Spatial and Temporal Pattern of Land and Water Productivity in the Lower Mekong River Basin

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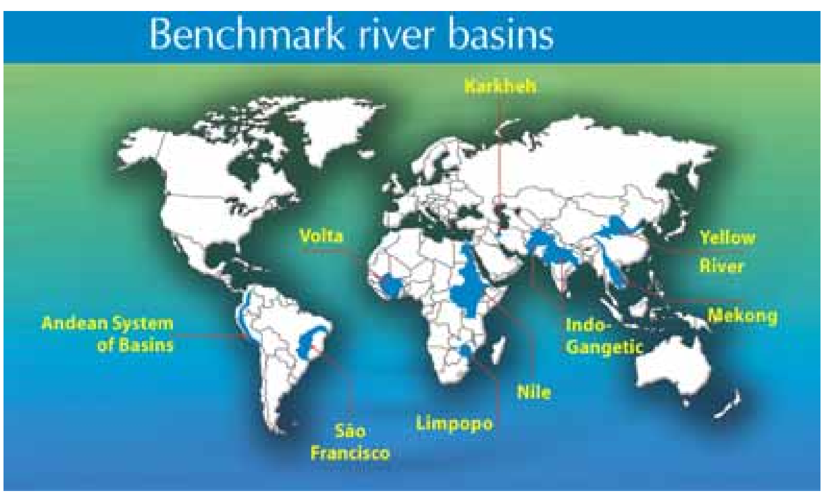

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Spatial and Temporal Pattern of Land and Water Productivity in the Lower Mekong River Basin

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Summary

We have assembled agricultural production and economic data from 1993-2004 for some 20 crops and several types of livestock, for all the administrative provinces of the Lower Mekong Basin. We combined these data with areas, with simple crop water use modelling based on FAO crop factors and with population data to produce maps and trends of productivity per land area, per water use, production per head, gross value and standardised gross value of production.

We did not consider the fisheries and forest resources, both of which are important in parts of the basin, due to basin-wide data not being available.

The results show that overall land and water productivity is higher in the Mekong Delta, moderate in Laos and lower in Cambodia and northeast Thailand. There is steady growth of productivity in Vietnam and Laos whereas growth in Cambodia and Northeast Thailand is very slow. The majority of agricultural income is from rice cultivation. However, income from livestock and other crops is not unimportant and is growing in both Laos and the Central Highlands of Vietnam.

1. Introduction

One of the greatest challenges of our time is to enhance water, food and environmental security. A step towards reaching this goal is to increase the productivity of water used for agriculture. This will play a vital role in easing competition for scarce water resources, prevention of environmental degradation and providing food security (Molden *et al.* 2003). The argument is simple: by growing more food with less water, more water will be available for other natural and human uses (Molden and Rijsberman 2001, Rijsberman 2001).

The Challenge Program on Water and Food (CPWF) undertakes research to maximise water productivity for agriculture in order to improve livelihoods in several of the world's major river basins. The main purpose of CPWF is to catalyse increases in agricultural water productivity at local, system, catchment, sub-basin and basin scales as a means to reducing poverty and improving health, the environment and food security. As part of that program, we are analyzing the water and land productivity of the lower Mekong River basin in Southeast Asia.

The Mekong River basin is one of the most dynamic, productive and diverse river basins in the world. It is home to approximately 65 million inhabitants, most of whom are rural poor with livelihoods directly dependent on the availability of water for the production of food. Agriculture, along with fishing and forestry, employs 85% of the people living in the basin, many at subsistence level (MRC 2003). The pressure on the natural resource base, particularly water resources, has increased in recent decades and has resulted in new patterns of development within the six riparian countries (Cambodia, China, Laos, Myanmar, Thailand and Vietnam). Note that in this paper we restrict the study to Cambodia, Laos, Northeast Thailand and Vietnam. Whilst living standards have generally increased markedly across the basin, there remain significant areas of poverty.

Agricultural productivity in the lower Mekong River basin, which is also expressed as land and water productivity, is a critical influence on both rural welfare and the economic growth that ultimately helps alleviate poverty. Agricultural productivity also strongly influences food security. Growth in productivity can increase and stabilize food supplies, as well as increase people's ability to purchase food. It is important to assess the current level of, and trend in, agricultural productivity and its links with poverty and other socio-economic conditions. This will help us identify the constraints for low productivity and suggest measures to improve them, which will eventually help alleviate poverty in the region.

Most of the previous studies of agricultural productivity in the lower Mekong Basin were based on part of the basin such as areas within one riparian country, on a single crop such as rice, and for a short period or for just one growing season. Chea *et al.* (2001) focused on the rainfed lowland agroecosystem and different cropping models to demonstrate an approach intended as a precursor to increasing the productivity of rainfed ecosystems in Cambodia. Kono *et al.* (2001) used a GIS-based crop modelling approach to evaluate the productivity of rainfed, lowland paddy rice in Northeast Thailand. Yamamoto *et al.* (2004) and Nawata *et al.* (2004) used a simple cassava model to estimate attainable yields for productivity analysis within Northeast Thailand. Shimizu *et al.* (2006) examined the relation between yields of rainfed paddy rice and factors that affect the yields in Cambodia. Schiller *et al.* (2001) summarized the known main abiotic and biotic production constraints in each of the rice-producing environments of Laos but did not examine the socioeconomic constraints, which can also have significant impact on farmer attitudes and production. Buu and Lang (2004) discuss the constraints affecting rice production and ways of improving productivity in the Mekong Delta of Vietnam.

None of the previous studies considered the whole of the lower Mekong Basin, nor did they consider the economics of production. Moreover, they concentrated only on rice, and did not take into account the other sectors such as livestock. Furthermore, these previous studies did not consider the temporal trends.

In this study, we consider the main crops in the Basin and include livestock in the productivity analyses. We shall consider fisheries in a separate analysis, which we shall report in due course. We did not consider forestry at all due to lack of data.

We consider provincial administrative boundaries as the spatial unit and we analyzed the trends in the data from 1993 to 2004. We estimated productivity both in terms of production (e.g. kg per ha or per m^3 of water) and production value ($ per ha or per m^3 of water). Thus far, this is the most comprehensive analysis of land and water productivity or agricultural productivity for the lower Mekong Basin.

2. Data sources

2.1 Land use, crop area, yield, production and number of livestock

Data of planted and harvested area, yield and production of different crops and the number of livestock were obtained from the following sources:

Laos: Regional Data Exchange System on food and agricultural statistics in Asia and Pacific countries maintained by the FAO Regional Office for the Asia Pacific Region (http://www.faorap-apcas.org/lao/busdirectory/search_results.asp). In addition, land-use area and provincial area were obtained from the Ministry of Agricultural and Forestry Website (http://www.maf.gov.la/Census/Land_Use/land_use.html) and from the Laotian National Statistics Centre (http://www.nsc.gov.la/).

Cambodia: Regional Data Exchange System on food and agricultural statistics in Asia and Pacific countries maintained by the FAO Regional Office for the Asia Pacific Region (http://www.faorap-apcas.org/cambodia/index.htm). Some of the data were also obtained from the Ministry of Agriculture, Forestry and Fisheries (http://www.maff.gov.kh/statistics/index.html).

Thailand: Statistical Year Books published by the Office of Agricultural Economics of the Ministry of Agriculture and Cooperative of the Royal Thai Government (http://www.oae.go.th/English/index.htm).

Vietnam: General Statistical Office of Vietnam (http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3).

2.2 Prices of crops and livestock

Local farm-gate prices of the crops and livestock are not available in the sources mentioned above except for Thailand. To make a consistent comparison of the productivity indicators among the riparian countries, we used the farm-gate prices of the crops and livestock available from the FAOSTAT database (http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0

Farm-gate price of some crops are not available for Thailand from the FAOSTAT database. In these cases, we used prices from the Thai Office of Agricultural Economics (http://www.oae.go.th/English/index.htm). Crop prices are not available after 2003 in the FAOSTAT database. For 2004 we used either prices from the other sources, where available, or if not we used the 2003 prices. We had to assume prices of some minor crops that were not available from any source.

Farm-gate price of the crops and livestock are not available for Vietnam in any sources that are available publicly. The General Statistical Office of Vietnam informed us that no such data are available. Through extensive search on World Wide Web, we found some data published by Ringler and Huy (2004) and Laper *et al.* (2003). Dr. C. T. Hoanh of the International Water Management Institute (IWMI) provided us with data of retail prices in Vietnam, whose original source was the Government Price Committee. Using the information from these three sources and the price data of neighbouring Cambodia, we estimated the farm-gate price of crops and livestock of Vietnam using the following assumptions.

a) The price of rice for 1999 is from Ringler and Huy (2004). The prices for the other years were estimated by multiplying the retail price for each year by the ratio of farm price to the retail price in 1999. The domestic price of rice for 1994 was obtained from the International Rice Research Institute (IRRI) database (http://www.irri.org/science/ricestat/)

b) The prices of maize, peanuts and sugarcane are from Ringler and Huy (2004) and were assumed to be constant for the period.

c) The farm prices of rice and maize are approximately 70% of the retail price. The price of soybean was also estimated to be 70% of the retail price and to be constant from 2000 to 2004.

d) The price of sweet potato and cassava were estimated to be the same as in Cambodia.

To estimate standardized gross value of production, we obtained the international price of rice from the IRRI database (http://www.irri.org/science/ricestat/). The international price for rice is for the 'free-on-board' price for milled rice, including 5% broken grain, whereas the farm-gate price is the price of paddy (unmilled) rice. Therefore, in estimating the standardized gross value of production we have used a milling ratio of 0.55 for all countries (see http://vietnamgateway.org/vanhoaxa/english/know_pub_detail.htm).

2.3 Currency exchange rates

The exchange rates (local currency to US dollars) of the Lao kip and the Cambodian riel were taken from the General Statistical Office of Vietnam (http://www.gso.gov.vn/default_en.aspx?tabid=491). However, the exchange rate for the Vietnamese dong is not available at that site. We obtained the exchange rates for the dong from the Economic and Social Commission for Asia and the Pacific of the United Nations (UNESCAP) (http://www.unescap.org/stat/data/statind/datatable.aspx) and from

http://en.wikipedia.org/wiki/List_of_historical_exchange_rates#Table and http://www.jeico.com/cnc57vtn.html

We took the exchange rate for Thai baht from http://fx.sauder.ubc.ca/etc/USDpages.pdf.

2.4 Population

The provincial populations of Laos are those published in the Statistical Yearbooks of the National Statistics Centre (NSC 2003, NSC 2004, NSC 2005). The provincial population of Cambodia for 1998 is from the Cambodian Government website (http://www.cambodia.gov.kh/unisql1/egov/english/

organ.admin.html) and for 2001 is from the Fertilizer Advisory, Development and Information Network for Asia and the Pacific (FADINAP) website maintained by UNESCAP, (http://www.fadinap.org/cambodia/Agstat20002001/population.htm). We estimated he population of Cambodia for other years from the data for 1998 and 2001 using equation (1) (http://web.nso.go.th/eng/stat/subject/subject.htm#cata1). The provincial population growth rate is available at the Ministry of Agriculture, Forestry and Fisheries of Cambodia (http://www.maff.gov.kh/statistics/index.html).

$$r = \frac{\ln(P_{n+t} / P_n)}{t} * 100 \qquad (1)$$

Where,

r = Population growth rate (percent per year),
P_n = Population in year n
P_{n+t} = Population in year $n + t$

The provincial population of Thailand for 1990 and 2000 and the growth rate are available from the National Statistical Office of Thailand (http://web.nso.go.th/pop2000/table/tab2.pdf). The population in other years was estimated using equation 1.

The General Statistical Office of Vietnam provided the yearly provincial populations of Vietnam.

2.5 Livestock information

The conversion factors (Table 1) to estimate the livestock unit density, carcass weight and percentage slaughtered by species for the countries were taken from the Livestock Sector Brief published in 2005 by the Livestock Information, Sector Analysis and Policy Branch of FAO (FAO 2005a, FAO 2005b, FAO 2005c, FAO 2005d). These publications are available at:

http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/lsb_THA.pdf

http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/lsb_KHM.pdf

http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/lsb_LAO.pdf

http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/lsb_VNM.pdf

Carcass weight and percentage slaughter by species are available for only a few years, which show very little variation. We therefore used the mean figures for all years in the analysis.

2.6 Climate data

To examine the relations of the agricultural production to the available water, we required observed climate records for the period of the yield and other records, from 1993 to 2004. We obtained climate data for observed rainfall, and maximum and minimum temperature from:

Table 1. Conversion factors for livestock units.

Species	Conversion factor
Buffaloes	0.70
Cattle	0.65
Sheep and goats	0.10
Pigs	0.25
Poultry	0.01

a) The global surface at 30 arcminutes resolution of precipitation and temperature from the Climate Research Unit (CRU) of the University of East Anglia (http://www.cru.uea.ac.uk/cru/data/),

b) The global surface summary of daily data produced by the National Climatic Data Centre (NCDC) of National Oceanic and Atmospheric Administration (NOAA) (http://www.ncdc.noaa.gov) in Asheville, NC, and

c) The daily rainfall data of the meteorological stations within the Basin from IWMI (www.iwmi.org).

2.7 Soil data

The estimation of crop water use requires data of soil field capacity, wilting point and saturated moisture content. The only soil data available to us was a digital soil map from the Mekong River Commission. It gave only soil unit names and contained no data about soil hydraulic properties. Instead, we assessed crop water use for generalised soil types including clay, clay loam, silt loam, very fine sandy loam, coarse sandy loam and loamy very fine sand and used average values in the analysis. We will comment on this assumption further in the methods section below.

3. Methods

Productivity, in general terms, is a ratio between a unit of output and a unit of input. The most encompassing measure of productivity used by economists is total factor productivity (TFP), which is defined as the value of all outputs divided by the value of all inputs. However, partial factor productivity (PFP) is more widely used by economists and non-economists alike. Partial factor productivity is relatively easy to measure and is commonly used to measure the return to scarce or limited resources, such as land or labor (Barker *et al.* 2003).

The term water productivity is also defined and used in variety of ways;. there is no single definition that suits all situations. Productivity, combining both physical and economic properties, can be defined is terms of either the gross or the net present value of the product divided by the amount of the water diverted or consumed by the crop (Barker *et al.* 2003). According to Molden (1997), water productivity is the physical mass of the product or the economic value of production measured against gross inflows, net inflows, depleted water, process depleted water or available water[1]. In general, water productivity broadly denotes the outputs (goods and services) derived from a unit volume of water.

In this study, we have used gross value of production (GVP), standardized gross value of production (SGVP), and crop production as the numerator and harvested area of different crops, agricultural area, total area of the province, population, rainfall and actual crop evapotranspiration (ET) as the denominator to estimate several land and water productivity indicators. In addition, we have estimated cropping intensity, livestock unit density both with respect to land and population. The definitions of the GVP, SGVP and other important indicators are described below.

3.1 Gross value of production

Gross value of production (GVP) (in $) can be defined as:

$$GVP = \sum_{i}^{n} A_i Y_i P_i \qquad (2)$$

[1] For definitions see Cook, S., Gichuki, F. and Turral, H. (2006). *Agricultural Water Productivity: Issues, Concepts and Approaches*, Basin Focal Project Working Paper No. 1, URL: http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_restricted/Paper_1_Final_14JY06.pdf.

Where,

A_i = harvested area of crop *i,* ha,
Y_i = yield of crop *i*, ton / ha,
P_i= local price of crop *i*, $ / ton, and
n= number of crops grown in the area

We considered 18 crops for Laos, 18 for Thailand, 14 for Cambodia and 9 for Vietnam, which are all the crops for which data were available (Table 2).

3.2 Standardized gross value of production

Standardized gross value of production (SGVP) was developed for cross-system or cross-country comparison as obviously there area differences in local prices at different locations throughout the world. SGVP (in $) can be expressed as (Molden *et al.* 1998, 2001):

$$SGVP = \sum_{i}^{n} \frac{A_i Y_i P_i}{P_b} P_{world} \qquad (3)$$

Where,

A_i = harvested area of crop *i,* ha,
Y_i = yield of crop *i*, ton / ha,
P_i = local price of crop *i*, $ / ton,
P_{world} = the value of the base crop traded at world prices, $ / ton, and
P_b = the local price of the base crop, $ / ton.

Rice is the predominant crop grown in all four riparian countries of the lower Mekong River basin and is therefore used as the base crop.

3.3 Cropping intensity (CI) and land use classification

Cropping intensity is defined as the ratio of total cultivated area of the crops grown in a year to the total agricultural area and can be expressed as:

Table 2. Crops included in the productivity analysis.

Laos	Thailand	Cambodia	Vietnam
Lowland rice	Major rice	Rice (lowland)	Autumn rice
Dry season rice	Dry season rice	Dry season rice	Winter rice
Upland rice	Maize	Upland rice	Spring rice
Maize	Mungbean	Maize	Maize
Sweet potato	Cassava	Cassava	Soybean
Cassava	Sugarcane	Soybean	Sweet potato
Mung bean	Soybean	Potatoes	Cassava
Soybean	Groundnut	Sugarcane	Sugarcane
Peanut	Kenaf	Vegetables	Peanut
Sesame	Cotton	Mungbean	
Tobacco	Sorghum	Peanut	
Cotton	Coffee	Sesame	
Tea	Garlic	Tobacco	
Sugarcane	Longan	Jute	
Watermelon	Potatoes		
Chillies	Onion		
Vegetables & beans	Shallot		
Coffee	Pineapple		

$$CI = \frac{\sum_{i}^{n} A_i}{A} \quad (4)$$

Where,

A_i = cultivated area of crop i, ha
n = the number of crops grown in a year, and
A = the total agricultural area available for cultivation within each spatial unit, ha.

The total agricultural area for each spatial unit depends on the how the land use is classified in each of the riparian countries of the Basin.

In Laos, land use within each provincial area is divided into four major classes:

(i) Agricultural land,
(ii) Forest land,
(iii) Grazing land, and
(iv) Other land.

Agricultural land is further divided into arable land and land under permanent crops. Arable land is further subdivided in temporary crops and fallow land.

In Thailand, land is primarily divided into three classes: *Forest land*, *farm holding land* and *unclassified farms*. The sum of these three classes equals the total area of the country. *Farm holding land* is further divided into 8 classes. These are:

(i) Housing area,
(ii) Paddy land,
(iii) Land under field crops,
(iv) Land under fruit trees and tree crops,
(v) Land under vegetables and flowers,
(vi) Grassland,
(vii) Idle land, and
(viii) Other land.

Idle land is fallow land that was once paddy and other cropland. This land has been purchased for non-agricultural purposes and the development work has yet to start. *Other land* is land used for roads, footpaths, ditches, fishponds and other similar uses within the farm.

In Cambodia, the total land area is divided into five classes. These are:

(i) Human settlement and infrastructure,
(ii) Agricultural land,
(iii) Forest land,
(iv) Water bodies, and
(v) Unused land

In Vietnam, the total area is divided into:

(i) Agricultural land,
(ii) Forestry land covered by trees,
(iii) Specially used land, and
(iv) Homestead land.

In estimating the cropping intensity, we used the *agricultural area* as defined in the land use classification for Laos, Cambodia and Vietnam. For Thailand, we used the sum of paddy land, land under field crops, under fruit trees and tree crops, and under vegetables and flowers as the agricultural area for each province.

3.4 Livestock unit density and gross value of livestock production

Livestock (buffaloes, cattle, pigs, sheep, goats, chickens and ducks) were converted to the equivalent livestock unit using conversion factors given in Table 1. Equivalent livestock unit (LU) is estimated as:

$$LU = \sum_{i}^{n} Ns_i Cf_i \tag{5}$$

Where,

Ns_i = number of each species *i*,
Cf_i = conversion factor of species *i,* and
n = total number of species.

Livestock unit density per unit area or per capita was estimated by dividing *LU* by the area or population respectively.

The gross value of livestock production (GVLP) (in $) is estimated as:

$$GVLP = \frac{\sum_{i}^{n} Ns_i Ps_i Cw_i Sp_i}{100} \tag{6}$$

Where,

Ps_i = price in US$/kg of live weight (also termed *biological meat*) of the species,
Cw_i = carcass weight in kg
Sp_i = percentage slaughtered, and
100 = conversion factor from percentage to fraction.

In estimating the livestock productivity, we did not consider revenue from milk and eggs. In Thailand, milk production is mostly limited to specialist dairy farms, which use dairy cows with high milk yield of 2,767 kg/year in 2002, compared to 200 kg/year in Laos, 170 kg/year in Cambodia and 1,405 kg/year in Vietnam (FAO, 2005a; FAO 2005b; FAO 2005c; FAO 2005d). The higher yields of Thailand and Vietnam result from the greater development of commercial farms, which use either imported cows or hybrid local stock. In contrast, in Laos and Cambodia the dairy farming is mostly non-commercial and use mostly local stock with much lower yields.

Milk available in the market mostly comes from corporate commercial dairy farms. Milk produced by farmers is used mostly for home consumption. The percentage of cattle milked (which also includes commercial dairy farms) is also very low (2.5% in Laos, 4.8% in Thailand, 4.1% in Cambodia and 1.4% in Vietnam in 2002). We assumed that the income from milk is insignificant compared to the overall income from livestock and did not therefore include it in the analysis.

Producers sell eggs both directly in the market or use them to produce hatchlings. The slaughter rate (number of birds slaughtered per layer hen) of poultry in Thailand is about 400% (FAO 2005b), which is possible only if a large proportion of the eggs produced are hatched. The revenue from selling eggs directly would be negligible compared to the total revenue generated by the poultry industry and we therefore did not include it.

3.5 Provincial average rainfall and reference evapotranspiration

We used the CRU data for 1981-1996 and the NCDC-NOAA and IWMI data for 1997-2005. From these data, we generated monthly rainfall surfaces from 1981 to 2005. We also estimated reference evapotranspiration (ET_o) by Hargreaves' method (Allen *et al.* 1998) using these same data sets and generated monthly surfaces for the years 1981 to 2005. ET_o is the evapotranspiration of a hypothetical, uniform surface of a short, vigorously growing grass crop with adequate water. It is a measure of the

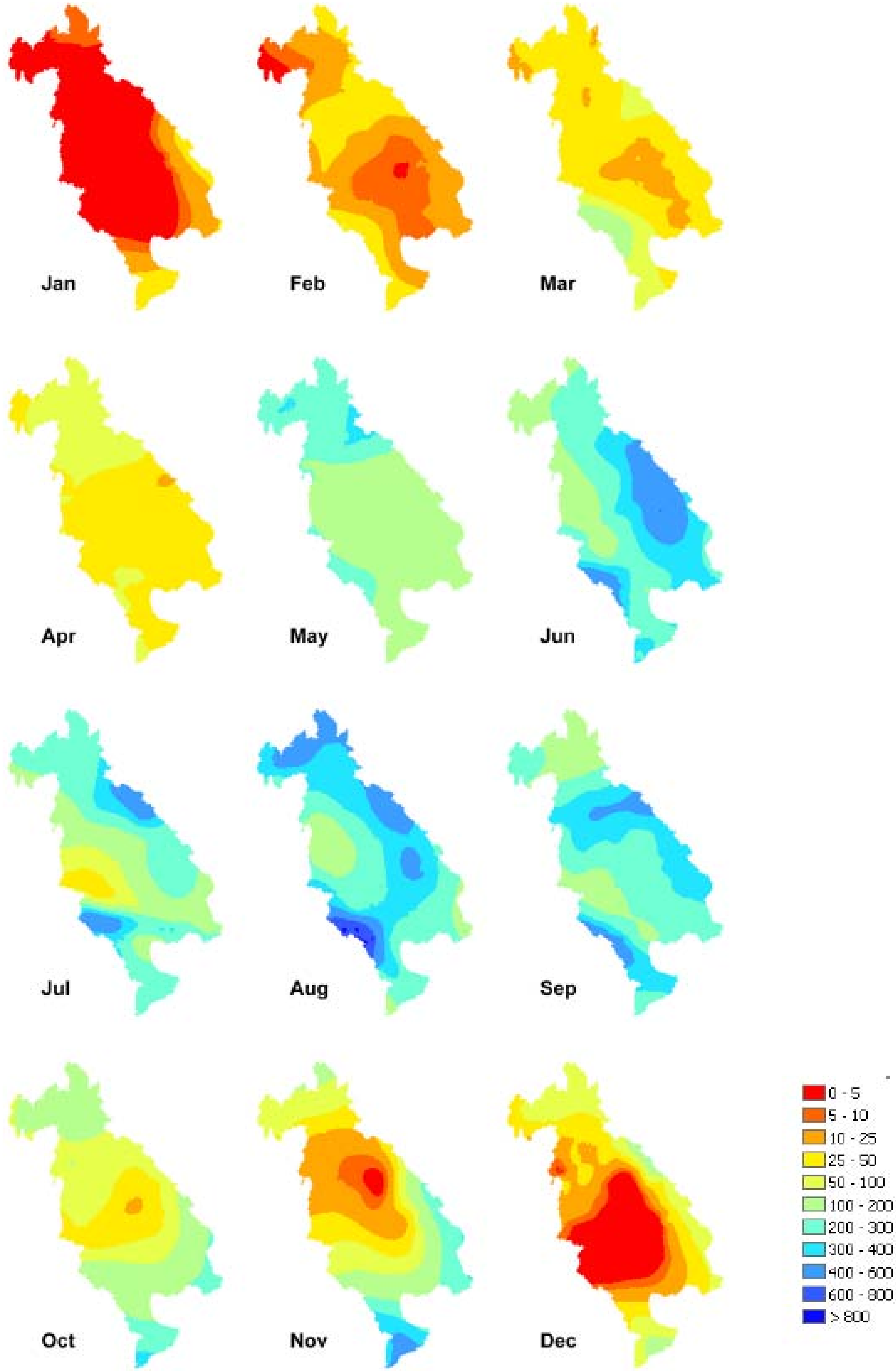

Figure 1. Monthly precipitation (mm) for 1994 (based on CRU data).

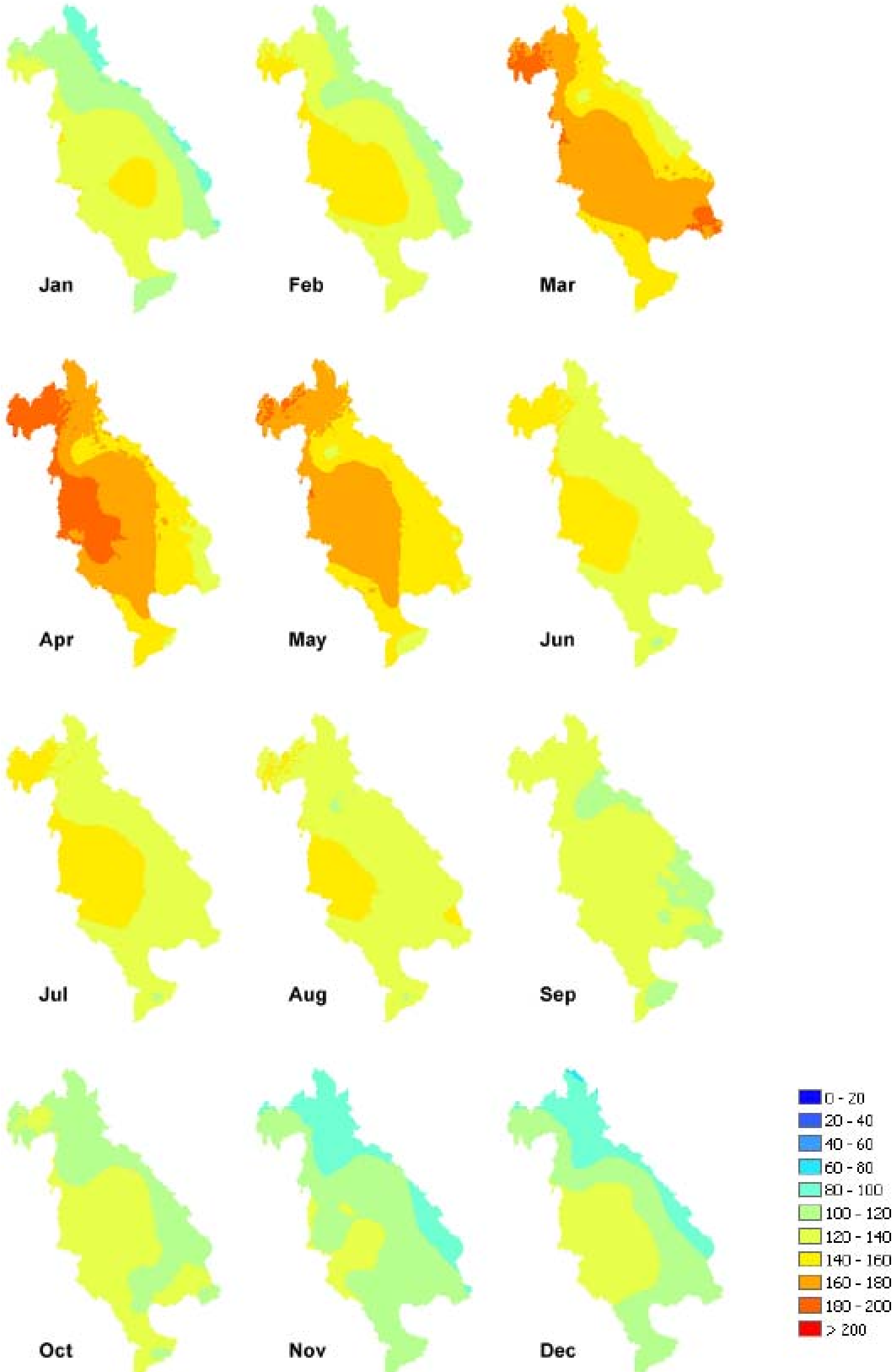

Figure 2. Monthly ETo (mm) for 1994 (based on CRU data).

evaporative demand of the atmosphere. Actual evapotranspiration (ET_a) for a particular crop at a given growth stage is estimated from ET_o by multiplying it by the crop coefficient and other appropriate scaling factors (e.g. soil water stress factor when there is not enough water in the soil). Figures 1 and 2 show the monthly surfaces of rainfall and ET_o for 1994. We then overlayed these surfaces with the provincial administrative boundaries of the lower Mekong Basin basin to obtain time series of the monthly average rainfall and ET_o by province for the period 1981-2005.

3.6 Crop evapotranspiration

We estimated actual crop evapotranspiration (ET_a) using a soil water balance simulation model with a 10-day time step. The model is based on the FAO Irrigation and Drainage Paper 56 (Allen *et al.* 1998), and similar to that of the CROPWAT model developed by FAO. The inputs of the model are monthly rainfall and ET_o, crop coefficients, rooting depth, crop planting time and growing period, length of growth stages, soil properties such as field capacity, wilting point, saturated moisture content, depletion factor, ponding water depth and percolation rate for rice. The model can simulate both irrigated and rainfed crops. The outputs of the model are actual crop ET, potential crop ET, irrigation requirement (for irrigated crops), and effective rainfall during the cropping period. The model has been used to estimate actual crop evapotranspiration and irrigation water requirements for a range of crops grown in the Murray-Darling Basin (Mainuddin *et al.*2007, Qureshi *et al.* 2007).

Agriculture in Laos, Cambodia, the Thai part of the lower Mekong Basin and in the provinces of Central Highlands of Vietnam are dominated by rainfed agriculture (Makara *et al.* 2001, Kono *et al.* 2001, Nesbitt *et al.* 2004, Chea *et al.* 2004). Rainfed rice is the dominant crop in Laos and Cambodia, the Central Highlands of Vietnam and the Northeast and part of North Thailand, while fully- or

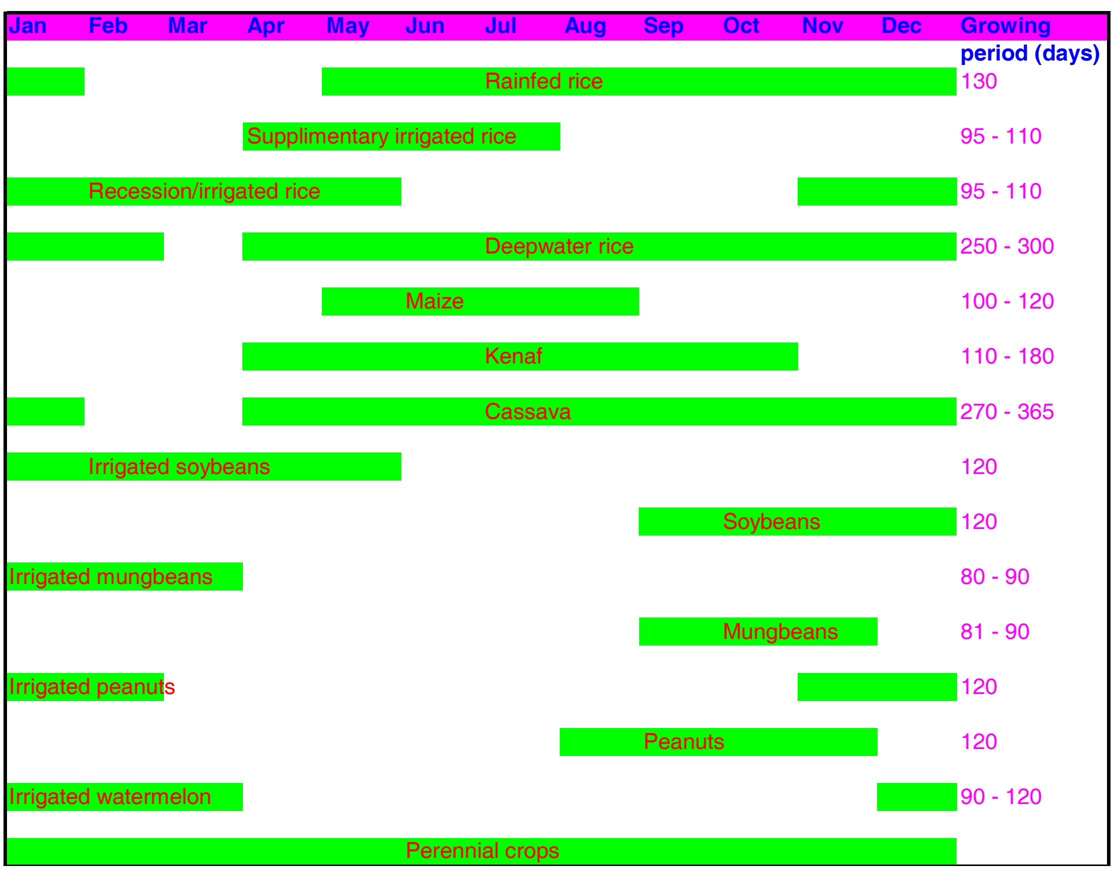

Figure 3. Generalized cropping pattern of Laos, Thailand and Cambodia (after MRC, 2005).

partially-irrigated rice is grown year round in parts of the Mekong Delta of Vietnam (Nesbitt *et al.* 2004, Buu and Lang 2004). The area of land dedicated to growing other crops is much smaller than that dedicated to rice and fluctuates in area from year to year. Figure 3 shows the generalized cropping pattern of Thailand, Laos and Cambodia (MRC 2005). The area and production of the crops other than rice in each season was not available.

Almost all the crops other than the dry season rice in Laos, Thailand and Cambodia are rainfed. Some areas may be fully irrigated or receive supplementary irrigation, but we consider them to be very small compared to the area of rainfed crops. We therefore assumed that all these crops were rainfed.

Irrigated rice dominates the Mekong Delta in Vietnam, with three crops a year as shown in Table 2. Winter rice is fully irrigated, while the other two crops are usually rainfed, although they may receive supplementary irrigation. According to the generalised cropping pattern (Figure 4) for the Mekong Delta all the upland crops are grown in the dry season (November-April), except sugarcane and cassava, which are grown year round. Therefore, we can consider that these crops are irrigated. However, it is possible that some of these crops are also grown rainfed particularly in the Central Highlands.

Crop coefficients, rooting depth and depletion factor are taken from Allen *et al.* (1998). Crop planting time and growing periods are mostly based on the cropping pattern as shown in Figures 3 and 4. We have also used cropping information (planting and harvesting time, percentage of area under different rice crops) available from Phaloeun *et al.* (2004), Chea *et al.* (2001), Sihathep *et al.* 2001, Makara *et al.* (2001) and Allen *et al.* (1998). Soil properties vary from province to province across the Basin. They also vary even from plot to plot. Because no data on soil properties were available, we therefore ran the model with a range of soil types such as clay, clay loam, silt loam, very fine sandy loam, coarse sandy loam and loamy very fine sand and used average values in the analysis. Where water limits crop growth and yield, this means that actual crop water use will differ from the values reported here. In much of the Mekong, and the wet season in most of the Mekong, this will not be a major factor. Nor will it be a factor in well-managed irrigation areas, which is likely to be the case in much of the Delta in Vietnam. In the dry season, particularly in Northeast Thailand and Cambodia, the difference could be important. Values will also differ when something else limits growth and yield, and this could include a range of factors such as pests and diseases, nutrient deficiency and poor management.

Figure 4. Generalized cropping pattern of the Mekong Delta (after MRC, 2005).

The crop water use that we have estimated is thus a generalized, regional assessment. We believe that it is reasonable, given that the crop coefficient approach is based on empirical crop factors – that is, on regressions of a very large number of observations of water use by many crops in many locations. Alternative approaches would mostly require much more data, especially soil hydraulic property data, and these are not available. Our aim was to find indicators to point out the main issues, and we believe this approach is adequate to do that.

4. Results

We grouped the estimated land and water productivity indicators into the following categories:

a) Average yield or land productivity of major crops (kg/ha),
b) Water productivity of major crops in terms of production (kg/m^3) and production value ($/$m^3$),
c) GVP and SGVP of rice, other crops, and all crops (rice + other crops) ($/ha and $/capita),
d) Contribution of rice and other crops in total crop production (%),
e) Cropping intensities (%),
f) Livestock density and GVP of livestock (LU/km^2, LU/capita, $/ha, and $/capita),
g) GVP of agricultural production (crop + livestock) ($/ha and $/capita),
h) Contribution of crop production and livestock in total agricultural production (%), and
i) GVP and SGVP in terms of water availability (rainfall) and actual ET ($/$m^3$).

Here we define the agricultural production as the sum of crop (rice and other crops) and livestock production. For Vietnam, according to the table "*Output value of agriculture at constant 1994 prices by kind of activity*" from the General Statistical Office (http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3&ItemID=3402) the output value of agriculture consists of three kinds of activity, cultivation, livestock, and services. As service data are not available for any of the other countries in the lower Basin, we have presented the results both with and without the service sector of Vietnam as part of the total agricultural production.

Figures 5 to 68 show the provincial and regional differences in productivity and their trends during 1993–2004. For comparison between countries, we estimated average value of the indicators for the whole areas of the lower Mekong Basin within the political boundaries of the individual countries. Vietnam has two regions in the Mekong Basin, the Mekong Delta and the Central Highlands. The productivity of these two regions is quite different so we considered these two regions separately as well as combined for the whole country. Figures 69 through 132 show the trend of the indictors between countries.

The yield of rice varies from 1.0 to over 5.0 t/ha, with the highest yields in the Delta region of Vietnam, moderate yields in some part of Laos and the Vietnam Highlands and the lowest yields in Cambodia and Northeast Thailand (Figures 5 and 69). The regions of highest productivity are those of highest rainfall or irrigation water use. The lower productivity of Northeast Thailand presumably results from the lower rainfall and longer annual dry period, though it could also result from other factors such as poorer soils and nutrient deficiencies. Drought is a major production constraint for rainfed lowland rice, being particularly severe in Northeast Thailand. It also affects large areas of rice cultivation in Laos and Cambodia (Fukai 2001). In these countries, late season drought is common, causing yield losses as high as 35% in Thailand (Jongdee *et al.* 1997). In all regions, productivity increased from 1993 to 2004, with the increase being more prominent in Laos and Vietnam. For Cambodia and Thailand, the yield has been almost stagnant since 2000 with slight variations from year to year. However, the population has also increased, and thus the increase in yield per capita was much less than that of yield alone (Figures 6 and 70).

Although the productivity of rice is lowest in Northeast Thailand, productivity of the other crops is highest (Figures 7-10 and 71-74). Sugar cane, for example, had the highest productivity in the Delta region of Vietnam and in Northeast Thailand. Much less was grown elsewhere, and we presume that the larger, more commercially-grown crops of those two regions led to better management and higher yields. Yield of cassava, soybean and maize are also higher in Thailand and Vietnam and lower in Laos and Cambodia. There is a trend for the yield for cassava and maize to increase over time. For other crops, yield fluctuates from year to year but with no clear trend.

Patterns of water productivity of the major crops in terms of production per unit of ET_a (kg/m^3) are similar to those for yield: high in the Delta region of Vietnam, moderate in Laos and the Central Highlands of Vietnam and low in Cambodia and Northeast Thailand (Figures 11-20 and 75-84). However, productivity in terms of \$/m^3 are distinctly different. Productivity of rice, maize and soybean (\$/m^3) show a decreasing trend since 1997. This is likely to be because of the devaluation of the local currencies after the economic problems that beset the Southeast Asia region in 1997. For example, while the farm-gate price of rice has remained stable in the local currencies, its dollar price fell because of their devaluation against the US dollar.

Although the yield of sugarcane is lower in Cambodia and Laos than in Thailand and Vietnam, the productivity in terms of \$/m^3 is higher (Figures 15-16 and 79-80). This is because the price of sugar-cane is higher in these two countries, which indicates that sugarcane is grown mainly for local trade in juice.

The GVP of rice per unit of harvested area follows the same patterns as yield, lower in Cambodia and Thailand (Figures 23 and 87). However, GVP per capita is different (Figures 25 and 89) with GVP of rice per capita higher in Northeast Thailand than in Laos and Cambodia. This is because the rate of population growth is falling in Thailand, but is rising in both Laos and Cambodia. Unlike yield, GVP of the other crops per unit of harvested area is highest in Laos and lowest in Thailand (Figures 24 and 88) because their prices are increasing in Laos while they are either falling or remaining static in Thailand. Therefore, the contribution of GVP of other crops to total GVP has gradually increased in Laos (Figures 27-28 and 91-92). The SGVP of the other crops and total crop production, in general, follows the trends of GVP (Figures 29-40 and 93-104).

Rice is the dominant crop contributing to the overall gross value of crop production in the Delta region (around 90%), central Cambodia and the eastern part of Northeast Thailand, whereas other crops are more important contributors in Laos (60%), the Vietnam Central Highlands (90%) and the western part of Northeast Thailand (Figures 27-28 and 91-92). The contribution of rice to GVP fell in Laos, some provinces of Thailand and the Central Highlands of Vietnam, with the GVP from other crops in some areas being higher than the GVP from rice in some years. GVP per capita for all crops is highest in Thailand, Laos and Vietnam.

The cropping intensity of rice remains stable, being highest in the Delta (130%) and lowest (15%) in the Central Highlands of Vietnam (Figures 41 and 105). The intensity of the other crops has increased in both Laos and the Central Highlands of Vietnam and decreased slightly in Northeast Thailand and the Delta (Figures 42 and 106). The overall cropping intensity has increased in Laos, Cambodia and Central Highlands of Vietnam and remained static for Northeast Thailand (Figures 43 and 107). In the Mekong Delta, overall cropping intensity increased gradually until 1999 and then remained almost constant.

Livestock density (livestock units divided by the total area of each province) is highest in the Delta and lowest in Laos (Figures 44 and 108). There has been a marked increase in livestock density in the Delta since 1999 because of increasing intensive poultry and pig farming in the area. In Laos, livestock density is lowest because the majority of its provinces are inaccessible hilly lands. However, based on the available agricultural area of each province, livestock density is higher in Laos (over 200 per km^2) than elsewhere in the Basin (around 25 to 75 per km^2) (Figures 45 and 109). Livestock density per capita follows the similar trends (Figures 46 and 110).

The GVP per unit agricultural area is lowest in Laos (Figures 47 and 111), at about $50/ha since 1999 for Laos, with Cambodia and Thailand showing a gradual downward trend since 1993. In contrast, the GVP per unit of agricultural area in Vietnam has increased from 116 to 156 $ / ha. The GVP of livestock per capita is also highest in Vietnam and lowest in Laos in recent years (Figures 51 and 115).

The GVP of livestock, crop production and service per unit of agricultural area and per capita is highest in Vietnam, moderate in Laos and lowest in Thailand and Cambodia (Figures 50, 52, 112 and 116). In Vietnam, the service component of GPV generates considerable income, which is included in the GVP estimation, while the other countries do not include data for the service sector. Livestock contributes between 15 and 30% of the agricultural production of crop and livestock together and is gradually declining (Figures 53-56 and 117-120).

Water productivity of crop production per unit volume of rainfall falling on the agricultural area of each province is higher in Laos and the Delta than in Thailand, Cambodia and Central Highlands of Vietnam (Figures 57, 58 and 121, 122). However, in terms of the volume of rainfall falling on the total area of the province, water productivity is the lowest in Laos (Figures 59, 60 and 123, 124) because much of the precipitation in Laos falls on non-agricultural land and is not used to grow crops. We did not consider rainfall used in forest production because the data were not available. If data for forestry were included, the results would likely be different.

Crop water productivity in terms of ET_a in Laos is almost twice that in Cambodia and Northeast Thailand (Figures 61, 62 and 125, 126). Although the Delta is the most intensively farmed and productive region of the lower Mekong River basin, the crop water productivity is lower than that in Laos and lies midway between Laos and Cambodia.

The total water productivity of agriculture (crop production, livestock and service) both in terms of available water and ET_a follows more or less the pattern of the crop production (Figures 63-68 and 127-132).

5. Conclusions

This report presents spatial and temporal patterns of land and water productivity of the lower Mekong River basin. Besides presenting the indicators based on the administrative provinces, the paper also shows the trend of the productivity indicators averaged regionally.

The results show that overall land and water productivity is higher in the Mekong Delta, moderate in Laos and lower in Cambodia and Northeast Thailand. There has been steady increase of productivity in Vietnam and Laos; in contrast, increases in productivity in Cambodia and Northeast Thailand were small. The majority of the agricultural income comes from the rice crop. Income from livestock and other crops, however, is also important and is growing in both Laos and the Central Highlands of Vietnam.

We have considered neither fisheries nor forest resources in this productivity analysis. It is noteworthy that fisheries make an important contribution to the overall production, especially in Cambodia and the Mekong Delta of Vietnam. We are conducting a study into fisheries productivity, and shall publish a report in due course. Forest resources are an important resource in the Basin, particularly in Laos, the northern and northeast parts of Cambodia, Northern Thailand and in the Central Highlands of Vietnam, but are not considered at all in the productivity analysis due to lack of data. If we considered fisheries and forests in the analysis, the overall land and water productivity would probably change.

In this report, we present the basin-wide data of agricultural productivity in terms of area, population, water inputs and prices. We leave for another paper the detailed analyses of the causes of variation in productivity, the contribution of fisheries and forest resources and the potential to increase crop productivity. We further emphasize that some of the maps and figures were not specifically discussed in the text. Nevertheless, we include them to show how information on water productivity can be presented in different ways.

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