (1) the value of 1.757 reported by Koopmans and Koppejan [6], and (2) the value of 0.750 obtained based on field survey in this study. The difference observed between the two values is due to the quantity of stubbles left in the field.

Regarding the corresponding energy release, this represents the energy content of the residues, and was estimated using the following equation.

$$E = M_{res} \times CV \quad (4)$$

where, E is the energy of the total crop residue after harvest (PJ), M_{res} is the total mass of crop residue after harvest (Mt), CV is the calorific value of the residue considered (MJ/kg).

Straw and stubbles have the same CV value of 14.00 MJ/kg [11].

3. RESULTS AND DISCUSSION

Biomass open burning activities

The biomass open burning activities observed by ANDES satellite for Thailand, Cambodia, Lao PDR and Vietnam, are reported in Figure 3, for both fire counts and burned areas. This latter is converted from fire counts based on a satellite sensor resolution of 2.7 km x 2.7 km.

Results from Figure 2 indicate that the peak season of forest fires in Thailand, Cambodia, Lao PDR, and Vietnam runs from January to April. Indeed, forest fires are significantly detected from October onward, i.e. starting month of the dry season in the region.

Regarding paddy field burnings, the peak season is also observed during the January-April period in Thailand, Lao PDR and Cambodia, while Vietnam displays a different pattern with frequent burning occurring throughout the year. Also with regards to the intensity of paddy field burning, Thailand and Vietnam are far ahead. The particular seasonal pattern of paddy field burning observed for Vietnam seems to confirm an agro-intensification of rice production in this country.

The frequency of fires, quantified by fire counts, indicates that forest is much more affected by open burning than paddy fields, although there are uncertainties in these estimations, notably in the case of satellite detection of rice residues open burning.

Monthly emission maps

An example of monthly emission maps of TPM during the peak period (January-April 2002) is reported in Figure 4, in order to investigate the spatial distribution of biomass burning during the high season of biomass burning.

From Figure 4, it is observed that paddy fields open burning occurs in Thailand in the central and in the northeastern regions of the country, especially in January and February. In Cambodia, burning is also intense during these two months and is located in the central part around the Mekong delta. In the case of Lao PDR, as

paddy fields and forest coexist, and the rice cultivation land is very limited, the burning is observed to spread throughout the country with very low intensity or frequency. Finally for Vietnam, only rice fields in the south along the border with Cambodia are affected by burning and are characterized by a similar intensity throughout the four months studied, confirming a possible intensification of rice farming in this region.

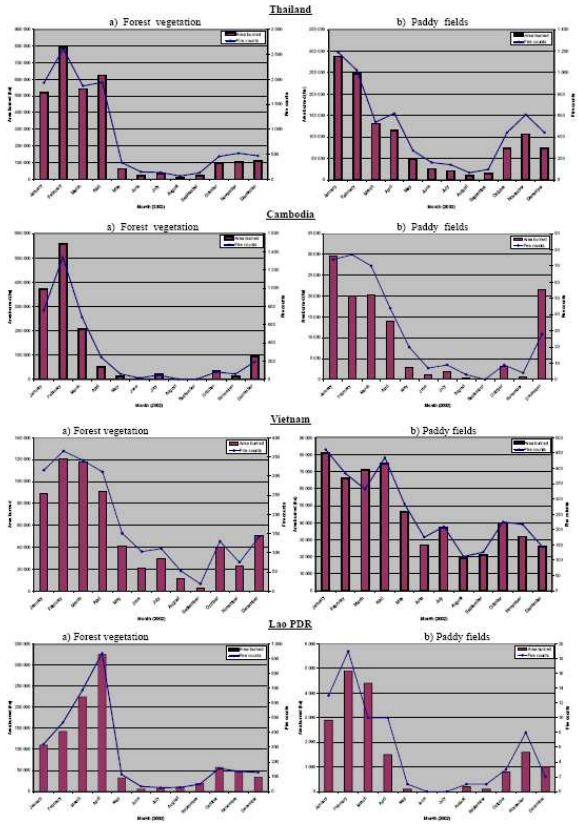

Fig.3. Fire counts (counts, in line graph) and burned area (ha, in bar graph) in Thailand, Cambodia, Vietnam and Lao PDR in 2002 for a) forest, and b) paddy fields.

In addition, the January to February period corresponds to a dry wintery season for the region, and so to the period where high pressure and cold air masses from China covers the North and Northeast of Thailand, the north of Cambodia, Lao PDR, and the north of Vietnam. This contributes to a poor dispersion of pollutants emitted from different sources in the atmosphere, and so to an increase in their ambient concentrations including the level of particulate matter, which can exceed the national standards. On the other hand, the dry weather conditions favor a fast propagation of the fires. Therefore, it is recommended to control paddy fields open burning from January to March, in particular in Thailand and Vietnam, the top two countries in rice cultivation of the region.

Amount of straw and stubbles consumed and corresponding energy released by open burning

Results obtained for the 4 countries in the GMS are reported in Table 4 and 5. They are also displayed in GWh in order to investigate their order of magnitude relative to electricity demand in each country.

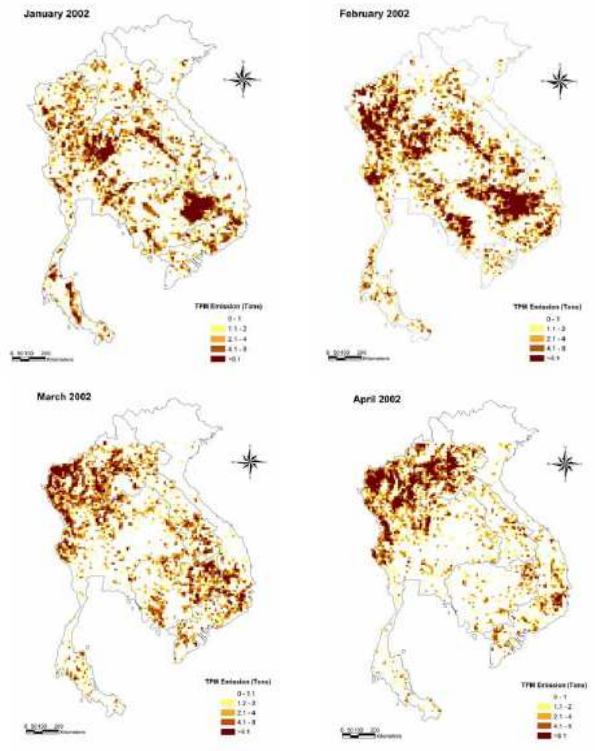

Fig.4. Monthly emission maps of TPM in GMS during January-April 2002.

Table 4. Amount of straw and stubbles and corresponding energy content, RPR = 1.757

Country	Paddy lands (Mha)	Amount of residues (Mt)	Energy content (PJ)	Energy content (GWh)
Cambodia	1.70	5.724	80	22,260
Laos	0.26	1.410	20	5,482
Thailand	10.58	48.499	679	188,607
Vietnam	4.86	39.197	549	152,432

Table 5. Amount of straw and stubbles and corresponding energy content, RPR = 0.750

Country	Paddy lands (Mha)	Amount of residues (Mt)	Energy content (PJ)	Energy content (GWh)
Cambodia	1.70	1.437	34	9,502
Laos	0.26	2.314	8	2,340
Thailand	10.58	1.957	290	80,509
Vietnam	4.86	3.443	234	65,068

Results reported in Table 4 and 5 represent actually the gross amount and energy availability of straw and stubbles. The use of 2 values of RPR enables to frame the range of this gross availability. It resulted from our

field survey that the value of 0.750 corresponds to the part of the residues able to be moved out from the fields, and so available for different utilization, while 1.757 represents the whole residue cut few centimeters above the ground. The net amount available for energy production will depend on two other main factors: other utilization and biomass to energy conversion technology in use.

Other significant factors influencing the net availability are the cultivation practices and the level of difficulty to collect, string the straw and stubbles together, and move them out of the fields. It should be noted that the size of paddy fields in the 4 countries of the region studied, is quite small, less than 1 ha in general, compared to the size reported in Europe or USA, and consequently quite difficultly to access by a commercialized tractor. Moreover, the plantation soil is relatively soft, and so the load of a heavy duty tractor would compact the soil, resulting in a hard plowing during the land preparation phase.

4. CONCLUSIONS AND PERSPECTIVES

The emission maps developed in this research work have allowed to easily monitoring seasonal changes of open burning, and the GIS database to identify the type of vegetation that is being burned. These developments have enabled to investigate the spatial and temporal distribution of paddy fields open burning in the GMS for the year 2002.

The results obtained in this study show that Thailand and Vietnam are the two countries, where paddy field open burning occurs most frequently. The peak period of this type of burning runs from January to April, with January and February as the climax period. As this period corresponds to the time when forest fires are the most intense and atmospheric stability is the most stable, i.e. difficult dispersion of air pollutants, it is recommended to control more stringently agricultural open burning to reduce impacts on air quality and therefore support the ASEAN Agreement on Transboundary Haze.

The quantification of gross amount of rice straw and stubbles consumed and corresponding energy released by open burning was helpful in estimating the energy amount that could be recovered from the waste biomass. However, further investigations, especially on updating the RPR values, and on the material flow of straw and stubbles after harvest via field survey in the GMS countries, are needed in order to support the formulation of national action plan of promoting the use of renewable energy resources, and of reducing agricultural open burning.

ACKNOWLEDGMENT

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Promoting Cooperation in the Mekong Region through Water Conflict Management, Regional Collaboration, and Capacity Building

Patrick R. MacQuarrie, Vitoon Viriyasakultorn, and Aaron T. Wolf

Abstract— *There are over 263 international river basins in the world covering almost half of the Earth's land surface. Over 145 nations are riparians to one or more of these basins, some sharing with up to 17 countries. Challenges facing the Mekong River Basin are prompting increased focus on water conflict prevention and management and regional collaboration. Discarding the water wars myth, research and case studies have shown that greater institutional capacity can prevent water conflicts, leading to enhanced cooperation in international basins. Strategic partnerships and conflict prevention activities such as training and "hotspot" mapping are current examples of collaborative cooperation in the Mekong Basin. Regional cooperation is driving most collaborative efforts including the emergence of civil society and stakeholder participatory processes at the basin level. Examples from the Nile and Columbia River Basins provide evidence from outside the Mekong region supporting claims that cooperative management institutions and collaborative processes are effective policies for promoting peace and cooperation transboundary and international water basins.*

Keywords— **Basin cooperation, basin institutions, capacity building, institutional capacity, Mekong, regional collaboration, river basin organization, transboundary water, water conflict management.**

1. SHARED INTERNATIONAL BASINS – THE SETTING

There are over 263 international river basins in the world, covering almost half of the Earth's land surface, nearly 40 percent of the world's population, and 60 percent global river flow [1]. Surface water, groundwater, and water quality and the ecosystem are all interconnected and widely utilized for a multitude of purposes, ranging from biological, economical, spiritual, cultural and domestic needs [2]. Over 145 nations are riparians to one or more international basins in the world. Some basins, such as the Danube, share up to 17 countries whilst many others share three or more boundaries between them [3]. Oregon State University's Transboundary Freshwater Dispute Database (TFDD) houses over 300 international agreements on international basins seen in Figure 1, an indication that cooperation may be prevalent on international transboundary water issues [4].

Beginning at over 4500 meters elevation in the Tanggula mountain range in Qinghai province, the Mekong flows for over 4800 km through China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, terminating in the South China Sea, draining over 795,000 km^2 [5]. Thailand and Laos both share the highest percentage of area in the basin with 23 and 25 percent, respectively, while Laos contributes the greatest amount of flow (35 percent) [5]. Vietnam has the highest population density (236 persons/km^2) and the lowest percent of basin area (8%), posing potential concerns with respect to its political influence [6]. The Mekong's annual flow varies widely based on the monsoon season, ranging from 78.8 to 475 cubic kilometers dry to rainy seasons, respectively [7].

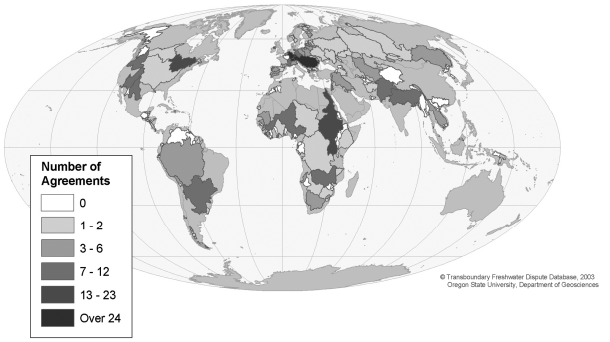

Fig. 1. Cooperative international agreements per basin [4]

The Mekong faces some monumental challenges in the years to come. Over 21 percent of the basin is eroding with only 31 percent of its original forests left intact and only 5 percent under protection [7]. Two percent population growth over the next 50 years combined with increasing environmental degradation leads the UNEP to predict severe and negative impacts in the areas of stream flow, pollution, loss of habitat, fish populations, and community health to those who rely on the Mekong for their livelihoods [7]. What is needed to prepare for

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these changes?

Water management is, by definition, conflict management. There is no such thing as managing water for a single purpose as all water management is multi-objective and based on navigating competing interests. Within a nation these interests include domestic users, agriculturalists, hydropower generators, recreation enthusiasts, and environmentalists - any two of which are regularly at odds, and the chances of finding mutually acceptable solutions drop exponentially as more stakeholders are involved. Add international boundaries and the chances decrease exponentially yet again [8].

This paper makes a case for promoting cooperation in the Mekong region through principles of water conflict prevention management, regional cooperation and collaboration, and multi-scaled capacity building. These activities must be clearly relevant; not to be ravaged by war or thwarted by political upheaval. Therefore we will refute the myth that wars are likely, and instead give evidence that water conflict, instead, is a catalyst for cooperation. Built on this premise, cooperative management techniques and collaborative efforts have their greatest influence on strengthening institutional capacity in the Mekong region.

2. WATER WARS OR CONFLICT MANAGEMENT AND COOPERATION? [1]

Many observers claim that increased geographical interdependence of water boundaries combined with population pressures and increased water scarcity leads to greater conflict. In contrast, historical evidence and current research demonstrate that tensions often become catalysts for cooperation, a much more prevalent strategy. People do affect their environment, but to what extent is the opposite true? Just how deep is the causal relationship between environmental stresses and the structure of human politics? This relationship is at the heart of understanding the processes of environmental conflict prevention and resolution. If, as the large and growing "water wars" literature would have it [9-13], the greatest threat for water conflicts is that water scarcity can and will lead directly to warfare between nations. The "water wars" idea potentially diverts a huge amount of resources to arrest these processes at the highest levels. When if fact, if the processes driving conflict are actually both more subtle, scalable, and more local in nature as suggested by [14, 15–18], then so too are the potential solutions to conflict over water [8].

It is important to note that shared water does lead to tensions, threats, and even to some localized violence. Later we offer strategies for preventing and mitigating these tensions. However, conflicts over water rarely lead to war. Moreover, these tense "flashpoints" or "hotspots" generally and eventually induce the parties involved to enter negotiations, often resulting in dialogue and, occasionally, precipitating creative and resilient working arrangements. Also significant is evidence discovered that shared water provides compelling inducements to dialogue and cooperation, even while hostilities rage over other issues.

An examination of the "water leads to war" thesis sheds some light on its relevance to reality on the ground. Although the extreme water wars literature mostly began to fade in the late 1990s, a number of articles dating back decades argue quite persuasively for some degree of causality between environmental stress and political decision making, employing rapidly approaching resource limits as a justification. One cannot discuss water institutions, for example, without invoking Wittfogel [19] and his classic argument that the drive to manage water in semiarid and tropical environments led both to the dawn of institutional civilization, described by Delli Priscoli [20] as the "training ground for civilization" and to particularly autocratic, despotic forms of government. Consequently, his argument was quite effectively challenged by Toynbee [21], among others. The premise that there is a critical link between how society manages water and its social structure and political culture remains as an important and valid insight.

This thread of causality between the environment and politics has been taken up regularly over the years. When Sprout & Sprout [22] describe the environmental factors inherent in international politics, it becomes the direct intellectual precursor to today's blossoming "environmental security" literature, as spearheaded by Homer-Dixon [23]. A summary of Homer-Dixon's findings, along with a debate on the topic is presented in [24]. In his defense, Homer-Dixon's arguments, along with many in the water wars camp, have become more muted over the last few years: In 1994, he wrote, "The renewable resource most likely to stimulate interstate resource war is river water" [25, p.16], which he repeats in his 1996 article [26]. He modifies the claim, elaborated in his 1999 book [27], "In reality, wars over river water between upstream and downstream neighbors are likely only in a narrow set of circumstances ...[and]...there are, in fact very few river basins around the world where all these conditions hold now or might hold in the future" [27, p.139].

The treatment of nations as homogeneous nations, rational entities linking internal and external interests is critical when we look at violent international conflicts [28], [29]. Gleick [30] is widely cited as providing what appears to be a history replete with violence over water resources. However, Wolf [31] points out that what Gleick and others have actually provided is a history rife with tensions, exacerbated relations, and conflicting interests over water, but not State level violence. Wolf [31] contrasts the results of a systematic search for interstate violence with the much richer record of explicit, legal cooperation with 3600 water-related treaties. In fact, a scan of the most vociferous enemies around the world reveals that almost all the sets of nations with the greatest degree of animosity between them, whether Arabs and Israelis, Indians and Pakistanis, or Azeris and Armenians, either have a water-related agreement in place or are in the process of negotiating one.

[1] This section is largely taken from Wolf, Aaron T., 2007, "Shared Waters: Conflict and Cooperation," Annual Review of Environment and Resources 32: 3.1-3.29.

International river basins

The Register of International River Basins of the world [32] defines a river basin as the area that contributes hydrologically (including both surface-and groundwater) to a first order stream, which, in turn, is defined by its outlet to the ocean or to a terminal (closed) lake or inland sea. We define such a basin as international if any perennial tributary crosses the political boundaries of two or more nations.

Similarly, the 1997 UN Convention on Non-Navigational Uses of International Watercourses defines a watercourse as "a system of surface and underground waters constituting by virtue of their physical relationship a unitary whole and flowing into a common terminus." An international watercourse is a watercourse with parts situated in different States [33].

Within each international basin, demands from environmental, domestic, and economic users increase annually, while the amount of freshwater in the world remains roughly the same as it has been throughout history. Given the scope of the problems and the resources available to address them, avoiding water conflict is vital. Conflict is expensive, disruptive, and interferes with efforts to relieve human suffering, reduce environmental degradation, and achieve economic growth. Developing the capacity to monitor, predict, and preempt transboundary water conflicts is key to promoting human and environmental security in international river basins, regardless of the scale at which they occur.

A closer look at the world's international basins gives a greater sense of the magnitude of the issues: First, the problem is growing. There were 214 international basins listed in a 1978 United Nations study [32], the last time any official body attempted to delineate them, and there are over 263 today [1]. The growth is largely the result of the internationalization of national basins through political changes, such as the break up of the Soviet Union and the Balkan states, as well as access to today's better mapping sources and technology.

A way to visualize the dilemmas posed by international water resources is to look at the number of countries that share each international basin in *Table 1*. Nineteen basins are shared by five or more riparian countries: one basin—the Danube—has 17 riparian nations; five others are are shared by between 9 and 11 countries; and the remaining 13 basins have between 5 and 8 riparian countries [3].

Fortunately, there is room for optimism due to the global community's record of resolving water-related disputes along international waterways. For example, the record of acute conflict over international water resources is overwhelmed by the record of cooperation. Despite the tensions inherent in the international setting, riparians have shown tremendous creativity in approaching regional development, often through preventive diplomacy, and the creation of "baskets of benefits," which allow for positive-sum, integrative allocations of joint gains. Moreover, the most vehement enemies around the world either have negotiated water sharing agreements, or are in the process of doing so as of this writing, and once cooperative water regimes are established through treaty, they turn out to be impressively resilient over time, even between otherwise hostile riparians and even as conflict is waged over other issues. Violence over water does not seem strategically rational, hydrographically effective, or economically viable. Shared interests along a waterway seem to consistently outweigh water's conflict-inducing characteristics.

Table 1. Number of countries sharing a basin. Source: [1]

Number of Countries	International Basins
3	Asi (Orontes), Awash, Cavally, Cestos, Chiloango, Dnieper, Dniester, Drin, Ebro, Essequibo, Gambia, Garonne, Gash, Geba, Har Us Nur, Hari (Harirud), Helmand, Hondo, Ili (Kunes He), Incomati, Irrawaddy, Juba-Shibeli, Kemi, Lake Prespa, Lake Titicaca-Poopo System, Lempa, Maputo, Maritsa, Maroni, Moa, Neretva, Ntem, Ob, Oueme, Pasvik, Red (Song Hong), Rhone, Ruvuma, Salween, Schelde, Seine, St. John, Sulak, Torne (Tornealven), Tumen, Umbeluzi, Vardar, Volga, and Zapaleri
4	Amur, Daugava, Elbe, Indus, Komoe, Lake Turkana, Limpopo, Lotagipi Swamp, Narva, Oder (Odra), Ogooue, Okavango, Orange, Po, Pu-Lun-T'o, Senegal, and Struma
5	La Plata, Neman, and Vistula (Wista)
6	Aral Sea, Ganges-Brahmaputra-Meghna, Jordan, Kura-Araks, Mekong, Tarim, Tigris and Euphrates (Shatt al Arab), and Volta
8	Amazon and Lake Chad
9	Rhine and Zambezi
10	Nile
11	Congo and Niger
17	Danube

3. SCIENTIFIC EVIDENCE OF WATER AS A CATALYST OF COOPERATION

Basins At Risk (BAR) projec [2]

In order to cut through the prevailing anecdotal approach to the history of water conflicts, researchers at Oregon State University undertook a three-year research project which attempted to compile a dataset of every reported interaction between two or more nations, whether conflictive or cooperative, that involved water as a scarce and/or consumable resource or as a quantity to be managed. The central focus of the study was that water was the driver of the all events over the past 50 years. The study documented a total of 1831 interactions, both conflictive and cooperative, between two or more nations over water during the past five decades and found the following (see Figure 2) [18].

First, despite the potential for dispute in international basins, the record of acute conflict over international water resources is historically overwhelmed by the presence of cooperation. Over the 50 year study, there were only 37 acute disputes (those involving violence); of those, 30 were between Israel and one or another of its neighbors, and the violence ended in 1970. The only water war between nations on record occurred over 4500 years ago between the city-states of Lagash and Umma in the Tigris-Euphrates basin [31, 34).

The total number of water-related events between nations of any magnitude is likewise weighted toward

[2] This section is largely taken from Wolf, A. T., Annika Kramer, Alexander Carius, and Geoffrey D. Dabelko. 2005. Chapter 5: Managing Water Conflict and Cooperation. In *State of the World 2005: Redefining Global Security*, 80-95. Assadourian, E., *et al*. Washington, D.C.: The WorldWatch Institute.

cooperation with only 507 conflict-related events versus 1228 cooperative events. The figures suggest that violence over water is neither strategically rational, hydrographically effective, nor economically viable [18].

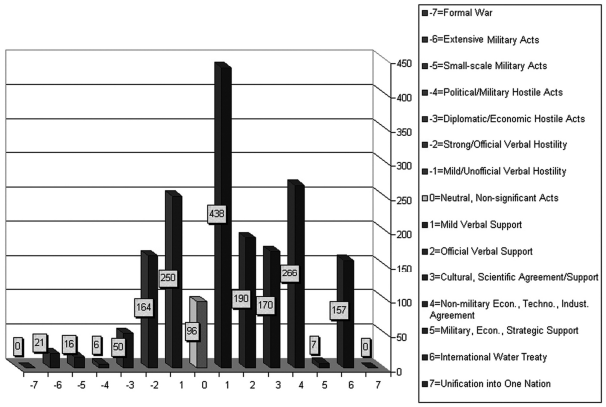

Figure 2. Number of events by BAR scale. Source: [18]

Second, despite the occasional fiery rhetoric of politicians - perhaps aimed more often at their own constituencies than at the enemy - most actions taken over water are mild. Almost two thirds of all events were only verbal, and more than two thirds of those had no official sanction [18].

Third, there were more issues of cooperation than of conflict. The distribution of cooperative events covered a broad spectrum, including water quantity, quality, economic development, hydropower, and joint management. In contrast, almost 90 percent of the conflict-laden events related to quantity and infrastructure.

Finally, despite the lack of violence, water acted as both an irritant and a unifier. As an irritant, water can make good relations bad and bad relations worse. Despite the complexity, however, international waters can act as a unifier in basins with relatively strong institutions [35]. This historical record suggests that international water disputes do get resolved, even among enemies, and the institutions they have created often prove to be resilient even when relations in other areas are strained.

Research done through Oregon State University's Program in Water Conflict Management and Transformation suggests that institutional capacity is key to successful and enduring cooperation. Results indicate that conflict in a basin is more likely if 1) there are rapid political or physical changes in the basin, and 2) basin institutions are unable to absorb and manage those conditions. International river basin institutions can effectively absorb and manage major changes in a river basin through a number of instruments, including: treaties, cooperative arrangements, creation and distribution of technical data, stakeholder involvement in management plans, equitable allocations, and the distribution of reasonable costs and benefits [3], [18], [35]. Tools such as databases combining hydrological, geographic, socioeconomic, and political data relating to transboundary water can be a valuable asset for river basin institutions to enable greater cooperation, training, and capacity building among basin riparians.

Demonstrations of cooperation over water

There are numerous examples of cooperative persistence found between riparians along shared waterways. Israelis and Arabs since the 1950's, the Indus River Commission which survived two major wars between India and Pakistan, and decades of dialog and cooperation on the Mekong River are all examples of cooperation while disputes remained unresolved among neighbors.

Israel and Jordan have held secret "picnic table" talks on managing the Jordan River since the unsuccessful Johnston negotiations of 1953–1955, even though they were technically at war from Israel's independence in 1948 until the 1994 treaty [36]. The parties have adopted a policy of cooperation over water rather than conflict, developing new water resources, sharing information, and providing assistance to alleviate water shortages. Institutional examples of this include arrangements for joint monitoring of common water resources and data exchange through the establishment of a Joint Water Committee.

The Indus River Commission survived two major wars between India and Pakistan [3], [37]. Despite all evidence to the contrary, India and Pakistan cooperated over the Sutlej River and signed the Indus Water Treaty in 1960, during which the broader conflict continued over the Line of Conflict within Kashmir. The intervention by the World Bank was an important institutional stop-gap that sponsored India and Pakistan's development of institutional capacity [38], [39].

With regards to the Mekong, cooperation goes back even further than the Mekong Committee to 1949 and the establishment of the Bureau of Flood Control and Water Resources [40]. Following this, the Mekong Committee was established by the governments of Cambodia, Laos, Thailand, and Viet Nam as an intergovernmental agency in 1957. It exchanged data and information on water resources development throughout the Viet Nam War [39], [41], and during the wars in Indochina, still managed in 1970 to produce medium and long range plans to develop water resources in the lower Mekong basin. Even after the withdrawal by Cambodia in 1975, the Secretariat continued to meet in Bangkok, eventually setting up the Interim Mekong Committee in 1978. With intense involvement by the US and Asian Development Bank (ADB), there is good evidence to suggest that existing cooperation in the Mekong was being offered as an alternative to war in Vietnam and Cambodia [42]. Hydropower works, such as the Nam Ngum project, were also seen as a link between Thailand and Laos, connecting Nam Ngum Dam to Vientiane to Udon Thani in Thailand and on to Nam Pong Dam in the Ubol Rattana province [42]. Eugene Black, one of the first presidents of the World Bank in 1949, voiced his perspective on cooperation explicitly,

"The most important aspect of the development of the Mekong Basin is to provide a means for inhibiting violence in the region, and evoking among riparian countries a sense of what is possible if they cultivate the

habit of working together." [43].

Again reinforcing the notion that strong institutions enable cooperation, the Mekong River Commission signed the Agreement on Cooperation for Sustainable Development in the Mekong River Basin in April of 1995 [40]. Regional cooperation took another step forward in 1992 by the formation of the Greater Mekong Subregion (GMS) to jointly development natural resources and infrastructure through increased economic cooperation.

4. REGIONAL COOPERATIVE ACTIVITIES TOWARD CONFLICT PREVENTION IN THE MEKONG REGION

As the Mekong sub-region develops, riparian countries have been constructing dams, dikes, irrigation infrastructure, and navigational waterways that potentially impact river livelihoods. A challenge for countries in the Mekong region is the adoption and implementation of policies and practices that enable participatory and collaborative engagement for planning and development, that support sustainable development, and that both protect vital ecosystems and promote economic and social prosperity, while ensuring prevention, management and mitigation of conflict. Regional institutions in the Mekong region are working to enhance regional cooperation through several mechanisms such as strategic partnerships, conflict management training, public participation, stakeholder involvement, and institution building [44].

The Mekong River Commission (MRC) fosters inter-governmental cooperation among the four lower Mekong countries of Cambodia, Lao, Thailand, and Vietnam. The MRC and the National Mekong Committees (NMCs) have a mission to preserve the natural resources and environmental quality of the river basin while promoting the interdependent and economic growth of the Mekong region. The MRC's goal is to achieve this mission through participatory and collaborative decision-making within and among the Mekong countries [45].

Cooperative partnerships

The MRC Strategic Plan for 2006-2010 includes Goal 2 for the MRC to enhance effective regional cooperation. One objective under this goal is, "To identify potential transboundary issues for negotiation, mediation and conflict prevention, and develop mediation and conflict management capacity" [45]. To achieve this objective, the MRC is working to develop new mechanisms and institutional arrangements for addressing transboundary issues and differences in cooperation with international and regional development partners. One such partner is Planning and Development Collaborative International, or PADCO, which implements the United States Agency for International Development (USAID) Environmental Cooperation-Asia (ECO-Asia) Governance project [46]. The MRC's strategic partnership with ECO-Asia aims to promote collaboration by the adoption of improved conflict prevention policies, plans, and mechanisms at regional and national levels. Cooperative arrangements between partners such as the MRC and ECO-Asia serve to provide a foundation to enhance regional cooperation in Basin activities and increase capacity for joint planning, cooperation, and resolution of transboundary water-related issues in the Mekong region [45].

Water conflict prevention and management training

Joint MRC and ECO-Asia workshops on conflict prevention and management are aimed at strengthening human and institutional capacity, including facilitating the identification of potential transboundary issues across the wide range MRC program activities including the environment, flood management and mitigation, agriculture, irrigation, forestry, and watershed management, navigation, fisheries, basin development planning, and water utilization. In addition to helping develop capacity at the MRC in the prevention and resolution of transboundary issues, training activities also promote cooperation between the MRC Secretariat and National Mekong Committees (NMCs) in each of the four member countries and line agencies. These activities are designed to dovetail into existing MRCS and NMC programs. Feedback from stakeholders and partners has indicated that training should be focused on general conflict prevention and resolution tools and techniques [47].

Water conflict prevention management training aims to enhance regional cooperation through three levels of learning objectives. The first type of training encompasses introductory training in transboundary water conflict prevention, management and cooperation. It provides a broad overview of transboundary water issues, basic knowledge, principles and practices in cooperation, and prevention and management of conflict. This type of training is designed specifically to build awareness and improve the general understanding of conflict prevention and management practices for several target stakeholder groups within the Basin [47].

The second type of training focuses on building skills in facilitation and mediation at the national and line agency level. In the Mekong region, training is aimed at NMCs and line agencies, which may be called upon to assist with potential transboundary issues or differences. Their responsibilities include information sharing and facilitation of meetings, activities requiring key skills essential to effectively address potential conflict involving shared water. In this setting, the training is designed to assist staff to carry out these tasks effectively, employing exercises and practices aimed at developing practical skills rather than concepts. Examples of skills emphasized in this area include communication, negotiation, facilitation, and mediation [47].

The third type of training being conducted is directed toward policy makers and senior water managers. It is critical that these participants have some knowledge of national, regional, and international legal issues relating to water. Policy implications are best understood using real life examples, and case studies and event analysis play a large role in developing these skills with policy makers [47].

Finally, all the water conflict prevention and

management material is combined into a cohesive package. Training programs need to be modular so that skills and concepts can be delivered in bite-size, digestible, and practical chunks. Hydropolitics and transboundary water are included in the conceptualization of international water, stages of water conflict transformation, water use and international law, and the effect of boundaries on basin management [48]. The states of negotiation, a critical component to managing water conflict, are put in the context of environmentally-based disputes. The training then moves to the concept of benefit sharing and institutional capacity, an active ingredient in preserving peace and cooperation in transboundary waterways. Moving to more practical training, specific skills in water conflict prevention and management are taught, including but not limited to public and stakeholder participation, collaboration, alternative dispute resolution, negotiation, mediation, and other conflict management methods. These concepts, combined with collaboration, communication, and negotiation skills, have the potential to yield significant transformations in participants involved. Initiating shifts in the thinking and attitudes of participants is an integral part of a complete and successful conflict prevention management training program. Additionally, tools such as databases, GIS, and other mapping tools provide systematic ways of understanding transboundary water conflict prevention and help to furnish current and legitimate data for making accurate situational assessments. Using data in addition to case studies provides powerful examples of how conflict can be transformed into cooperation and reinforces cooperative approaches to resolving water issues [31], [44]-[50].

Mapping "hotspots"

The identification of potential transboundary "hotspots" and historical events through a collaborative participatory process contributes to the transformative initiative to strengthen capacity in the Mekong transboundary basin.

The theoretical benefits of identifying transboundary issues are that prevention is more effective and inexpensive than fixing a problem or issue after an event. In fact, the process of cooperation in addressing the operative issues may identify options and opportunities not previously realized. Because the MRC is fundamentally aimed at promoting cooperation and the sustainable development of Mekong River Basin, cooperation requires capacities to address constraints, impacts, priorities, and opportunities, and directly addressing issues contributes to these goals. The process of addressing issues allows the MRCS to focus energy on the prioritization of the most critical issues. Developing clear criteria in this process allows for early issue identification and proactive management of transboundary issues [47].

As part of the MRC and ECO-Asia joint program, representatives from MRC Secretariat, NMCs and line agencies met and identified potential transboundary issues in an effort to raise awareness and provide a foundation for capacity building and tools development. As part of this effort, stakeholders developed criteria that could be used to identify issues and to identify an illustrative list of potential transboundary issues. The criteria discussed were well-defined, existing or potential activities that could result in significant impacts across national boundaries. Hotspots were designated as geographical or non-geographical. This activity has the potential to be an important step in building institutional capacity within the MRCS, the national committees, and line agencies, engaging local stakeholders and NGOs in the capacity building process [45], [47].

In addition to mapping hotspots, employing a collection of historical events on conflict and cooperation is an essential tool used to dissect indicators of conflict or cooperation in the basin geography. As already mentioned, data from the TFDD and subsequent analysis have led to published conclusions indicating greater institutional capacity reduces the possibility of water conflicts [35]. A well conducted study of the Mekong region with local, national, and regional level data is an excellent opportunity to enhance cooperation and strengthen institutional capacity among stakeholders, partners, and institutions.

5. COOPERATIVE MANAGEMENT INSTITUTIONS AND COLLABORATIVE PROCESSES - EXAMPLES

Much of the research internationally confirms that cooperative management organizations emphasizing collaborative processes can reduce potential conflict by including conflicting interests in decision-making, providing forums for negotiation and discussion, building trust and confidence through stakeholder collaboration, and encouraging stakeholder and participatory involvement in basin planning and development projects [49], [50]. Examples of basins employing these methods include the Nile and Columbia River Basins, among others. Some of these principles and approaches may be developing in the Mekong region.

Civil society has a potential role in these institutions, although its role is not fully being realized in the Mekong region. Badenoch [51] makes the point that the lack public involvement in national planning activities permeates into regional institutions, suggesting that the role of stakeholders and civil society in organizations such as the MRC is limited. Compared with European and American standards this may be the case, however regional organizations such as the MRC are involving civil society directly through integrated basin development planning [52].

Phase II of the MRC's Basin Development Plan (BDP) facilitates various degrees of stakeholder participation through a number of mechanisms, ranging from public hearings, consultations, sub-area forums, to multi-stakeholder forums or "regional multi-stakeholder dialogues" [52, p.33]. The forums provide an ongoing mechanism for civil society to provide input into the planning process while Regional Technical Working Groups (RTWGs) involve the academic community in basin planning details. BDP has also created its own

training program aimed at capacity building at regional, national, and community groups. In this respect, the MRC is tapping into civil society, NGOs, and the NMCs through its regional planning process despite the absence of stakeholder involvement at the national level – championing a regional-based collaborative approach to basin planning.

Some observers are critical of collaborative approaches to decision-making in river basins, and fear they complicate regional cooperative approaches to water governance. They think that these local-based efforts may exacerbate tensions and strain relations between riparians [53]. The problem with these claims is similar to the water wars debate already discussed; there is simply an overwhelming amount of credible evidence to the contrary.

Nile basin

The Nile Basin Initiative (NBI) is an example of collaborative management of a river basin at a regional level. Its mission is to cooperatively share the river, share substantial socioeconomic benefits, and promote regional peace and security in the Nile Basin. The NBI started its organizational development with a participatory process of dialogue among the riparians (10 countries), resulting in an agreement on a shared vision to "achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources" [54]. In addition to providing security and peace among Nile riparians, the NBI also ensures that cooperation and action is taken jointly. The NBI contains the NBI Strategic Action Program, which has two main legs: the Shared Vision Program (SVP) and Subsidiary Action Programs (SAP). The SVP contains the primary coordination component, focusing activities on stakeholder involvement, capacity building, and training, including on-the-ground activities. By 2004, more than $35 million dollars had been allocated toward these activities by donor countries [55]. Outside funding has been a key component to the NBI's success in building institutions that are long-standing, stable, and well-defined resulting in cooperation rather than conflict in the basin [56]. The evolution of cooperation has been largely process focused, building collaborative structures and sustainable institutions at both the national and regional levels, expanding capacity in water uses, and importantly, building trust amongst riparian states.

Pacific northwest

Conflict resolution through collaborative management is actively working in the Pacific Northwest on the Columbia River Basin. The Northwest Power and Conservation Council (NPCC), is an example of an institution that is responding to ecological and institutional dilemmas, bringing together federal, regional, state, local and tribal actors. It was authorized by the 1980 Northwest Power Act (NPA) that prompted Oregon, Washington, Idaho, and Montana to enter an interstate agreement for devising basin-wide planning for energy conservation and fish and wildlife protection and restoration in the Columbia River Basin [57]. Federal, regional, state, county, tribal, and local agencies are working together to integrate recommendations for fish and wildlife management while considering the region's needs for efficient, economical, and reliable power. The Bonneville Power Administration operates most of the dams on the Columbia River and is tasked by the NPA with funding the majority of costs for the NPCC's Fish and Wildlife Program. Other federal agencies involved in managing the basin's dams and hydropower, like the Corps of Engineers, are responsible for acting in accordance with the plans devised by the council. Importantly, the NPCC also cooperates with the BPA and Army Corps of Engineers (USACE) in managing the Columbia Basin Treaty (CBT) between the United States and Canada [58].

In the state of Oregon, local watershed councils are working with agencies to restore the ecological integrity of the Columbia River Basin as well as other basins in Oregon. While also motivated by federally mandated Endangered Species Act (ESA), local stakeholders and private landowners are making decisions and taking actions on the ground, improving the quality of their respective watersheds, and interacting with agencies at many scales of governance. Communities are developing social and institutional capacity at multiple scales, involving local, tribal, state, and regional and federal stakeholders in the process.

The contemporary trend in river basin management is to organize into integrated units – around hydrological boundaries. Many communities in river basins are seeking new ways to cooperate and participate to avoid conflict, resulting in the emergence of new and innovative governance models. Throughout this important but at times erratic process, a few lessons are available. Stakeholder participation is critical to institutional effectiveness. Institutions that plan and carry out significant water resources management measures without stakeholder involvement often end up reworking major projects or paying large (legal) mitigation costs. In fact cost recovery is proving to be elusive when stakeholders are left out of the planning process of many water projects [49].

Alaerts [50] lists a number of distinctions that separate water management necessities from other resources. Importantly, he provides an analytical framework to model successful river basin institutions and institutional frameworks, placing cooperative and collaborative decision-making with stakeholder involvement firmly in the center of the model. Moreover, his analysis shows that "smaller is better," meaning that decisions made at the lowest levels have the greatest chance of success [50].

6. CONCLUSIONS

Water is daily basin need to humans. Access to it is being recognized by some as a human right. Catchment-based cooperative water management has been achieved where water users put their common long-term interest ahead of their desire for short-term personal gains. These are not new ideas. Bali's *subak* village-based system, Spain's medieval *confederaciones hidrográficas* [50],

and the tribal Berber allocations of time rather than water [59], are old examples of cooperative institutions. In the modern context, the complexity of borders, population growth, changes in governance, and climate change are placing pressures on shared water users and demanding that effective, sustainable, and peaceful solutions be found to conflicts. Research and case studies show that water conflict prevention management, regional collaboration including civil society, and capacity building at all scales provide credible solutions to these challenges, creating an environment of peace rather than conflict on international and transboundary waterways.

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Effect of Paddy Area Conversion to Rubber Plantation on Rural Livelihoods: A Case Study of Phatthalung Watershed, Southern Thailand

Anisara Pensuk and Rajendra P. Shrestha

Abstract*— *This study examines the land use change, paddy to rubber in particular, for last three decades in Phatthalung watershed of Thailand to explore the effect of land use change on rural livelihoods. Land use change was studied using remote sensing data acquired over 1976 to 2006 where as livelihood assessment was done using household data collected through household survey. The study revealed that rubber plantation has been growing in the area with the decrease in paddy area and others and the driving factor is better income from rubber. Overall livelihood between two groups of households (rubber-based and rice-based) is although not significantly different, there are some differences at individual livelihood indicator level. The result however explains some important characteristics, such as poor status of natural asset compared to other assets, on which the sustainable rural livelihood resides.

***Keywords*— Land use change, Livelihood assessment, Thailand.**

1. INTRODUCTION

The modification of land use and land cover contributes to watershed degradation through important environmental consequences on soil and water quality, biodiversity, methane emission and reduction of CO_2 absorption [1]-[2]. There have been number of studies relating to land use changes in the past but are limited to understanding the causes and effects of land use changes on biophysical aspects. Studies on the effects of land use changes on rural livelihoods are still inadequate.

Land use is an important factor influencing livelihood of farmers. In the context of Thailand, land use issue plays an important role as majority area of the country is under agriculture [3] employing the majority of Thai population. The change in farming system, through land use change and modification can affect farmer livelihoods and also the livelihood strategies in changing circumstance [4]-[5].

Sustainable Livelihood Approach (SLA) developed by DFID [6] was applied in this study in order to assess farmers' livelihoods due to the change in land use system. According to SLA, livelihoods resources comprised of five different capitals or assets, namely, human asset, natural asset, financial asset, social asset and physical asset [6].

Human asset is skills, literacy, knowledge, ability to labor and health of household members which enable to achieve their livelihood objectives [6]-[7]. Natural asset is very important for livelihoods, especially for rural households in which most household activities are resources-based activities. Natural asset can be considered as the natural stocks (soil, water, air, genetic resources, etc.) and environmental services (hydrological cycle, pollution sinks, etc.) [7]-[8]. Financial asset includes financial flows and stocks [6] as well as cash, savings and credit are the basic needs for livelihoods. For example, livestock [4], [9]-[12], and remittances [8], [12] are the financial asset indicator. Social asset is rather complicated [6]-[7]. It can be networks and connections, memberships of formalized groups and relationships and the relationship of trust [8]. Density of active community and benefit from kinship could be other social asset indicators [9]-[10], [12], as well as the collective action and accessibility to knowledge [4]. Physical asset comprises of basic infrastructure and producer goods which are needed to support livelihoods [6]. Houses and occupational equipments are basic physical asset indicators [8], [10]-[11], as well as road and transportation [9]. Vehicles, machinery, shops and other agricultural implements can be also considered as physical asset [12].

This study was carried out in Phattalung watershed of Thailand where the agricultural systems are undergoing change driven by a variety of internal and external forces. The objective of the study was to examine effect of land use change, in particular paddy to rubber conversion, on rural livelihood.

2. THE STUDY AREA

The study area, Phatthalung watershed is located between 7º 5´-7º 55´latitute and 99º 44´ to 100º 25´longitute covers Phatthalung and Songkhla province of the Southern part of Thailand (Fig.1). The western part of the area is mountainous covered by evergreen forest. Rest of the area is flood plain with some rolling terrain. The watershed area is approximately 302,699 ha. and the elevation in the area ranges between 0-1200 m above m.s.l. The annual average rainfall is 1,853.5 mm with average annual rainy days of 154. Rainfall distribution is bimodal, with the long rains from September to January and the short rains from May to June. The average annual temperature is 28.14ºC [13].

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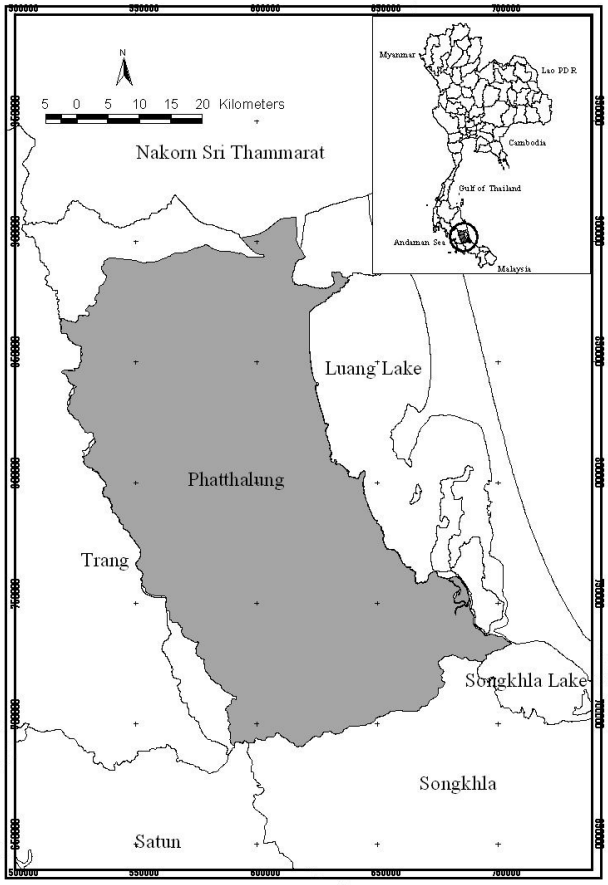

Fig.1 Map of Phatthalung Watershed

The estimated households (HH) and population of the study area are 140,618 and 500,000 respectively in 2006 [13]. Agriculture has been primary source of livelihood for the majority of population. Land use activities include rubber, rice, orchards cultivation and shrimp and livestock farming. The major farming system consists of a highland rubber plantation (*Hevea brasiliensis*), intercropped with pineapple, and a lowland rainfed paddy in some areas. Majority of population are smallholders with an average land holding size of 1.96 ha.

3. RESEARCH METHODOLOGY

Analysis of Land Use Change

In order to investigate land use change, the remote sensing data (Landsat images, Path/Row-128/55) were used. Landsat Multispectral Scanner (MSS) data acquired on 30 March 1976 was downloaded from http://glovis.usgs.gov/. Landsat Thematic Mapper (TM) acquired on 1 June 1990 was obtained from GLCF (Global Land Cover Facility) at http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp and Landsat Enhanced Thematic Mapper (ETM+) acquired on 27 August 2006 was purchased from the United States Geological Survey (USGS).

Remote sensing data was interpreted to produce land use maps of three time periods, i.e. 1976, 1990, and 2006. The interpretation was done using a supervised maximum likelihood classification procedure in ERDAS IMAGINE software. The maximum likelihood classification algorithm requires training area which represents the spectral behavior of every land use class for classes identification [14]. For this study, Level I of land cover classification as suggested by Anderson et al. was followed [15]. Seven major land use classes namely forest, rubber and perennials, paddy field, urban or build-up land, aquaculture, wetland and water body were classified as presented in Table 1.

Table 1. Description of Land Use Types

Land use/cover	Description
Forest	Deciduous forest, coniferous and evergreen forest, and mixed forest
Para rubber and perennial	Para rubber plantation, fruit trees including perennial trees
Paddy field	Paddy field and rice field
Urban and build up area	Cities, towns, villages, highways and transportation areas
Aquaculture	Shrimp farms, fish farms and other types of aquaculture
Wetland	Mangrove and swamp areas
Water body	Lake and man made reservoirs

The final land use classification of three time periods was examined against all available reference data and field information including author's own experience in the study area by constructing the confusion matrices, which compare on category-by-category basis, the relationship between known reference data and the results after classification [16].

Socio-economic and Livelihood Assessment

The secondary socio-economic data and the household survey were used in order to analyze the socio-economic and livelihood of farmers. The secondary socio-economic data e.g. numbers of households and population were obtained from the Ministry of Interior of Thailand (MOI) and were used for sample size determination. Out of 140,618 HH in the study area, a total of 140 HH was determined as sample size using the sample size determination technique given by Arkin and Colton [17]. A total of fifteen villages who have been practicing paddy and/or rubber cultivation were selected in the first step to draw those 140 sample HH. Out of 140 HH, 95 HH including those who changed from paddy field to rubber plantation, called as Group I in the paper. The second group of HH (Group II) consisted of 45 HH who have been growing rice throughout the study periods at least for last 30 years.

A household survey was conducted by administering structured questionnaire which included both close and open-ended questions to collect qualitative and quantitative data on households and their activities. The questionnaire was pre-tested and revised before conducting interview of sampled HH. The survey was

carried out in January and February 2007.

The surveyed household data were analyzed by using Statistical Package for the Social Sciences (SPSS). A three point rating scale with discrete value of 0, 0.5 and 1 was used for measuring and rating the livelihood indicators.

Natural asset index was computed from three indicators, namely, land holding size, soil fertility status and the availability of water. Households holding a larger plot of land were given the higher score than households which hold smaller land area. The soil fertility status and water availability indicators were derived from the perception response of households. The 'increase' perception in soil fertility and water availability was given the highest score of 1, the 'no change' was given a medium score of 0.5, and the 'decrease' was given the lowest score 0. Income from crop and livestock production and loan were used as indicators for computing financial asset index. In the rural area, since household income generally comes from crop and livestock production, both sources of income were used as financial asset indicators. Higher income was given higher score than lesser income whereas it was vise versa amount of loan. Human asset index was computed from three asset indicators, namely number of household member, working age labor (15-60 years old) and full time labor in agriculture. Higher score was given to high value in each indicator. Social asset index was derived from the accessibility to knowledge (literacy level) and benefit from kinship (remittance). High education level was given higher score and so was the remittance, i.e. higher the remittance higher the score. Physical asset can be defined as the basic necessary infrastructure which however does not vary considerably within the study area. However, accessibility to market was selected as only physical asset indicator for this study. Higher score was given to households which located near the market and the lower score to those located far from the market. Scores of all indicators in each asset were summed up and categorized into three classes with score values of 0, 0.5 and 1 in order to generate livelihood asset index of rural livelihood in the study area. A compared mean with independent T-test was employed at $p<0.05$ level to examine the difference in various livelihoods indicators between two groups.

4. RESULTS AND DISCUSSION

Land Use Change

The land use change analysis conducted for three time periods (1976, 1990 and 2006) and the results are presented in Table 2. The classification results were reasonably satisfactory in terms of classification accuracy as suggested by Anderson et al. [15]. In the past, paddy cultivation was dominant in lowland area of Phatthalung watershed while rubber plantation was mostly confined to the hill side of watershed. In the recent past, there has been decrease in forest and wetland area and even paddy field and area rubber plantation has tremendously increased.

Forest cover has been depleted from 15.30% in 1976 to 14.65% in 1990 and 12.96% in 2006. The forest reduction rate was higher in 1990-2006 (-11.56%) compared to the eriod of 1976-1990 (-4.22%). The depletion of forest was basically due to the encroachment, particularly rubber plantation (Table 2).

Table 2. Land Use Change between 1976, 1990 and 2006

Land use types	Year			%Change	
	1976	1990	2006	1976-2990	1990-2006
Forest	15.30	14.65	12.96	-4.22	-11.56
Rubber plantation	44.36s	44.65	61.20	+0.67	+37.05
Paddy field	36.23	37.23	23.76	+2.83	-36.24
Wetland	4.10	3.42	1.97	-16.62	-42.32
Water body	0.01	0.02	0.07	+50.71	+341.76

Similarly, wetland area has been depleted from 4% in 1976 to about 2% in 2006 (Table 2). The total gross depletion was observed higher in the later period compared to the former period under study, i.e. -16.62% during 1976-1990, and -42.32% during 1990-2006 and the reasons are encroachment of paddy field and wetland areas mostly under aquaculture due expanding rubber cultivation and infrastructure development.

At present, more than 80% of study area is under agricultural area, mainly paddy and rubber, whereas residential area is less than 1%. Paddy field occupied about 37% in 1976 and 1990 but has been decreased to 23% in 2006 (Table 2). During 1976-1990, nearly 25% of paddy field has been converted to rubber plantation. The conversion rate of paddy field was higher in the recent past (1990-2006) as more than half of paddy areas are replaced by rubber plantation compared to the period of 1976-1990.

Assessment of Rural Livelihood

The livelihood indicators are presented in Table 3. Mean comparison through independent T-test for two HH groups under study indicated that the three variables chosen to represent human asset indicator did not show any significant difference between the groups while comparing respective score means. So was the case with human asset index, calculated based on those three variables, however the calculated human asset index was slightly higher for Group II (0.5) compared to Group I (0.47).

In case of natural asset indicator, there was no significant difference between two groups as shown by natural asset index, however the computed index was slightly higher for Group I (0.47) compared to Group II (0.43). When considered the variables of natural asset indicators, water availability status was higher for Group II (0.58) as opposed to Group I (0.44). It was also observed that, means were significantly different at $p<0.05$. The other two variables, namely land holding size, and soil fertility status, scored slightly higher for Group I compared to Group II.

Table 3. Livelihood Asset Indicators

Livelihood indicator	Group I		Group II		Sig
	Average	SD	Average	SD	
Human asset					
Household members	0.61	0.41	0.60	0.38	0.944^{ns}
Working age members	0.54	0.37	0.59	0.43	0.465^{ns}
Agriculture as main occupation	0.47	0.35	0.47	0.34	0.912^{ns}
Human asset index	0.47	0.40	0.50	0.41	0.699^{ns}
Natural asset					
Land holding size	0.51	0.42	0.37	0.43	0.062^{ns}
Soil fertility status	0.51	0.28	0.50	0.30	0.919^{ns}
Water availability status	0.44	0.29	0.58	0.34	0.015*
Natural asset index	0.47	0.39	0.43	0.46	0.641^{ns}
Financial asset					
Income from crop production	0.38	0.41	0.19	0.32	0.007*
Income from livestock production	0.15	0.33	0.09	0.27	0.256^{ns}
Credit and loan	0.77	0.36	0.68	0.43	0.171^{ns}
Financial asset index	0.54	0.32	0.40	0.31	0.019*
Social asset					
Access to knowledge	0.53	0.41	0.50	0.41	0.723^{ns}
Kinship	0.04	0.18	0.33	0.16	0.913^{ns}
Social asset index	0.56	0.41	0.50	0.41	0.058^{ns}
Physical asset					
Access to market	0.89	0.26	0.99	0.07	0.020*

Source: Field survey (2006)
*ns = Non-significant at p>0.05, *Significant at p<0.05*

Financial asset index presented significant difference between two groups as indicated significantly higher by compared index of income from crop production (0.38) for Group I and 0.19 for Group II. When considered the other two variables, namely income from livestock and credit and loan, both indicators scored higher for Group I compared to Group II, however there was no significant difference between groups.

Social asset was assessed through two variables, namely access to knowledge and kinship. Group I has higher score in access to knowledge while Group II had higher score in kinship. However, those two variables, and also composite social asset index were observed to have no significant difference between two household groups although Group I (0.56) showed slightly higher in overall social asset index compared to Group II (0.50).

Accessibility to market, as social asset, was significantly different between two groups, Group II (0.99) had higher accessibility to market than Group I (0.89). However, the accessibility to basic infrastructure e.g. road, school, hospital, electricity, water and sanitation was considered as the important physical asset indicators and included also in this study due to its contribution of better livelihoods, but it was assessed and considered to be of same level for both groups.

The livelihood index of each livelihood asset derived from livelihood indicators are presented through radar diagram in Fig.2 in order to compare and differentiate better-off indicator of each asset over others. HH in Group I tended to be better-off in terms of financial asset due to more income generation, however Group II was better-off in physical asset due to easier market access. Human, natural and social asset were found not to be significantly different between the groups.

5. CONCLUSION AND RECOMMENDATIONS

The land use change study showed a dramatic decline in rice growing area due to expansion in rubber plantation area. The study revealed that, many rice growing farmers tended to convert their land to rubber plantation due to the higher income from rubber production. Land tenure

as such was not a major problem in the area since most of the farmers do own their lands.

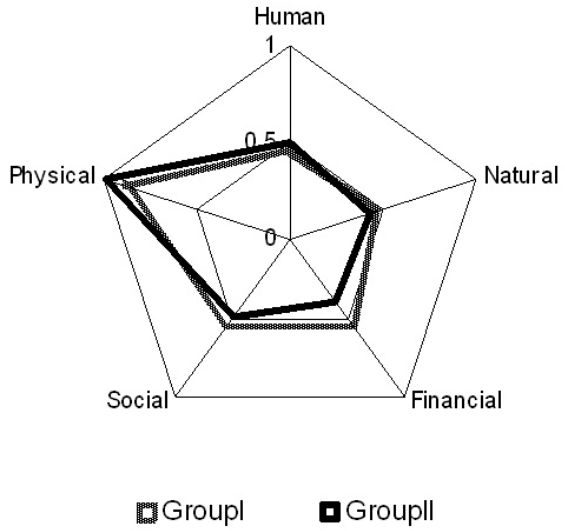

Fig.2. Livelihood Pentagons of Rubber-based HH (Group I) and Rice-based HH (Group II).

According to the statistical results, both HH groups have moderate level of livelihood for four out of five livelihoods assets (human asset, natural asset, financial asset and social asset). In general, rubber-based households are relatively better-off in financial asset than rice-based households due to higher price of rubber than rice. In order to improve financial asset of households, livestock can be an alternative source of income which should be promoted since livestock can generate the additional income for households. However, both household groups have low level of natural asset as indicated as the lowest score compared to others assets. This implies there is the need to take into account of these indicators, such as land holding, soil and water quality, for developing appropriate strategies.

Understanding the situation of rural livelihood is important for sustainable rural development. However, the assessment would be more effective when the most relevant livelihood indicators can be included in the analysis.

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