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Viet Nam: Water Productivity Measurement-Water Efficiency Improvement in Drought Affected Provinces Project

Prepared by Xueliang Cai, Wim Bastiaanssen, and aNguyen Van Manh

IHE Delft Institute for Water Education, The Netherlands

For Asian Development Bank

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Water Productivity Assessment for Improved Irrigation Performance and Water Security in the Asia-Pacific Region: Viet Nam

Technical report

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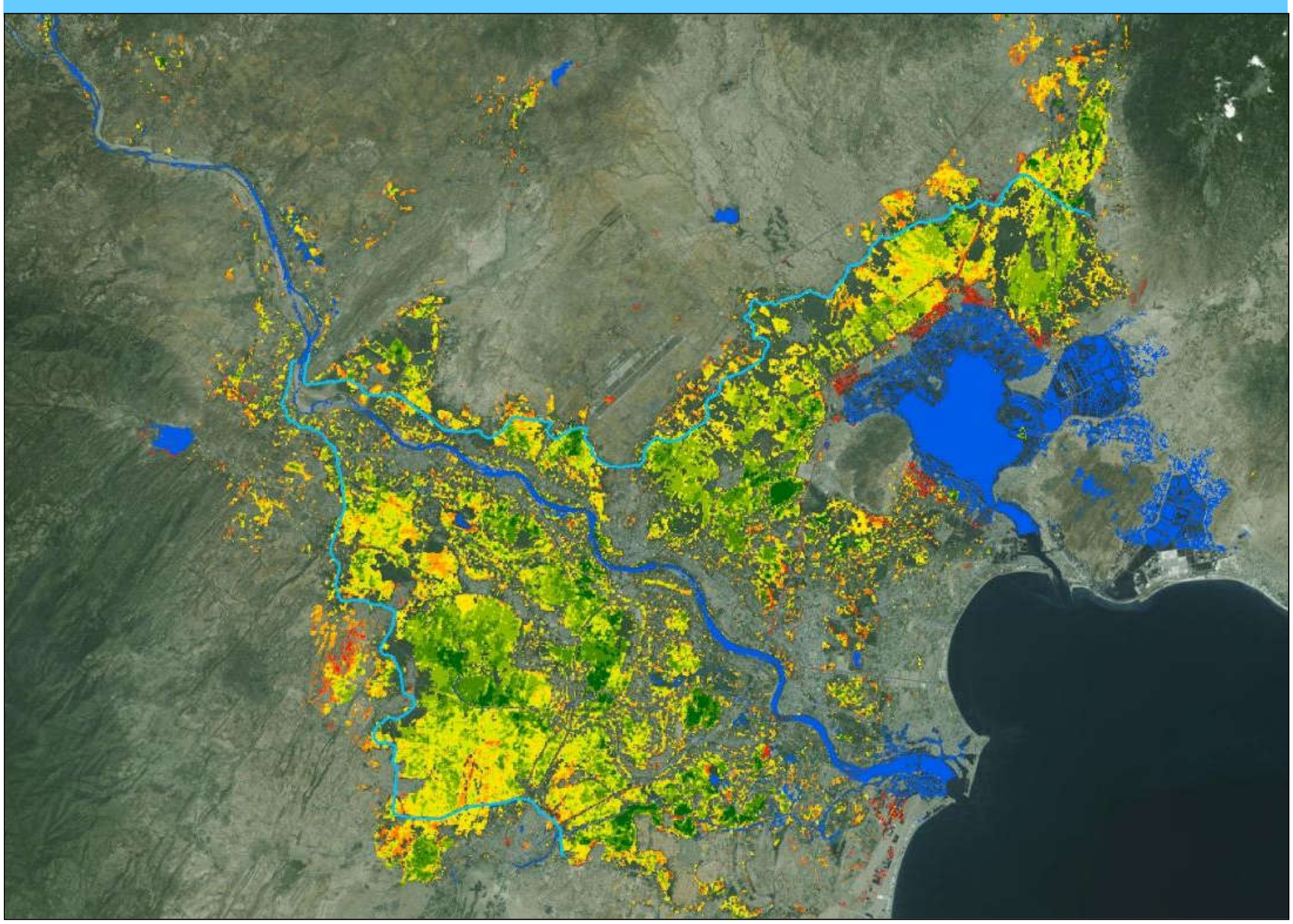

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Executive summary

Vietnam develops new irrigation systems and rehabilitate existing ones. The irrigation water management of an increasingly diverse agricultural system in eleven irrigation systems in the central highlands and adjacent coastal areas needs to be improved with a loan from the Asian Development Bank (ADB) through the Water Efficiency Improvement Project in Drought Affected Areas (WEIDAP). The current report describes the application of a remote sensing approach to assess crop water productivity in the WEIDAP project area. Baseline conditions were established by means of mapping the crop type, water consumption, crop water deficit, crop yield, and the crop water productivity in the reference years 2015 and 2016 at resolution of 10 and 30 m pixels. The seven major crops analysed include coffee, mango, apple, grape, dragon fruit, pepper and paddy rice. All satellite images used as a source of input data are freely available, as is with the pySEBAL model, with a dedicated training workshop conducted to introduce and build up local capacity.

The spatially distributed and geographically rectified data shows a wide variety of irrigation conditions. Mixed performance is observed for different crops with paddy rice having relatively high CWP at 1.37 kg/m^3. Fruits have higher CWP ranging from 2.29-5.33 kg/m^3, while coffee and pepper generally have low CWP at 0.13 and 0.16 kg/m^3 respectively. However, when converted to monetary terms expressed in 2017 constant Vietnamese Dong (VND), The CWP of mango stands out at 110 thousand VND/m^3, 15 times that of rice and 12 times that of coffee. Relatively high average coefficient of variation (standard deviation / mean value) on water productivity within a given crop ranges from 0.13 to 0.29. This implies that for most crops considerable savings in water consumption can be achieved (approximately 10 to 20%), together with increased productions (approximately 20 to 30 %). This number is based on the fact that local “hero farmers” were detected and that they have systematic higher land and water productivities as compared to the average performing farmer with the same type of crop and same agro-ecological zone. Hence it is practically feasible to get more food from less water. Notably it is observed that:

- A highly diverse cropping system is induced by changing market demands. Crops maps generated from Sentinel satellite images with 10 m pixels and extensive field survey show that famers are growing more high value crops in traditional paddy rice or dry land areas;
- Water consumption and water productivity have a moderate performance as compared with international standards. However, significant variations exist within individual irrigation systems and across the systems which pinpoints local *hotspots* as well as *bright spots*;
- Water productivity expressed in monetary terms shows that a shift towards high value crops produces more income for the same amount of water consumptions;
- For the first time in Vietnam that the variability of consumptive water use of coffee, pepper, mango, and dragon fruit is quantified and analysed. A comparison with international literature value for certain crops is difficult to make. The cross systems and intra-system variability provides, however, an indirect way of identifying the gaps, and estimating site specific water saving potential;
- The crop water deficit was also measured, and it shows areas with under-irrigation and over-irrigation. These spots could be identified and visited. One observation is that areas with a (mild) crop water deficit show a higher water productivity. Thus when the crop is stressed, it becomes more efficient with water;
- The reference year was a below average rainfall year. In spite of these drier than normal conditions, crop water consumption of perennial crops is little affected in most sites. Perennial crops seem to be resilient in coping with droughts;

- The open access pySEBAL model approach – that can be applied without a priori crop and soil information - showed great potential in irrigation performance evaluation. This requires pySEBAL to be used on a more regular basis by a small group of modelling experts

While in some cases crop water productivity can be improved by increasing water availability through expanding storage infrastructure (or dredging), in other cases it is related to non-uniform distribution of irrigation water through the canal network (classical head-tail effects) or poor on-farm water management practices. A first quick analysis shows whether low performance is related to agronomy or to water management. The actual reasons for low performance has to be collected from field surveys. A palette of options is deemed necessary to develop sustainable irrigation systems with more shared profits. WEIDAP is about linking the right solution to the right problem on the right location.

The identification of spatially distributed land and water resources information is the first step. There current ADB investment strategies for target sites and crops could be re-assessed having independent basic data sets of both water productivity (this report) and water accounting (end of 2017). The recommendations for the Vietnamese Government are:

- Prepare clear guidelines on good irrigation water management; use target values of land and water productivity, as well as other irrigation performance indicators such as ETdeficit and beneficial consumption ratio (T/ETa);
- Guidelines also include a definition of non-uniformities in access to water and consumptive use. Access to water with fair amounts to everybody is a good policy target, but it needs to be expressed in measurable performance indicators;
- Follow-up investigations on crop yield, water consumption and crop water productivity are recommended for the creation of time series and benchmark values for perennial crops as they consume large volumes of water;
- Building up capacity in WP and remote sensing applications. Based on the training workshop, promote use of the tools among the training participants, and encourage further learning and development for applications in local context.

This Vietnam pilot study has introduced new irrigation monitoring technologies to the country, show some results of limited areas and train technical staff. The training of one week was insufficient to transfer the pySEBAL technology. It was good for creating awareness on new advances in modelling. Additional modelling exercises in specific regions should be set up as part of investment and lending projects such as WEIDAP.

Considering the great potential to analyse crop water productivity and irrigation performance for more irrigation systems in Vietnam, a number of future steps have been identified for consideration by ADB:

- Follow up with field investigations to inspect the local irrigation conditions and establish a link between WP values surveyed and actions on the ground (e.g. reservoir storage, gate operations, groundwater abstractions, land preparations, agronomic practices). These investigations are essential in understanding the reasons behind variability, and identify locally relevant intervention strategies;
- Prepare maps with gap in water productivity to indicate which fields, areas and villages need more technical assistance by agricultural and irrigation extension agencies

- Build target values for both land and water productivity into irrigation project design and monitoring. WP will not replace irrigation efficiency but it represents a significant step forward in food security during water limited conditions;
- Build technical capacity to apply WP assessment to larger areas and more frequently for creating time series and report WEIDAP progress. This includes also building up experiences with cloud removal algorithms and inclusion of 100 m ProbaV/VIIRS satellite data;
- Expand the economic component to WP studies. Inclusion of monetary data helps appraising the returns of infrastructure investment. It will show the difference of cultivating high value crops on agricultural economy. The WP economic analysis needs to help further diverting irrigation development from engineering perspective to economic considerations.

This report comprehensively describes the technical results of manifold data sets that have been analysed. The authors realize that the amount of information is overwhelming, and a short policy brief will be prepared separately to make the great insights understandable and available to a larger public as well as to water policy makers.

Whilst focusing on technical aspect of the report, the capacity building part through a successful training workshop was conducted with the aim to further promote and build up national capacity. The training gave the participants an overview of the latest concept, exposure to technology, and opportunities for hands-on exercises with state-of-the-art remote sensing WP capabilities.

1. Introduction

1.1 Water productivity for water and food security

Asia is the world's most dynamic region with fastest economic growth. Due to economic and demographic development pressures, water is becoming an increasingly scarce resource. If left unmanaged, this poses a real threat to continued growth and prosperity of the Asia region. The latest analysis by the International Institute for Applied Systems Analysis indicates that 80% of the population in Asia will be water insecure by the year 2050 (IIASA, 2016). Global water demand is projected to increase by about 55% (from 4,500 billion cubic meters in 2010 to 6,350 by 2030) with growing demand from manufacturing, thermal electricity generation and domestic use (Addams et al., 2009). Agricultural demand for water will be most intense in India whereas the People's Republic of China will have the greatest growth in industrial water use.

According to an unpublished and recent research from the WaterAccounting.org group, the irrigation water withdrawals in Asia are about 73% of the global total. Table 1.1 summarize the modelled irrigation water withdrawals by 4 different groups. The irrigation water withdrawals in Asia is estimated to be from 1174 to 3861 with an average value of 2,350 km^3 in year 2010. Over the past few years many Asian countries have seen renewed investment interest into irrigation, leading the region's irrigation development to outpace world average. Hence the role of Asian irrigation systems in the world is dominant, and their management is of great significance to global food and water security.

Table 1.1: Assessment of irrigation water withdrawals in Asia based on 2010 conditions

Data source	Asia % of world	Total irrigation withdrawal world	Total irrigation withdrawal Asia
		Km^3/yr	Km^3/yr
LPJmL model	63.4	1851	1174
Globwat	77.5	2640	2047
PCR-Globwb	86.6	4457	3861
WaterGap	64.5	3591	2317
Average	**73.0**	**3219**	**2350**

The gap between food production and food demand is increasing in many countries. While this is mainly related to the population growth and changing diets, there is also an emerging issues of insufficient water resources being available to produce the large amounts of food required. Food production consumes significant amounts of water, ranging from 4,000 to 12,000 m^3/ha/season, and for certain tropical fruit crops this can even reach 22,000 m^3/ha. One of the solutions is to produce the same amount of food from less water, or when feasible, produce more food from less water resources (or popular "*more from less*"). The key performance indicator to express this is the crop water productivity (or popular "*more crop per drop*").

Increasing crop water productivity (CWP) involves dual objectives of increasing crop yields and/or reducing crop water use. CWP is a relative indicator and higher WP does not necessarily mean better performance. For example, CWP of rainfed agriculture could be higher than that of irrigated agriculture. Local conditions vary and the potential in crop yields are different. Depending on water resources availability, water saving in agriculture is not always desirable across space and crop growing duration. An assessment by the Challenge Program on Water for Food of CGIAR fund vast differences in the performance of agricultural water management in ten international river basins across Asia, Africa and Latin America (Cai et al., 2011). The CWP changes in spatial and time domain with the changes in underlining yields and water consumption, and that local conditions determine the potential and means for improvement.

1.2 A shift from efficiency to water productivity

The WP concept is developed in recognition of the constraints with traditional irrigation efficiency indicators. The traditional indicators focus heavily on engineering aspects of irrigation, which has a bias towards infrastructure investments like canal lining. It does not capture water reuse in a system and the ability of irrigation systems to turn water supply into food production. It does not reflect the competitive demand from outside the agriculture sector at a larger scale. Figure 1.1 shows that irrigation efficiency in effect represents only a small portion of hydrological processes in a farming system. Irrigation efficiency is not addressing the concepts of consumptive use from a viewpoint of total water resources available. It merely looks at water from sources to the field from a “supplier” point of view. Farmers are more interested in the results of irrigation (e.g. nutrition, income, jobs) rather than on how efficient that production is acquired. Food production is more essential for them, and if water is the major input constraint to food production, it make sense to express it per unit of water consumed. This philosophy is now widely accepted and adopted in the international community, including donor agencies.

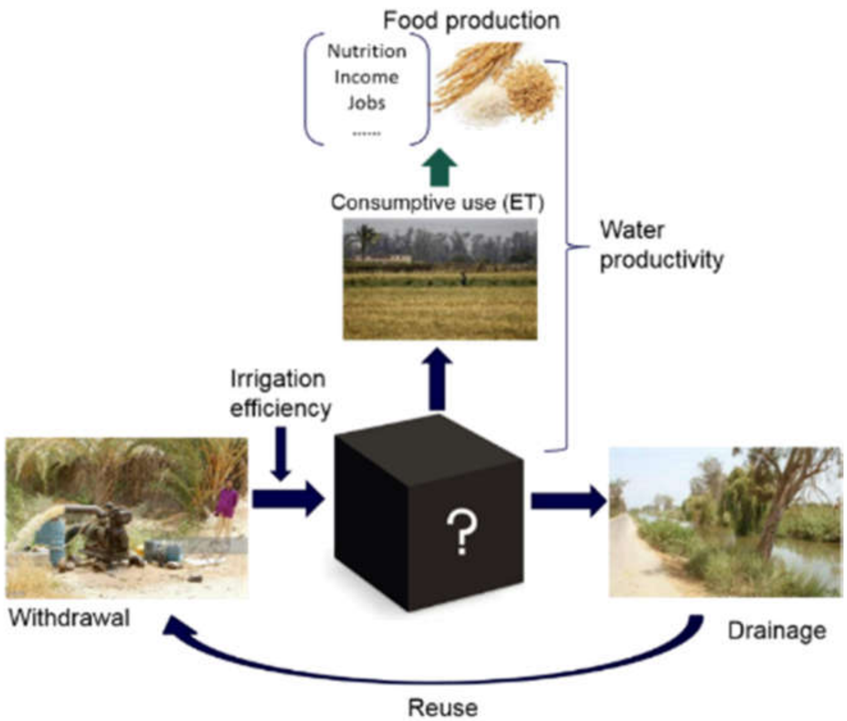

Figure 1.1. The irrigation efficiency and water productivity indicators for irrigation systems. The two indicators are complementary while WP covers more advanced and broader components of irrigation performance.

WP indicators are broader than irrigation efficiency indicators. As shown above WP does not replace irrigation efficiency. Rather it brings two major outcomes of irrigation water management into one single expression: Crop production, the purpose of farming and irrrigation, and the water consumed, the means to achieve the production. In achieving higher WP, it is still important to look at field level application efficiency, and cross sector, upstream/downstream allocative efficiency at catchment/basin level.

WP focuses on consumed water. Irrigation systems are highly modified, leading to complex water cycling processes, which is further exacerbated by management practices including irrigation and drainage. Remote sensing based WP assessment focus on actual evapotranspiration (ETa) – the water actually consumed. Further, the ETa is divided into crop transpiration, a beneficial consumption, and evaporation from soil/water and canopy interception, a non-beneficial consumption from production point of view (Figure 1.2).

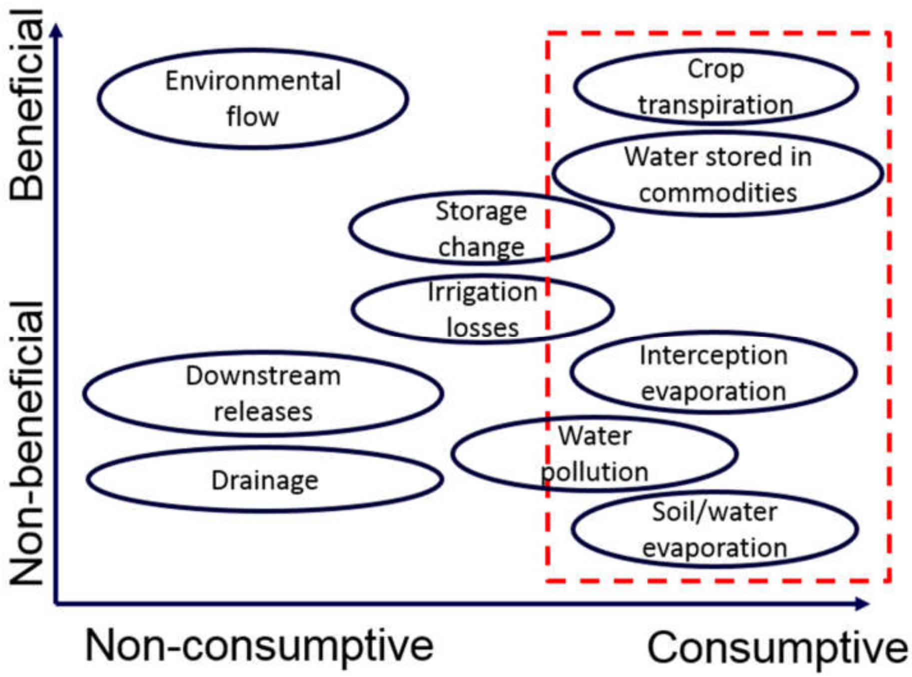

Figure 1.2. Remote sensing based WP approach focuses on the beneficial and non-beneficial consumptive use of water.

WP also promotes more integrated approach to water management. Water productivity was originally an agronomy term to measure plant water use efficiency. It was revised and given a new definition to represent the ability of a system to covert water consumed into goods and services (Molden, 1997). WP is a significant step forward in linking water management with broader policy goals such as water security, food security, and economic development. Kilograms of fresh food can be converted into gross returns ($), employment (jobs), nutrition (calories). Reducing the consumptive use enables more water to remain in the physical system for allocation to other sources. WP benchmark link water managers with development target settings and investment strategies.

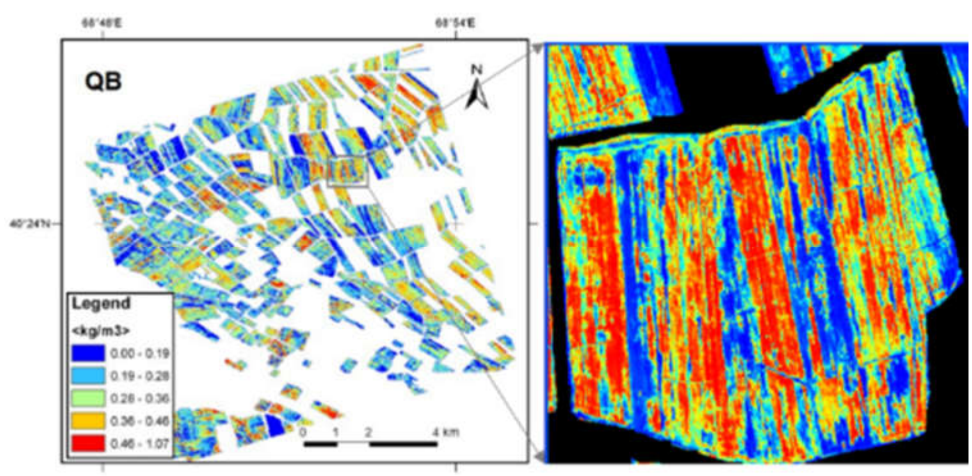

Figure 1.3. Remote sensing based water productivity assessment helps the identification of hotspots and bright spots. The best practices and most productive fields are indicated in red and poor practices in blue (cotton and rice fields in Central Asia).

Although improving crop water productivity can indeed contribute to the solution to combat the water and food crisis, in reality it is more difficult to achieve crop water productivity improvements at farm level, partially because target values are absent and farmers/irrigators are not guided by any means. They often associate water savings with a lower amounts of applied water, fewer irrigation turns, or a higher on-farm irrigation efficiency, and are not considering the consumptive use of irrigation water and the production that is associated with that.

Various strategic programs ranging from United Nations to National Departments assume that crop water productivity can be improved. This is recently confirmed by scientists from FAO and UNESCO-IHE that showed a skewed behaviour of crop water productivity towards the lower side (see Figure 1.4). This simply means that for many cereal fields, it is feasible to improve water productivity from a below-average value to a mean value.

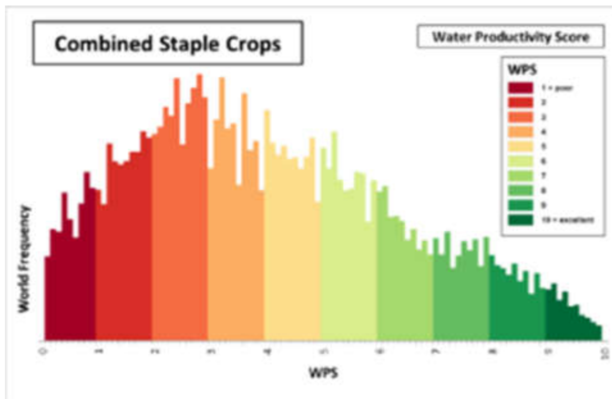

Figure 1.4. Frequency distribution of the Global Water Productivity Score (GWPS) reflecting wheat, rice and maize crops at the global scale. This graph could be created due to climate and crop normalization. A GWPS of 1 is poor and of 10 is excellent (Bastiaanssen and Steduto, 2016)

1.3 Irrigation water management in Viet Nam

Vietnam has a diverse cropping systems. Paddy rice remains the predominant crop with annual cultivated area more than 7 million ha out of 4.7 million ha of areas equipped for irrigation. Paddy rice is grown in three seasons, namely spring rice from January to April, Summer rice from May to August, and Autumn rice from September to December. Maize, coffee and maize are also important crops with an area of about 260 thousand hectare each. Other significant crops include fruits, cassava, groundnuts, soybeans, sweet potatoes, and sugarcane. Over years the country has seen continued investments in irrigation development and irrigated areas rapidly increased (Figure 1.5).

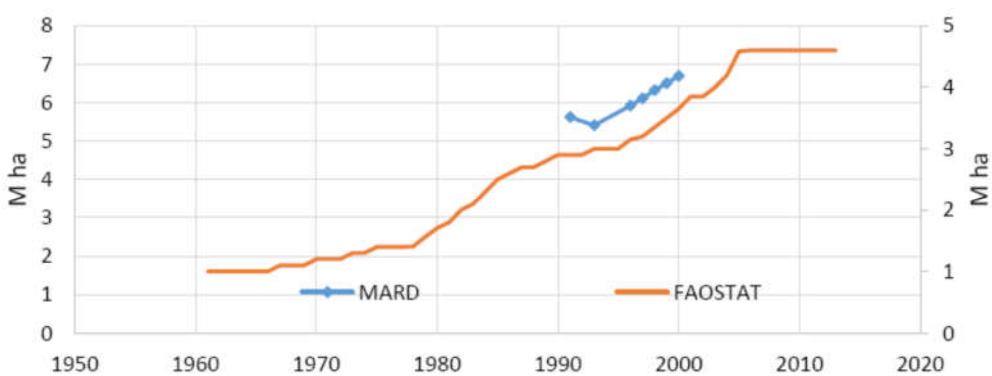

Figure 1.5. Trends in reported irrigated areas in Vietnam considering intensity by Ministry of Agriculture and Rural Development and areas equipped for irrigation by FAO.

There are few WP studies in Vietnam and they are often concentrated in the southern part of the country. An analysis by Cai et al., (2011) reveals that the WP of rice has an interesting trend in the lower Mekong region (figure 1.6). Rice yields have gradually increased while ETa has decreased. As a result, CWP has increased by 20%. WP of rice expressed in US$/m^3, however, has declined significantly over this period. Markets have played an important role here. The farm gate price of rice has decreased from US$166/t in 1995 to US$126/t in 2003, with even greater inter-season fluctuations within this period. This means that the farmers' gain from improved crop and water management has been offset by the market.

Shortage of fine dataset is a main constraint for accurate assessment. It has to be noted that above estimate in figure 1.6 is largely based on statistics interpolation for rice yields and global climate data set for ETa estimate (Mainuddin et al., 2008). The results of these are acceptable for regional trend analysis and for policy makers. The value for WP has increased from 0.8 kg/m3 in 1995 to more than 1.0 kg/m3 in 2002. This is an increase of 20% in a time span of 7 years. However, such type of information is too coarse for detailed assessment of irrigation systems. We therefore used satellite based measurements with a spatial resolution of 30 m x 30 m.

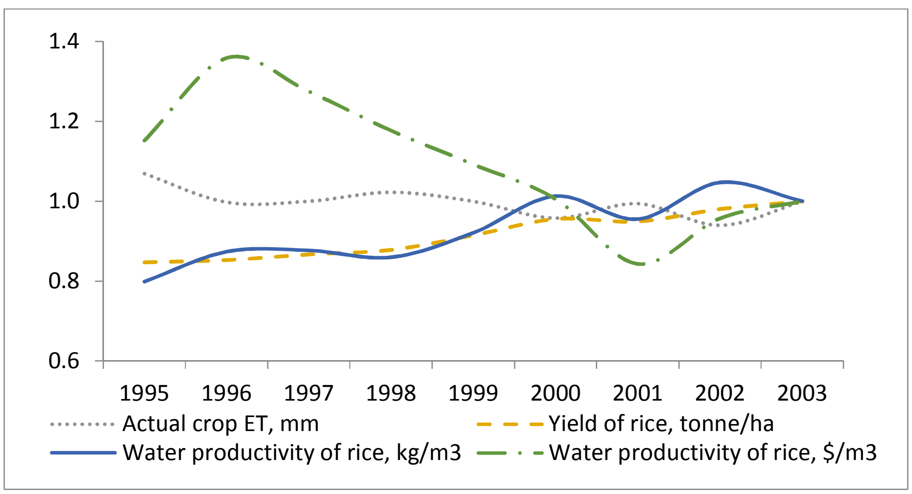

Figure 1.6. Crop ETa, yield and water productivity of rice in the lower Mekong Basin. The data was normalized to 2003 values.

1.4 The collaboration between IHE Delft, ADB and MARD/IWRP on building up capacity in water productivity for better investment

The Sustainability Development Goals (SDG) has selected SDG6.4 to describe efficient use of water in agriculture. The implication of this recently endorsed SDG by the General Assembly of the UN, is that countries now have to report on their water productivity. This is a result of continuous efforts by international research and development community. The WP was largely a research tool to benchmark irrigation and water management performance (Kijne et al., eds 2003). The term and concept gradually received attention from international development agencies such as FAO (2003), World Water Assessment Programme (2009), USAID (2009), World Bank (2010), and regional development cooperation such as CAADP (2009). The wide uptake of WP marks a shift from technically focused investment in irrigation and agricultural water management to outcome oriented decision making.

The Asian Development Bank (ADB) results based lending on agricultural water management should lead to increased production and more sustainable water use. While most projects are currently targeting on improving land productivity (kg/ha), this will be complemented with water productivity (kg/m3) improvement requirements, in new projects and lending during 2016 and beyond. It is rather unclear - however - what the current status of water productivity is, both at the start and at the end of ADB-related projects. There is a large gap in the understanding of the concept of water productivity at various levels, and how to measure and implement it. A capacity building program for stakeholders is necessary, and policy makers, irrigation engineers, agronomists and practitioners should be reached. This cannot be accomplished with a one year project, but a start needs to be made with introducing the concepts and make some local diagnosis of good and poor performing farms.

In recognition the importance of CWP in water management, especially in irrigated agriculture, UNESCO-IHE is working with Asia Development Bank (ADB) to raise awareness, build capacity, and test frontiers of WP with irrigation and water managers in six Asia countries (Vietnam, Indonesia, Sri Lanka, India, Pakistan, and Uzbekistan). The project will establish a performance baseline for irrigation systems which can be used to measure the benefits of ADB investments. The implementation of the project will be carried out closely with national partners to raise the awareness of using WP to benchmark agricultural water management, hence improving the planning, design, and management of irrigation systems.

The overall objective of this pilot and capacity building project with UNESCO-IHE is to help improve planning processes of the ADB investments in water security and irrigation systems, and enhance capacity to the six different ADB countries on the concepts of crop water productivity. The recipient organizations should be explained on the difference between water productivity and irrigation efficiency. These organizations should learn about using remote sensing technologies to compute crop water productivity on a field-to-field basis, followed by a diagnosis of good and poor performing fields, as well as the determination of target values. A water productivity diagnosis of selected irrigation projects in these countries will be provided to the local organizations. Information on their own backyard will increase their understanding on how to operationalise concepts of water productivity under practical conditions in Asian developing countries.

The project is expected to contribute to ADB agenda on water security which is heavily underlined with irrigation water use in many Asian countries. "More crop per drop" will help ADB and its clients look at more efficient way of developing and managing the biggest water user – irrigation, and potentially, exploring possibility of building WP as diagnostic tool and monitoring indicator into ADB and country investment and management plans (figure 1.7).

Figure 1.7. The role of Water productivity in irrigation systems, the single biggest water user, to support ADB initiatives for Asian water security.

This project started in Vietnam with a focus on rice. The origin and character of the project was to demonstrate new technologies for improved irrigation management. Because simultaneously the preparation for the WEIDAP project started, this Vietnam case study turned into a preparations of baseline conditions for WEIDAP with more high value crops to be investigated at more project sites. This technical report summarizes the rational, methodology, and results of SEBAL based water productivity assessment in the central highlands of Vietnam. The second chapter of the report describes the update of the SEBAL model including open source development. The third chapter describes the applications and results of SEBAL water productivity assessment for eight project sites. Chapter 4 further analyse water productivity scores in all the sites. And the last chapter summarizes findings as well as lays out the way forward to be followed up by ADB and Vietnam national partners.

1.5 pySEBAL training workshop

A training workshop was organized as part of the capacity building of the project. The objective of the training workshop is to introduce the concept and frontiers of crop WP (CWP) for applications in irrigation investment and management, and to build up in-house capacity using remote sensing and model tool (SEBAL) for assessing CWP. Specifically:

- What is CWP?
- How to use SEBAL and remote sensing data to assess CWP?
- How to use remote sensing based CWP assessments to improve irrigation planning, design, and management.

The workshop was organized with MARD and IWRP. There were strong interests in the training and the number of participants were increased from 15 to 25, after agreement was made for IWRP to provide GIS support in order to ensure smooth flow and adequate interactions with all participants. Eventually the workshop was held from 19-23 December 2016, at the Long Thuan Resort, Phan Rang – Thap Cham, and drew 25 participants from various parts of the country.

The tailor-made-training course includes introductions to general concept and applications of WP for management and policy making, hands on exercises, and discussions linking the training with participants' job responsibilities. A short field visit was also organized for participants to learn mobile data collection, and linking maps to ground situations.

The participants in general were enthusiastic and active during the training. Both WP and remote sensing are new to most of them and may not be closely linked to their daily works. There were still strong interests and in fact, towards the end of training, they requested to add further contents on land cover classification. Considering the enthusiasm of the participants the trainer, Xueliang Cai, agreed to provide such a training at the end even though the materials had to be prepared overnight as it was not in the original plan.

A short anonymous survey was conducted at the completion of the training to collect feedbacks. They overall rate the training workshop 8 out of 10 and most of them agree that the training meet their expectations. Twenty three participants out of 24 found the information generally very useful and that 16 participants think they could apply what they learned in the future, a significant improvement considering that half of them had no experience with RS at all before the training. When asked what they liked most about the training, 10 responses were about WP and RS as "new" and "interesting"; 4 responses were about the trainer as "enthusiastic", and other terms such as "professionalism" and "friendly".

There are also areas for improvement. Most of them think the pace of the training too fast. This is actually contradicting with their requests to include more contents (classification) and reluctance to reduce any content (Q10) in the training. They are eager to learn but add too much content in one week's training will also create problem. In fact one response suggested to increase the training to two weeks. Advanced sharing of training materials came out to be a common request, which was unfortunately not possible due to lack of a mailing list for all confirmed participants until the day of the training workshop. There were several responses on the instructor, including increasing the number of instructors as areas requiring improvement. However, given the budget limit, more strict enforcement of limiting number of participants are probably more appropriate. There were also issues with software package installation which took too long. It was attributed to unlicensed version of ARCGIS installed on most participants' laptops except one. After the ARCGIS was uninstalled, the problem was solved. This also suggests in the future QGIS, an open source free software, should be promoted as standard.

2. The pySEBAL model

The Surface Energy Balance Algorithm for Land (SEBAL) was initially developed by the DLO-Winand Staring Center, in Wageningen, The Netherlands. The fundamental steps on thermally based energy balance modelling using earth observation measurement was formulated in the Ph.D. thesis of Massimo Menenti at Wageningen University during 1984, which was a few years after the launch of the first thermal HCCM satellite mission. The solution with a linear relationship between surface temperature and the vertical air temperature gradient dT for anchoring the range of sensible heat flux was established in 1989, which still governs the main feature of SEBAL that appeared to be a robust solution for many environments and land use systems.

SEBAL was first published at an international symposium organized by the University of Leuven, Belgium (Bastiaanssen et al., 1992). Wim Bastiaanssen received the degree of Doctor from Wageningen University during 1995 on his Ph.D. thesis Regionalization of Surface Flux Densities in Composite Terrain, application studies in the Mediterranean region. His dissertation was summarized into a double article in the Journal of Hydrology that was published as a special issue of the Biosphere-Atmosphere-Hydrological-Cycle (BAHC). These papers (Bastiaanssen et al., 1998a, b) have been cited frequently according to various search engines. An overview of SEBAL related papers produced since 2005 is presented in Annex 2.

Currently the model has further evolved into a crop water productivity model integrating crop growth and soil moisture. Biomass accumulation of plants is a result of canopy photosynthesis processes which absorbs solar radiation to convert CO_2 and H_2O into carbohydrates or dry matter production. The rate of biomass accumulation depends on (i) the amount of Absorbed Photosynthetically Active Radiation (APAR) which is affected by the amount of available total solar radiation and (ii) environmental stress factors. Environmental stress is expressed by means of stomatal aperture, that is included in a parameterization of the Light Use Efficiency, or LUE (Bastiaanssen & Ali, 2003). All c3 crops have the same response to light and water, and for this reason SEBAL can be applied without information on the type of crop, the type soil, root depth and more essential bio-physical parameters that most crop production models require to be defined. A more detailed description of the model is attached in Annex 1 of this report.

The new model, coded in Python, is named pySEBAL and is in version 3.6.6. The pySEBAL incorporates several new developments towards improving accessibility by users. These include open source, open data, and automated processing of various options of input data, which represents several breakthroughs for public uses. The hot and cold pixels will be selected automatically. The model is accessible through a github account.

2.1 Open source automated approach

Python is an open source platform widely used by research community and industries. Python based model is transparent and users can exam or improve each and every command or module to their needs and specific contexts. For simplicity the inputs are organized in a separate Excel file where users fill in image information and weather data, and have the opportunity to change few parameters if needed. Python is also supported with a large and growing list of spatial data tools compatible or transferrable with different systems, which allows more advanced analysis of large dataset.

Automated processing represents one of the major technological advance of the new model. PySEBAL can now automatically process images from raw data to a range of outputs, avoiding previous manual hot and cold pixel selection processes, therefore reduces experience related uncertainties. The automated version involves no manual image preparation or processing, which can greatly reduce processing time for multi-year seasonal analysis which often involves large amount of images.

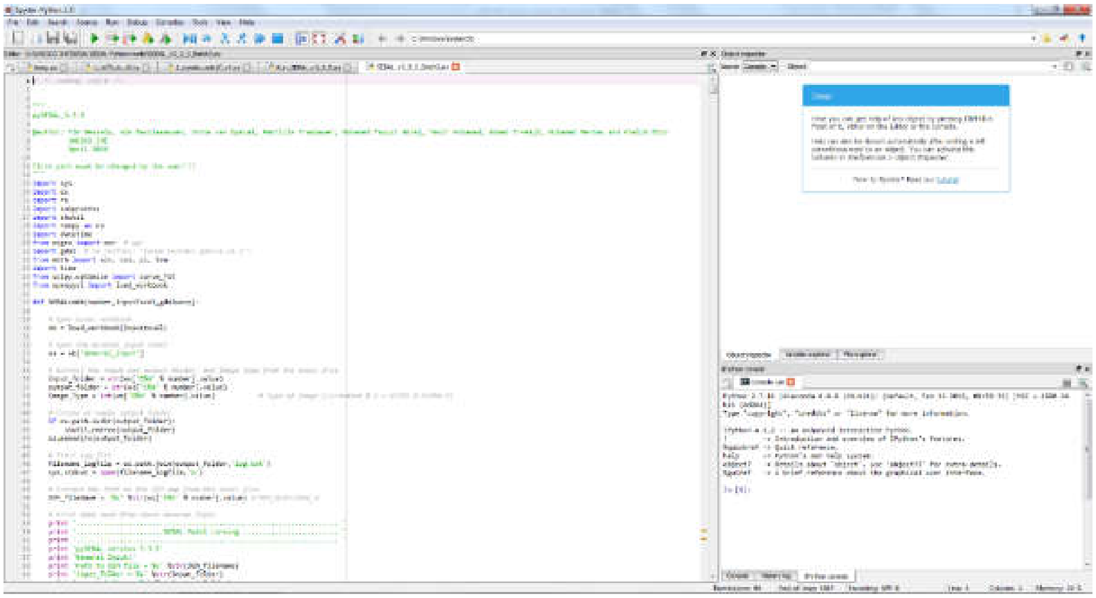

Figure 2. 1. Screenshot of the Spyder2 (a version of Python) software as platform for implementation of pySEBAL

2.2 Open access data

Open data approach is another underlying principle of the new SEBAL model. The current version of pySEBAL has the ability to read Landsat 5, 7 and 8 images (Landsat 6 never functioned), hence Landsat 5 images archived since 1984 can be processed. The spectral definitions and additional information provided varies for every Landsat satellite. The Landsat number therefore needs to be specified among the input requirements. While Landsat 5 and 7 have a single thermal band, Landsat 8 has a dual thermal system. One of the switches in the code is related to the amount of thermal bands to be identified by the user for Landsat-8 as this may affect the atmospheric correction in the thermal infrared part of the spectrum. It is preferred thought, to use the dual band approach.

There are also images from several other public domain satellite sensors not included in current version of SEBAL. Examples include Sentinel from European Space Agency (ESA), and many other sensors with multiple spectral bands. Images of these satellite sensors are useful for water productivity assessment at irrigation scheme, river basin and country level. SEBAL development will continue to expand support to more data sources.

2.3 Crop type mapping for crop specific assessment

PySEBAL processes the surface energy balance and plant growth at landscape level with a grid of 30 m independent of crop type information. All c3 crops namely show the same response to solar radiation and environmental conditions. The ETa and biomass production of individual crops can be made without any a priori information on the type of crop and type of soil. A crop map is however required for making crop specific production analysis such as for (i) crop yield and (ii) water productivity. The storage organs that will be harvested are a fraction of the total biomass production, and this fraction (i.e. harvest index) is thus crop dependent.

The main crops as requested by MARD/ADB for inclusion in the study are all high value crops (compared to traditional crop rice). The main crops are Apple, grape (in Ninh Thuan), Mango (Khanh Hoa), Dragon fruit (Du Du), and coffee in central highlands area. However, significant rice and pepper area were also present from field survey and initial image analysis. They were therefore added to the classification and subsequent analysis.

The crop types were mapped using a supervised classification approach with the Maximum likelihood algorithm. Much of the high value crops is grown in small field plots in this area with complicated cropping patterns including inter-cropping, making it difficult to separate these crops. Sentinel 2 images of the study area at a resolution of 10 meter were therefore used instead of the standard Landsat images used in the main WP studies. The classification focuses on agricultural areas and water bodies, and is supported with extensive field surveys, crop calendars, and Google Earth high resolution zoom-ins.

3. Project areas and data collection

3.1 Study area

The Water Efficiency Improvement in Drought Affected Areas (WEIDAP) project, with loan from ADB, aims to improve agricultural water productivity by increasing water use efficiency in irrigated agriculture by developing new irrigation schemes or rehabilitating existing ones in the Central Highland and South Central Coastal regions of Vietnam. The project will work on identified sites in five provinces: Binh Thuan, Dak Lak, Dak Nong, Khanh Hoa, and Ninh Thuan (Figure 4.1).

Figure 3.1: The preliminary sub-project sites of the WEIDAP project in Vietnam

The region has diverse climate and topography. The elevation ranges from the coastal areas to 2442 m in the Chu Yang Sin national park, Dak Lak Province. Consequently, the climate also varies significantly from the coast to mountain areas. Average annual rainfall is between 1200 mm to more than 3000 mm. The main rainy season is from June to November, with January to March being a dry period with little rainfall. The patterns, however, do vary across the five provinces, for example Phan Thiet in Binh Thuan Province has a relatively even distribution of rainfall from January to December, while the months of May to October experiencing about half of the normal rainfall amount (Figure 4.2).

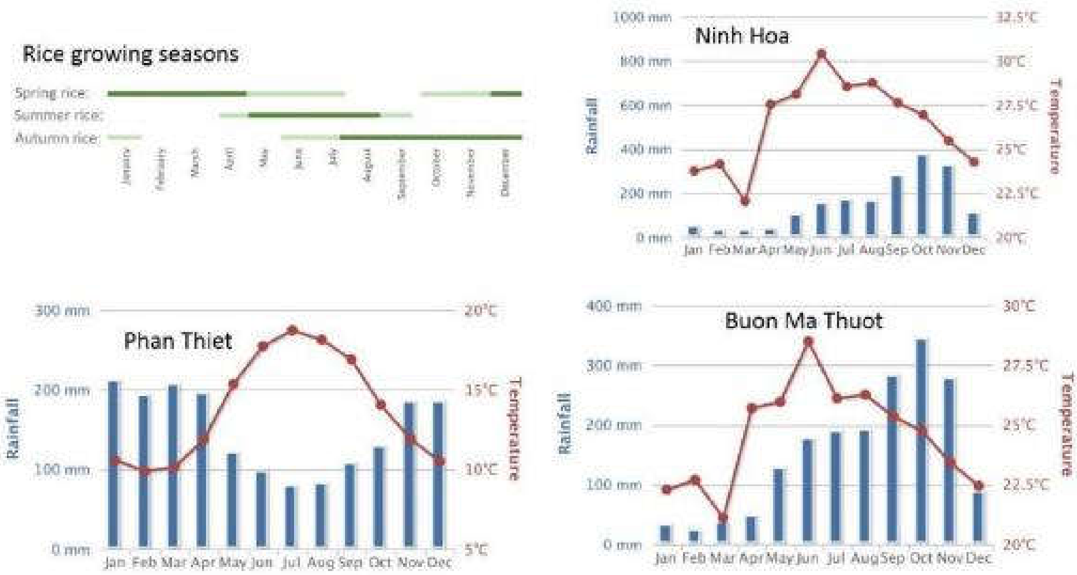

Figure 3.2: The average monthly rainfall, temperature, and main rice growing seasons in the five provinces.

The region has a diverse agricultural system from rice, vegetables, to banana, grape, to dragon fruit, and rubber plantation. Many of these are perennial while rice is often cultivated year around in three seasons, namely the spring rice from December to April, the summer rice from May to August, and autumn rice from August to December (figure 4.2).

3.2 Data

The water productivity assessment primarily depend on satellite images while various other data is also collected. The eight project sites are covered with three tiles of Landsat 7/8 images, namely path/row 123/52, 124/51 and 124/52 (figure 4.3). Images of Landsat 7 and 8 from these three titles for the period of 16 November to 15 March were downloaded and combined for inputs to SEBAL model as well as crop type identifications. A total of 42 images were downloaded, and eventually 28 were used after removing the images severely affected by clouds (Figure 4.4). The SRTM 1 arc-second (30 meter) DEM was downloaded from Earth Explorer, the USGS data portal where Landsat images were also downloaded from.

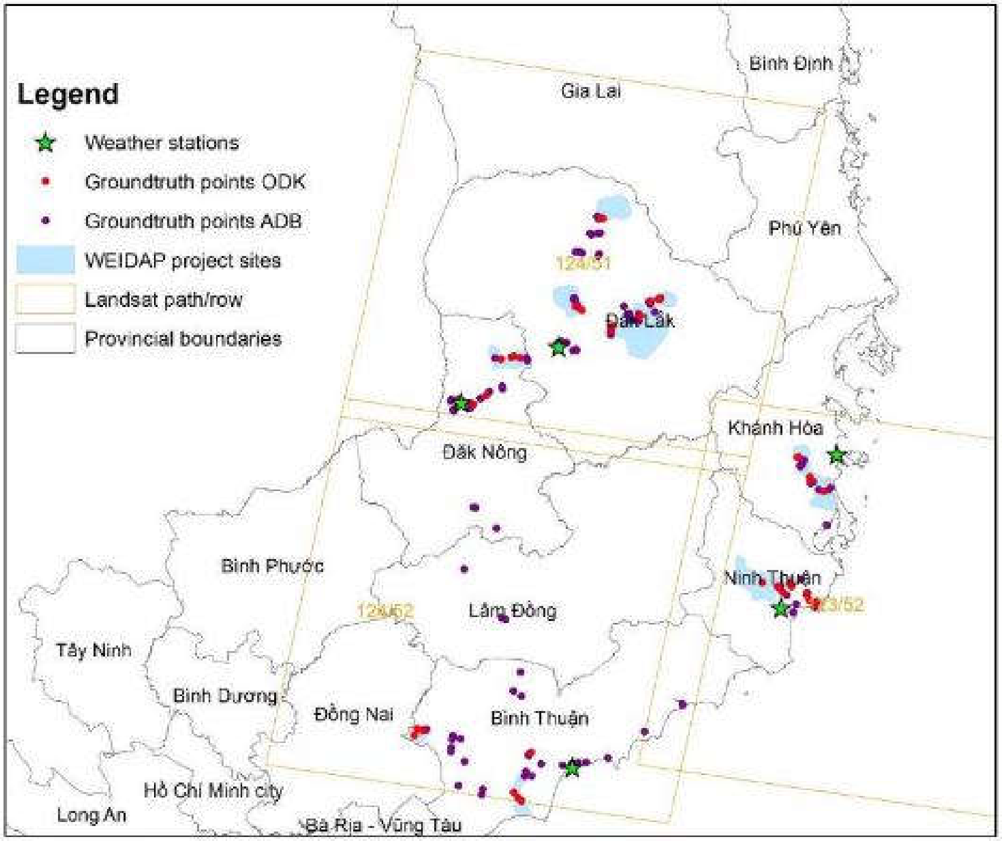

Figure 3.3: The project sites, Landsat image footprints, and groundtruth points

Date	09/11/2015	17/11/2015	03/12/2015	11/12/2015	12/12/2015	27/12/2015	28/12/2015	04/01/2016	13/01/2016	20/01/2016	21/01/2016	05/02/2016	13/02/2016	14/02/2016	21/02/2016	22/02/2016	29/02/2016	01/03/2016	08/03/2016	09/03/2016	16/03/2016	17/03/2016	24/03/2016	25/03/2016	01/04/2016	02/04/2016	09/04/2016	17/04/2016	18/04/2016	19/04/2016	20/04/2016	25/04/2016	26/04/2016	03/05/2016	04/05/2016
P123R52					L8		L8		L8		L7			L8		L7		L8		L7		L8		L7		L8			L8		L7		L7		L8
P124R51		L8	L8							L8			L7		L8						L7		L8		L7		L8					L8		L7	
P124R52	L7	L8	L8	L7		L7		L8		L8		L8	L7		L8		L7		L8				L8		L7			L7		L8		L8		L7	

mostly clouds   half   cloud free

x x x x x

Figure 3.4: Availability of Landsat 7 and 8 images for the study area and the image quality analysis.

Six-hourly weather data from five meteorological stations were collected for the same period. These weather stations are namely Buon Me Thuot, Dak Mil, Phan Thiet, Nha Trang, and Phan Rang. The temperature, relative humidity, and wind speed and direction were recorded four times a day at 01:00, 07:00, 13:00 and 19:00 hours respectively. Sunshine hours, precipitation and evaporation were recorded once daily. These six-hourly data is then used to estimate the weather condition of the image capture time using a linear extrapolation algorithm. In this case it is about a few minutes past 10AM local time, which is applicable to both Landsat 7 and 8.

A ground truth survey form was developed which was available both in paper and digital forms. The digital form is built into an Android smart phone application ODK Collect which also takes advantages of the GPS, camera, and internet connection of phones. More information of ODK Collect tools can be found in the annex. The App allows for two types of data collection: the normal mode which has some questions on crop yield, growing season etc to be answered by a farmer in the field; and a quick mode which allows for non-stop quick tagging of crop type on the map. A detailed description of the GT survey methods and the ODK Collect is attached in Annex 2.

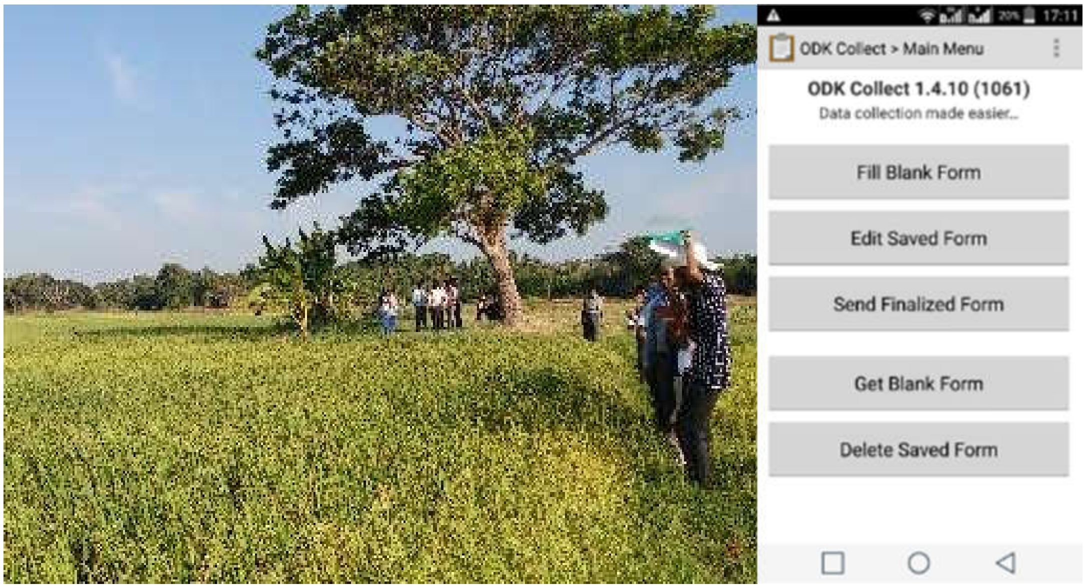

Figure 3.5. Ground truth with smart phones

Two field surveys were carried out from 27 June to 4 July 2016, and then again from 1 – 8 March 2017 to identify main crop types, water sources information, and crop yield. This survey was designed to capture the main growing season from January to April. A total of 1304 points (including 908 quick mode points and 396 normal mode points) were collected during this survey covering mainly the eight project sites. A set of route points from an earlier field visit around January 2016 by the WEIDAP project and ADB was used (Groundtruth points ADB). These points did not have as much information as the GT points had. However, the pictures taken at the points with coordinates serve as a good source of information to determine if the point is agriculture and the types of crops grown. In addition, Google Earth high resolution zoom-ins were extensively used to help identify main crops. Annex 1 provides more details into the ground truth points and their distribution at each site.

The crop calendar is a useful guide to determine the start and end of the growing seasons of different crops. A crop calendar of targeted crops was provided by the Ministry of Agriculture & Rural Development (MARD).

No	Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Note
1	Coffee	blossom									harvesting			perennial tree
2	Pepper		harvesting		blossom									perennial tree
3	Dragon fruit	Mixed schedule because of lightning for extra crop, the main harvesting is from Mar to August												perennial tree
4	Mango		harvesting											perennial tree
5	Apple	3-4 crops per year, harvesting any time over a year, main harvesting in August - September												perennial tree
6	Grape	3-4 crops per year, harvesting any time over a year, main harvesting in August - September												perennial tree
7	Onion	4-5 crops per year, harvesting any time over a year, main harvesting in Jan - Feb												2-3 moths/crop
8	Garlic	harvesting									planting			1 crop/year
9	Rice	planting			harvesting		planting			harvesting				2 crops/year

Figure 3.5 Common crop growing seasons of selected crops in the study area

4. Water consumption, shortage, yield and water productivity of selected crops in the central highlands of Vietnam

The eight project sites, including 16 independent sub-project areas, are distributed across five different provinces. The total study area in the five provinces is encompassed by three separate Landsat image path/row combinations. Each path/row combination occupies an area of 185 km x 185 km. Basic image processing was conducted for the entire Landsat image, where after production and water related data was extracted for the project sites followed by crop specific analysis.

4.1 Khanh Hoa

The area, in the shape of a long, narrow stretch, lays in between two mountains along the coast. The irrigation water to the area is supplied by originating from two reservoirs. The WEIDAP project aims to rehabilitate the South Main Canal served by the Cam Ranh Reservoir and the main canal of Suoi Dau Reservoir in Khanh Hoa Province. The field survey and land cover classification identified two major crops: mango and paddy rice. The WP assessment in Khanh Hoa focuses therefore on a perennial and arable crop.

4.1.1 Irrigation systems and crop area

Mango is the dominant crop of the area (Figure 4.1). A total of 8,061 ha, or 60% of the land area, is covered with mango trees. Mango is a traditional high value crop in the region. There are two main types mango trees in the region: one is local tranditional variety and another imported new variety. The local variety has low yields (4-8 ton/ha) although they have very tall trees and large canopy. The new varieties (mostly from Australia and Taiwan) on the other hand have very high yield (15-40 ton/ha) and much smaller trees. The local variety is however a household fruit scatting out and they have much smaller areas compared with new varieties which are mostly cultivated through commerical farming practices (figure 4.1). The mix of the two varieties are not possible to separate with medium resolution images such as Landsat, the assessment therefore focused on the new variety through crop type mapping (Most of the local variety was classied into the same group as trees and forest).

The age of an average mango tree is 11.7 years, with some reaching 50 years. The paddy rice is about 740 ha, or 3% of the total land area. The rice area is mostly in the north or central parts of the project area close to the reservoirs (Table 4.1). Other crops are fragmented with a total area of 381 ha. There are about 2700 ha of built-up area, representing high population densities, and 1357 ha of forest. Water flows from the centre to the south and north separately, and drain into rivers and then the sea from both directions.

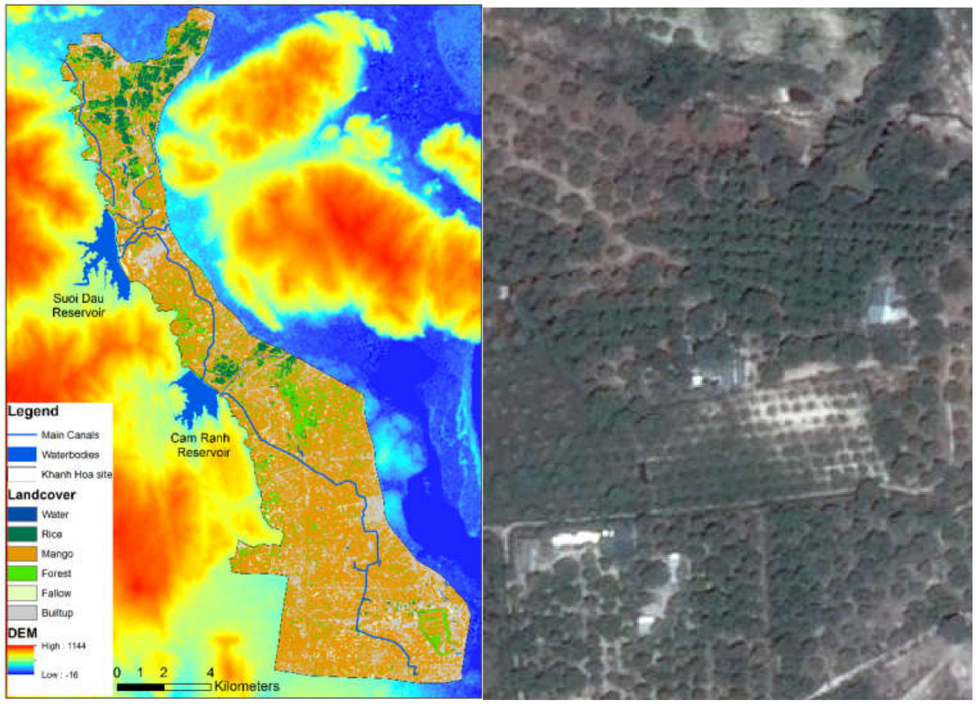

Figure 4.1 Land cover map with mango and rice fields of Khanh Hoa project site (left) and mango trees (right). The area is served by the Cam Ranh Reservoir and Suoi Dau Reservoir. This crop map was produced using SENTINEL 2 images (10 m) of 7 Feb 2017. The trees with large canopy around houses are local variety.

The mango area of Khanh Hoa project site is significantly larger than those reported in statistical year books. The total mango area of 3 related districts (Cam Lam, Cam Ranh, Nha Trang) as reported in 2015 Vietnam statistical year book is 4091 ha, only half of what is mapped here. There are several possible reasons, (1) mapping uncertainty (inaccurate mapping, classification accuracy was 82%); (2) reporting differences (the RS map indicates all areas where mango trees are growing, for example, around houses, by the road, in the bush); (3) statistical uncertainty (limitations in statistical and reporting approach).

Table 4.1 Land cover and crop type area of the Khanh Hoa project site

Class	Area (ha)	%
Cropland	8,776	66
Rice	715	5
Mango	8,061	60
Fallow	481	4
Forest	1,357	10
Water	32	0
Built-up	2,701	20
Total area	**13,347**	**100**

4.1.2 Water consumption

The consumptive use through evapotranspiration was computed by means of pySEBAL for the period of 1 May 2015 to 30 April 2016, which corresponds to the harvest cycle of mango in the region. The mangos are harvested in February and March. The average annual ETa for all land use classes present in the study area was 1160 mm/yr. The total rainfall measured at the nearby Nha Trang station during the same period was 1411 mm/yr.

The accumulated ETa of mango and rice was extracted separately for their respective growing periods and areas. Figure 4.2 shows the ETa and Ta (actual transpiration) values of mango. The average ETa rate was 1118 mm/yr, or 11180 m3/ha. The ETa showed a gradual transition from higher values (about 1300 mm) in the north to the lower values (about 900 mm) in the south. The total annual water consumption by mango over the 8061 ha area was 90 million m^3.

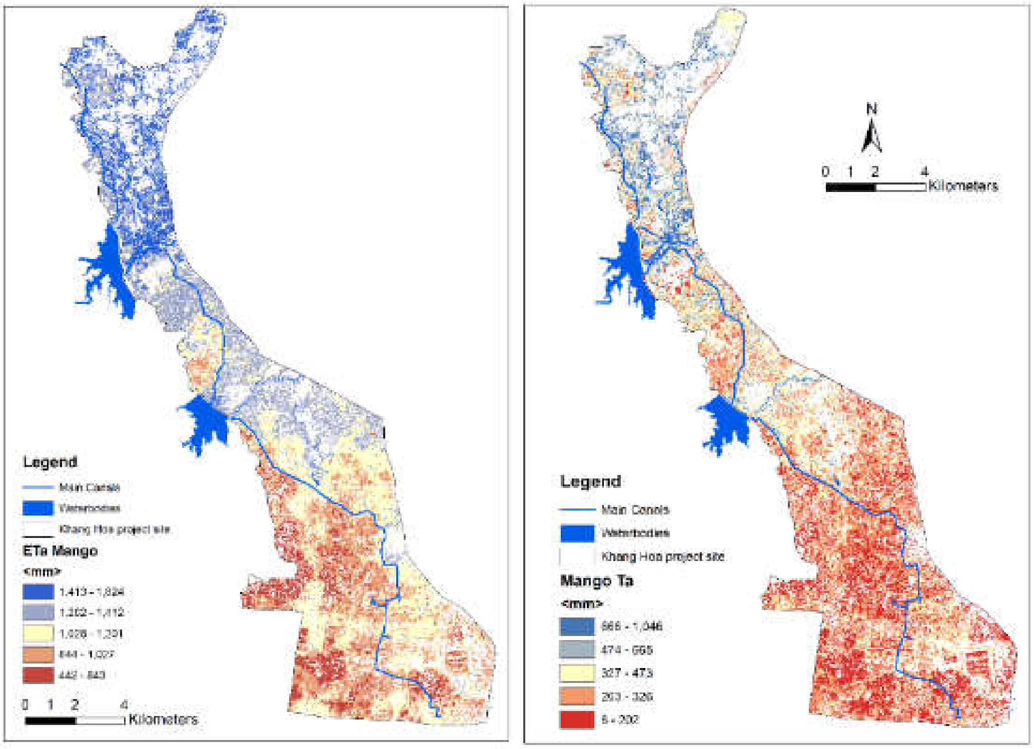

Figure 4.2 The actual ET of mango in the Kanh Hoa project site for period of 1 May 2015 to 30 April 2016

The actual transpiration (Ta) of mango is also an output of pySEBAL. Ta is the water consumption directly used by plant during the photosynthesis processes. Therefore it can be regarded as a *beneficial consumption* contributing towards crop production. The average Ta of mango was 310 mm, or 28% of total ETa, being an extreme small portion. Ta distribution followed a similar trend as ETa, with higher values in the north and lower values in the south.

The ET deficit is another essential irrigation parameter that can be inferred from pySEBAL. ETdeficit is calculated as the difference between potential ET (i.e. water unlimited ET at the actual crop development), and actual ET. ET deficit is a direct expression for water shortage the crop is experiencing on a pixel by pixel basis (figure 4.3). It learns without any further information on canal flows whether a certain field has received sufficient irrigation water, or not. The ET deficit map is a direct measurement of water shortage, i.e. the lack of ET due to limited soil water availability.

The average ET deficit of mango in Khanh Hoa for the 2015-16 season was 92 mm and very similar to ET deficits reported from Brazil (73 to 95 mm/yr) by Teixeira et al. (2008). Figure 4.3 shows that in the southern part of the project site, the deficit is higher. Clearly the right bank of the Cam Ranh canal show more pockets with ETdefict and thus water shortage. It would be interesting to detect the reasons for this shortage: is the capacity of the reservoir the limiting factor for water supply or is too much water send to the North? In case of the latter, a classical non-uniform distribution of water resources is detected. The total ET deficit over the entire project area was 7.4 million m^3, or 8% of the total actual consumption.

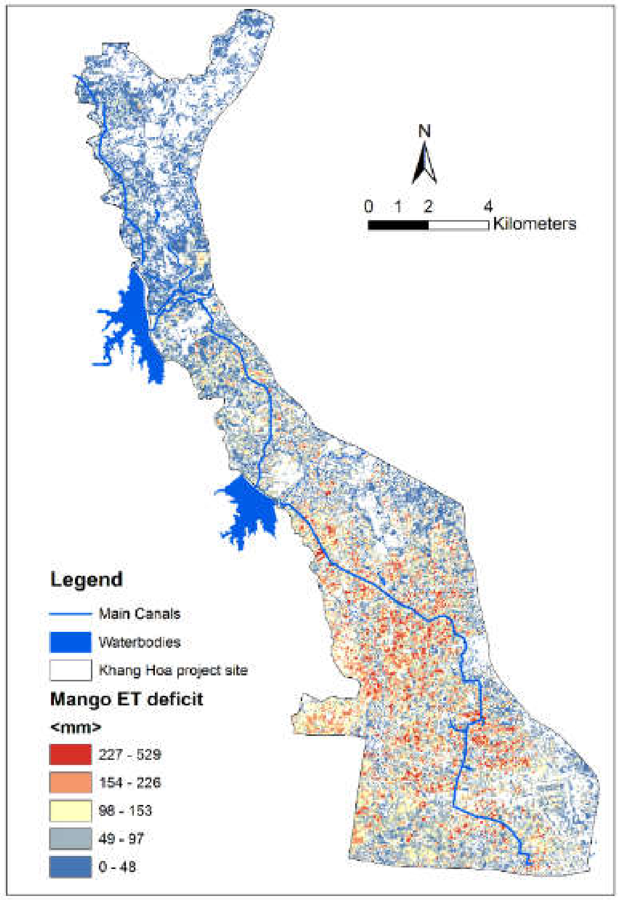

Figure 4.3 The ET deficit of mango crop for the 2015-16 season. The deficit is calculated as potential ET minus actual ET.

Rice ETa was mapped for the period from 30 Nov 2015 to 30 March 2016 (figure 4.4). Average seasonal ETa was 385 mm. in comparison, average annual ETa from 1 May 2015 to 30 April 2016 was 1498 mm, almost 3 times of the spring rice ETa. Paddy rice is cultivated 2 to 3 times a year in the region, and spring is the dry period, which explains the relatively low ETa rate.

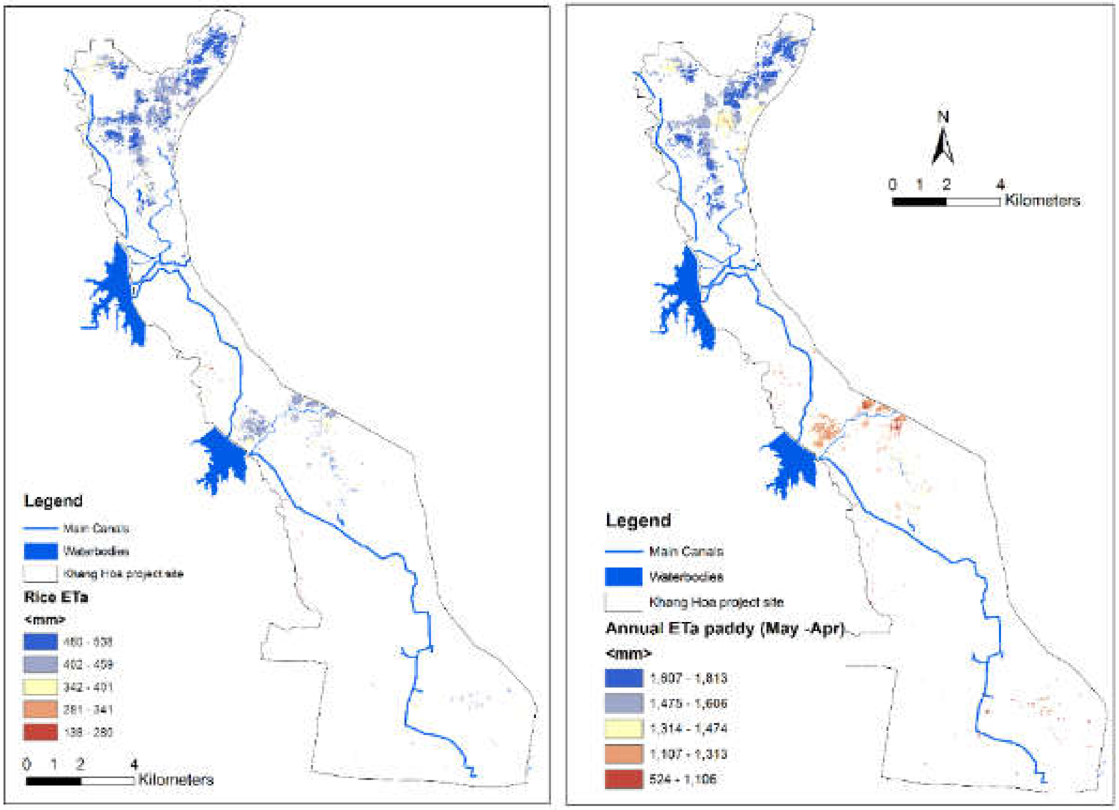

Figure 4.4 The map of ETa for paddy fields for the spring rice season (left, from 30 Nov 2015 to 30 March 2016) and for the year (from 1 May 2015 to 30 April 2016).

4.1.3 Crop yield

The total above ground biomass production of mango trees were mapped for May 2015 to April 2016 (figure 4.5 left). The average biomass production (dry matter) of the site was 22.3 ton/ha, with a trend of higher value in the north and lower in the south, consistent with that of ETa. The average yield to biomass ratio was 1.25. The average yield of fresh fruit with approximately 80% moisture content was 27.9 ton/ha, consistent with international literature but much higher than that reported in the 2015 statistical year book of Vietnam, which is only 8 ton/ha. FAOSTAT, mostly based government sources, estimated the yield of 2014 to be 9.7 ton/ha, along with India (7.3 ton/ha), China (8.1 ton/ha), and Thailand (8.8 ton/ha)[1].

[1] FAOSTAT, for year 2014: http://www.fao.org/faostat/en/#data/QC

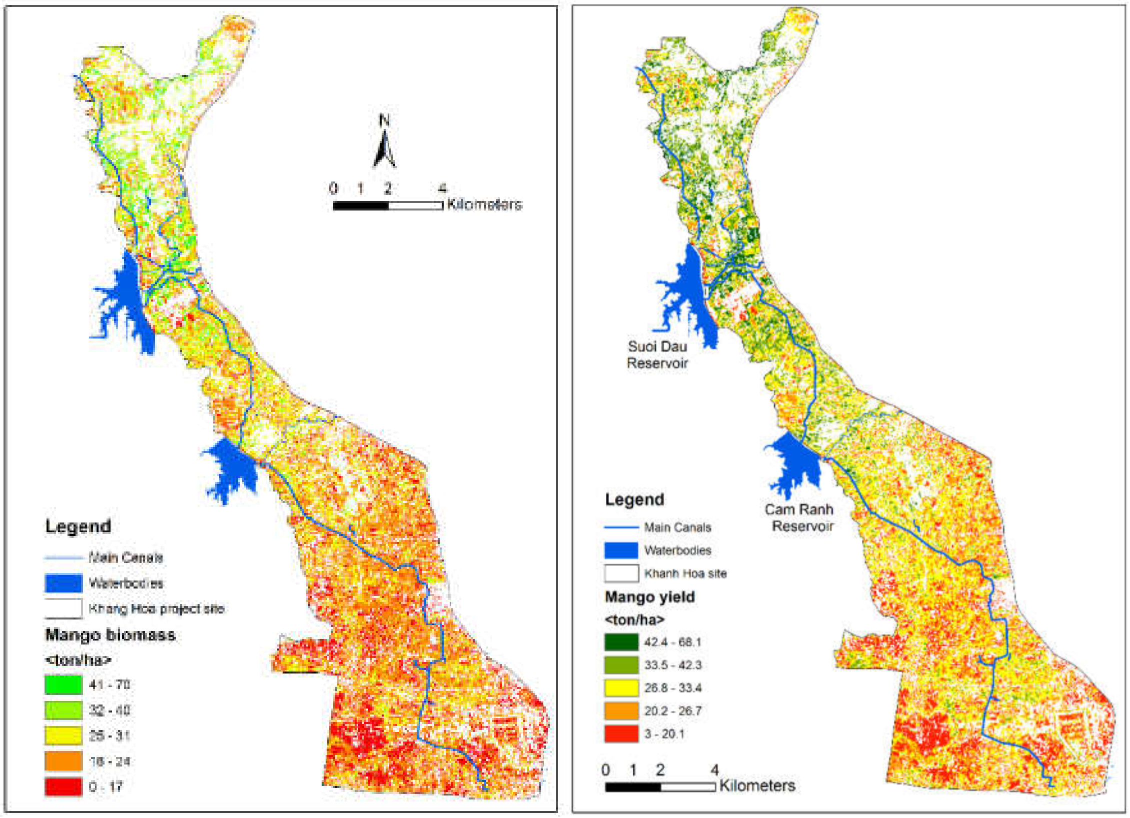

Figure 4.5 The total above ground dry biomass production of mango trees (left) and fresh fruit yield

The production zone in the north has an average fresh mango yield of 40 ton/ha while in the south it reaches only to less than half of it: 19 ton/ha. The production results in the south occur in an area 1235 ha, and are a direct result of the current canal water distributions (assuming that groundwater is not of essence; this statement has not been verified). In fact, a yield gradients from the Cam Ranh reservoir to the south can be observed: The downstream part of the irrigation system reflects in lower yields.

These relatively larger area with lower mango yields can be further observed on Figure 4.6. While overall the yields have a near normal distribution, the shape is slightly skewed with high yields slimmer.

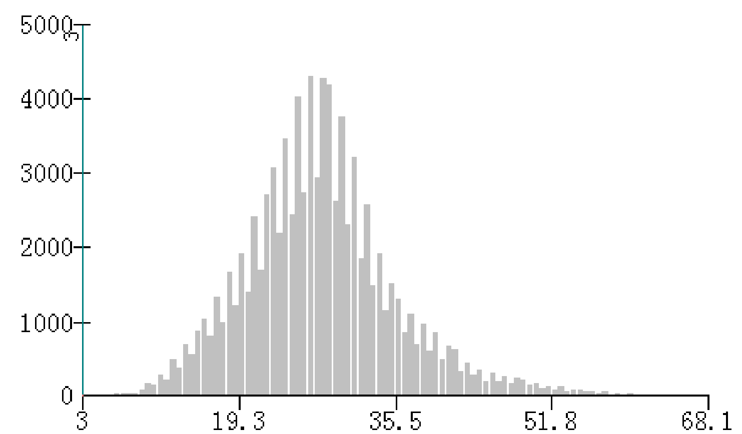

Figure 4.6 yield distribution of mango

The yield gap of mango was also determined. Assuming maximum yields are obtained with no stress on crop canopy photosynthesis, i.e., maximum light use efficiency, the yield gap can be defined as being the difference between the actual yield and the maximum obtainable yield. The average yield gap was 8.8 ton/ha, or 31.5% of current yield values.

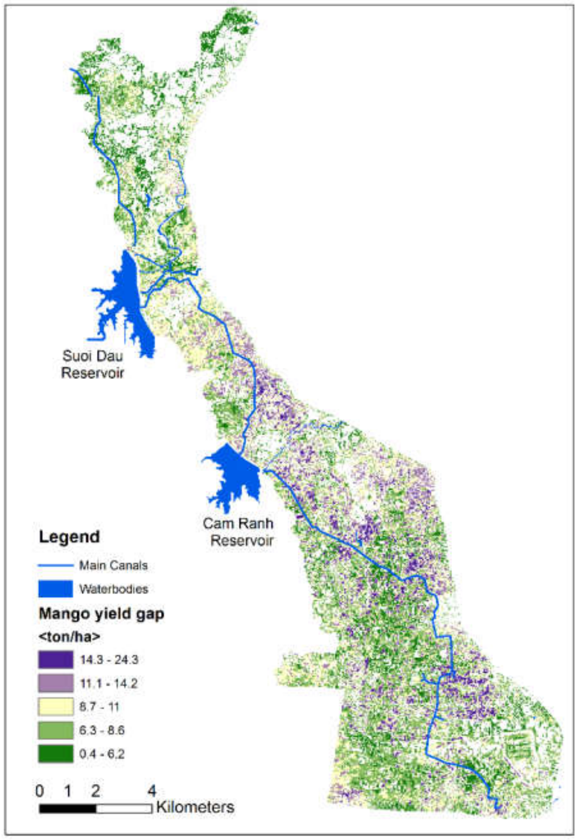

Figure 4.7 yield gap of Mango. The yield gap is the maximum obtainable yield of mango in 2015-16 growing season minus the actual yield.

The yield map of spring rice is shown in figure 4.8. The average yield for the 2016 spring season was 5.9 ton/ha. The yield gap is 0.68 ton/ha or 12% of current yields. The area is relatively small and concentrated. The total production was 4366 ton.

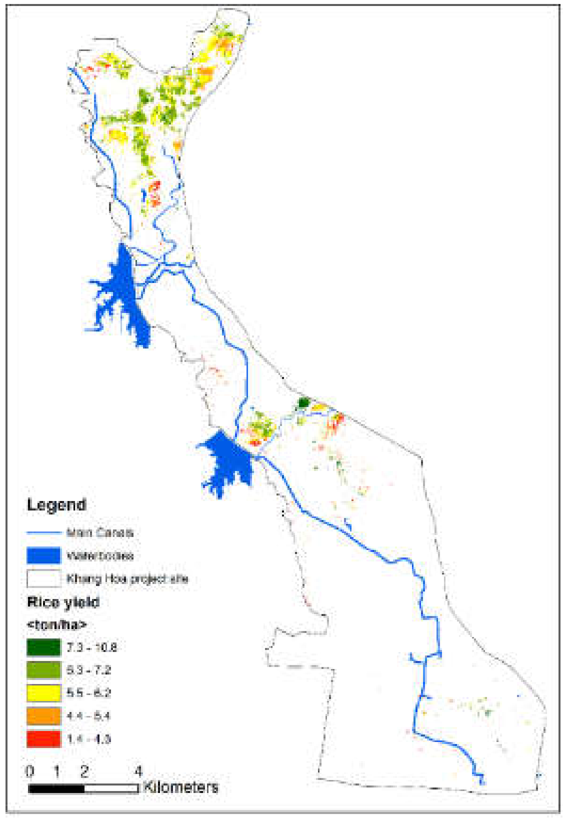

Figure 4.8 Yield map of spring rice

4.1.4 Water productivity

Water productivity maps of mango and rice were produced using the yield maps divided by ETa maps, after the units were converted. The average WP of mango (figure 4.9 left) was 2.52 kg/m^3, with a CV of 0.19. The average WP of rice (figure 4.10) was 1.33 kg/m^3 and the CV was 0.15. Mango has a high annual ETa but also very high yield, leading to higher WP values.

The spatial variability of WP for mango is different as observed for ETa or yield, as a result of combined effects from these two. There are pockets of areas, for example to the northern most corner, and the areas to the east of Cam Ranh Reservoir, with very low water productivity. This is explained by low yields, and relative high amount of water consumptions. The areas with a high ET deficit show the best water productivity values. The right bank of the Cam Ranh Reservoir canal exhibits values exceeding 3.0 kg/m3 frequently. The histogram distribution of water productivity values by areas (number of pixels) clearly shows the overview of performance. There are WP champion farmers who manage to have the best yield to water use ratio. This is achieved either with high yield and moderate water consumption, or with moderate yield but low water consumption. On the other side, “hot spots” for interventions are easily identified with low WP areas. These areas represent the best chances to either improve yield, or reduce water consumption.

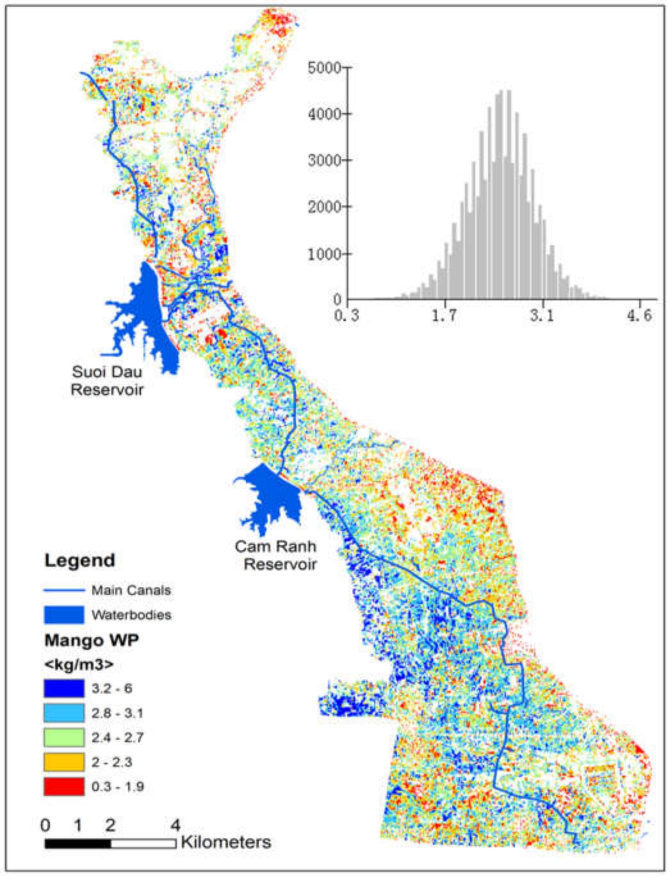

Figure 4.9 Water productivity of mango at the Khanh Hua site. The histogram diagram shows the frequency distribution of pixels with different water producitivty values.

The WP and the spatial variations are shown on figure 4.10. It can be observed that for both reservoirs, the middle reach area of the commands have higher WP than the most upstream, and especially the tail end farmers. The differences in the performance is not caused by rice yield, but water consumption.

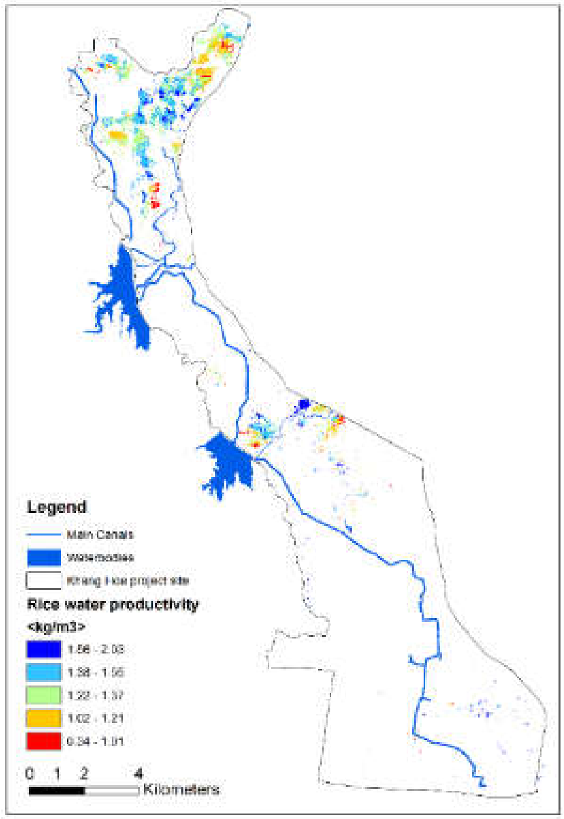

Figure 4.10 Water productivity of paddy rice

4.1.5 Summary for Khanh Hoa site

The main results of the WP assessment at the Ninh Thuan sites are summarized in table 4.2 below.

Table 4.2 Summary information for apple, grape and rice at the Ninh Thuan project sites

Crop	Crop season	Area	Rainfall	ETa	ET deficit	T/ETa	Water use	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	'000 VND/m^3	CV
Mango	May - Apr	8061	1411	1118	92	0.27	90122	27.9	8.8	224902	2.52	110	0.2
Rice	Dec - Mar	740	284	385	20	0.48	2849	5.9	0.68	4366	1.53	8	0.15

The key recommendations generated from above results for the site are:

1. There is significant scope for mango WP improvement, through both yield increase and water saving;
2. Yield increase needs to target at the southern part of the Khanh Hoa site where average yield is much lower;
3. Reexamine the water allocations to the northern and southern parts of the study area;
4. More efficient irrigation application methods, such as partial wetting (drip irrigation), soil moisture conservation, will help reduce soil evaporation;
5. Depending on the condition of the southern canal of the Cam Ranh reservoir, expansion of tertiary canal systems and management are likely importmant factors for improving the poor performing southern parts.

4.2 Ninh Thuan (Thanh Son – Nhon Hai)

A new irrigation system is being constructed near the delta area of the Kinh Dinh River. The delta is supplied with two diversion canals about 24 km upstream of the river mouth. The new system covers parts of Ninh Son, Ninh Hai and Bac Thuan Bac districts in Ninh Thuan province. The proposed project site, mainly along the left bank of the river, is upstream to the extensively irrigated delta areas (Figure 4.11). The delta area has intense rice cultivation practices with high water demands. The new project operations could potentially jeopardize the downstream water availability. Therefore the irrigation management analysis at this site includes the delta area.

4.2.1 Irrigation systems and crop area

The WEIDAP project at these two sties target at apple and grape, both high value crops, for investments. A land cover map was produced for the study area using a Sentinel 2 image acquired on 7th February 2017. A total of 374 ground truth points (364 in 2017 and 10 in 2016) were collected and 80%, or 300 points, were used for the crop classification process. The other 74 points were used for the accuracy assessment. The overall classification accuracy was 86%, with the accuracy for cropland being 92%.

Grape, apple, rice and fallow cropland were mapped (figure 4.1). Rice is mostly concentrated in the delta area with irrigation supply from two main diversions. The current land use at the two proposed project sites are mainly rainfed seasonal crops such as garlic, spring onion, peanut. Grapes and apples are mainly found at the Nhon Hai site.

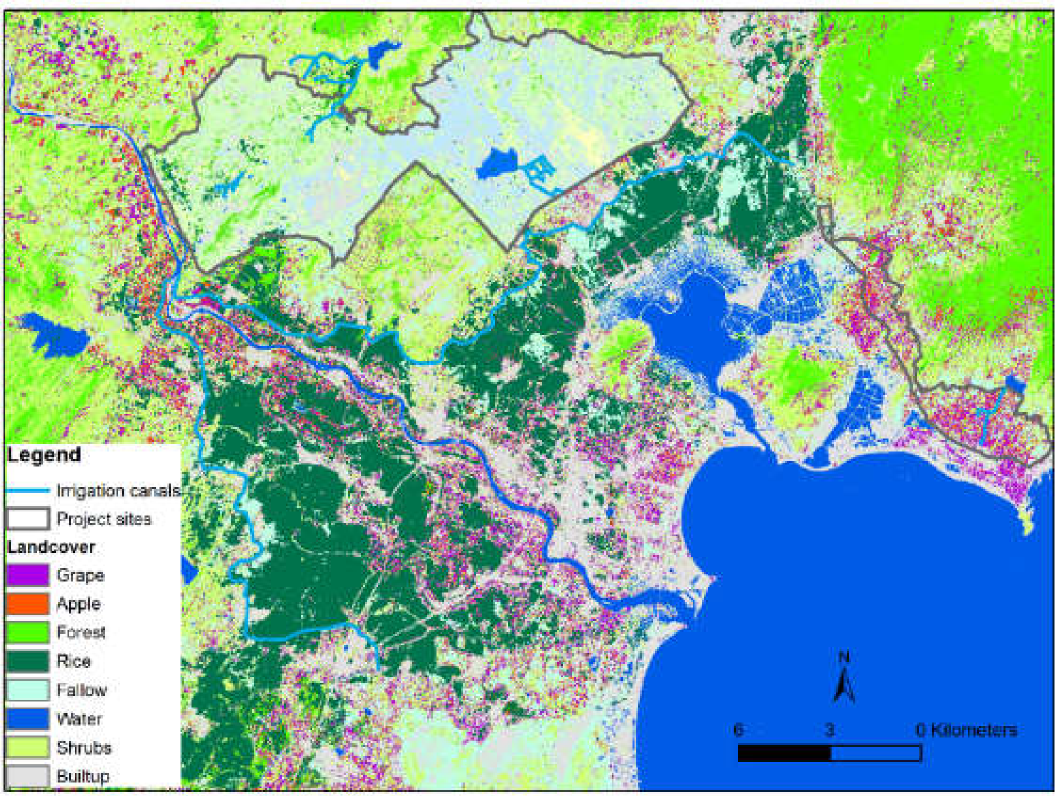

Figure 4.11 Cropland areas of the Ninh Thuan study site. Apple and grape are highly segmented at the Nhon Hai site, while large areas of paddy rice are found in the delta area.

Year 2015-16 was a dry year in the region, causing most upland areas (including the two project sites) to be fallow. Table 4.3 shows that the Thanh Son project site has only 55 ha of its 229 ha of cropland planted. The Nhon Hai site has 42 ha out of 64 ha of total cropland with crops growing, of which 21 ha for grape and 14 ha for apple. These two crop fields, with relatively low density, dotted throughout the Nhon Hai project site, which increase difficulties for centralized water supplies through canal systems. The very low density of crops also rendered it less effective (and less meaningful) in yield, ETa and WP assessment. This is because there are often other areas mixed in pixels classified as apple or grape, changing the avreage values at pixel level.

Table 4.3 cropland area and land cover of the Thanh Son – Nhon Hai project area (ha)

	Thanh Son	Nhon Hai	Delta area
Cropland	229	64	
Grape	0	21	
Apple	0	14	
Rice	4	0	1,572
Other crops	51	7	
Fallow	174	21	
Forest	31	2	
Water	11	0	
Shrubs	326	29	
Builtup	87	13	
Total area	685	64	

4.2.2 Water consumption

The annual ETa was mapped from 1 Oct 2015 to 30 September 2016. Figure 4.12 shows the annual ETa for the entire landscape ranging from the inland mountainous region towards the delta. The delta is dominated by paddy rice, and the annual average ETa is approximately 1600 mm/yr. Two to three crop cycles occur. The two projected sites with rainfed crops have an average ETa of 580 mm/yr only. In this relative dry region, the annual ETa map reveals clearly where irrigation occurs as these areas have higher ETa amount than non-irrigated areas.

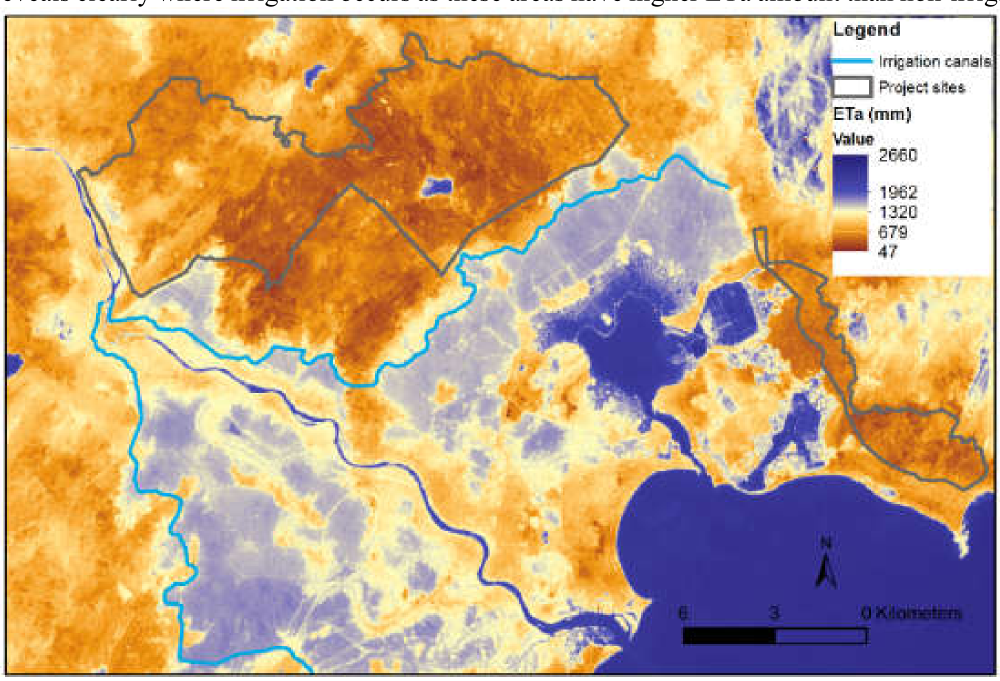

Figure 4.12 Annual ET (1 Oct 2015 – 30 Sept 2016) of the two projects and delta irrigation system in Ninh Thuan province.

The water consumption of grape and apple is extracted separately using the crop type map. Figure 4.13 shows annual ETa of apple and grape. The average rate of ETa is 968 mm and 854 mm for grape and apple respectively. The total areas of grape and apple are only 21 ha and 14 ha, respectively. Even these small areas are sparsely distributed in different parts of the planned irrigation site (Nhon Hai), resulting in highly fragmented maps. The ETa map showed no obvious trend in distribution along the long stretch of the planned project site. That is probably because of a lack of irrigation infrastructure forcing farmers to adopt various methods, resulting in wildly different performance from one field to another.

Total water consumption of the two crops are relatively small. The 21 ha of grape consumed 203 thousand m^3 of water for the 2015-16 growing season, while 14 ha of apple consumed 120 thousand m^3. The low density causes ETa of the two perennial crops to have relatively low annual ETa, due to presence of large gap areas among the crops.

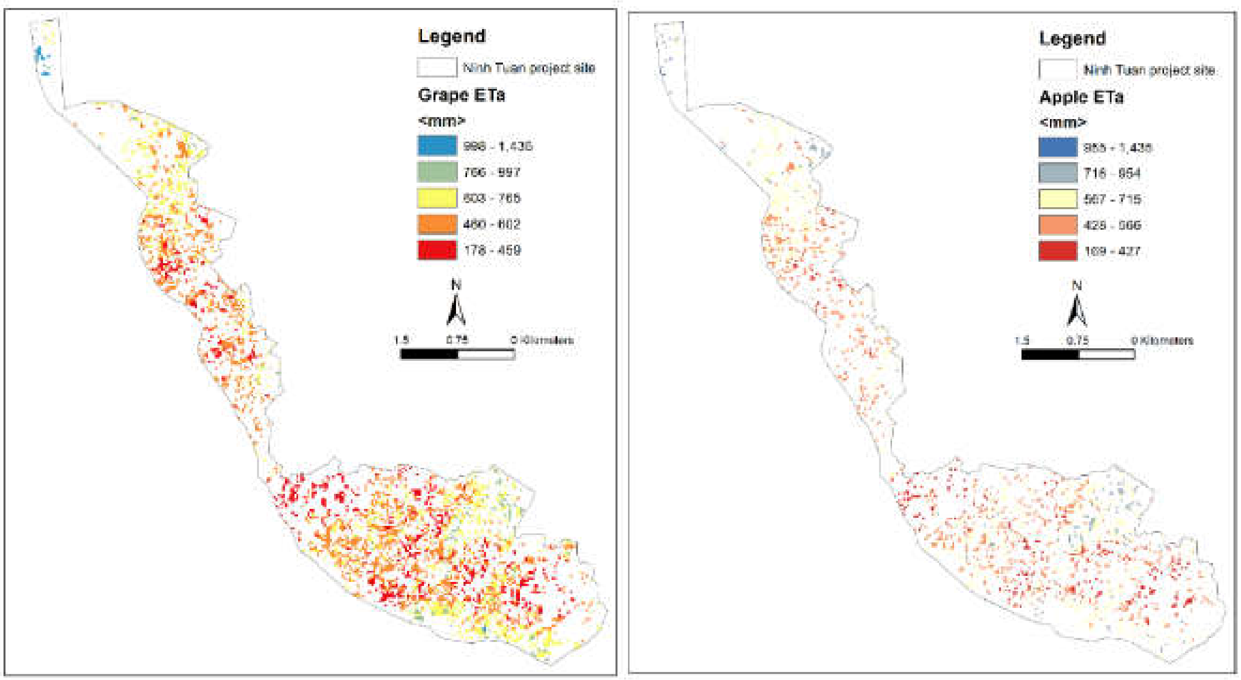

Figure 4.13 Annual ETa of apple and grape at the Nhon Hai project site, Ninh Thuan Province.

It is worth noting that only one third of the Thanh Son project site is currently covered with cropland, majority of which is rainfed with low cropping intensity. The development of new irrigation facilities are likely to drive farmers to convert non-cropland, for example scrubland, to irrigated cropland. These will significantly alter the total water demand, as well as the water demand of the currently irrigated apple and grape. Current irrigation practices are likely to adjust to the new irrigation system. Increased water consumption can be expected with better availability of water, and larger scale operations.

4.2.3 Crop yields

The areas of grape and apple are small and fragmented with varying yields. The yield maps of grape and apple are shown in figure 4.14. The average yield is 22.2 ton/ha for grape and 30.1 ton/ha for apple. The Coefficients of Variation (CV) are 37% for grape and 41% for apple, high than other crops. The yields of these two crops as reported in the yearbook 2015 are 22.8 ton/ha for grape and 30.2 ton/ha for apple respectively. However, we note with caution that the density of apple trees are low. Therefore the yields cannot be linearly extrapolated should the areas change through expansion of apple tree areas or increase in tree density.

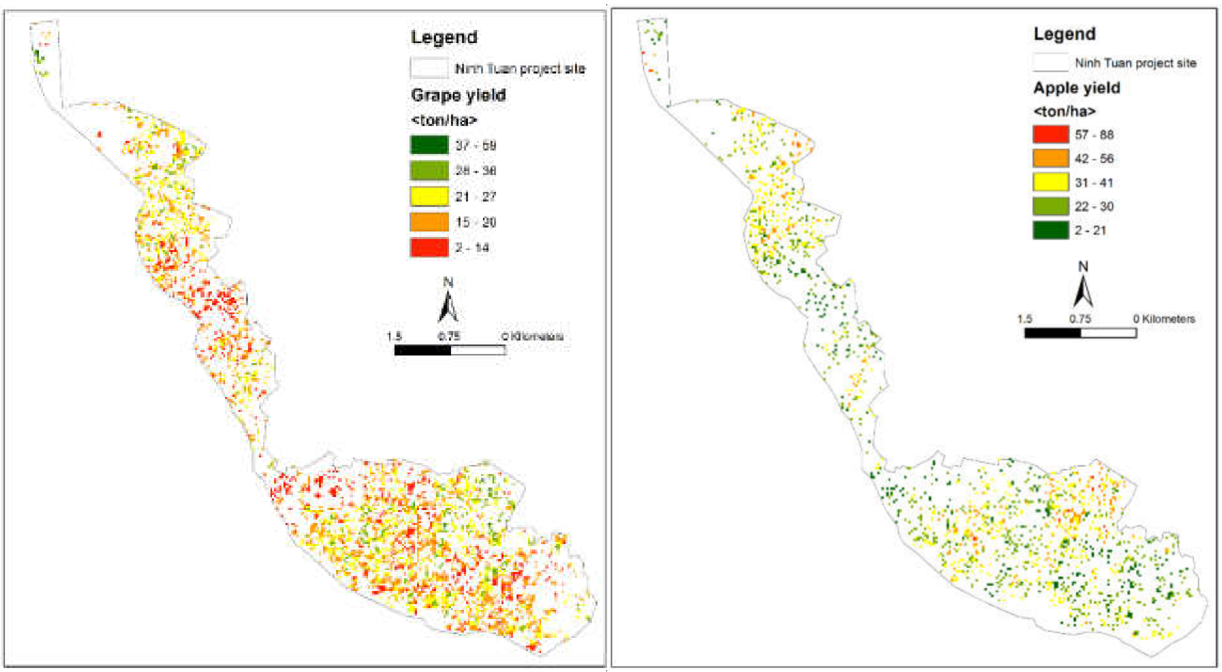

Figure 4.14 Yield of grape and apple at the Nhon Hai project site, Ninh Thuan Province. The apple yield is low mainly due to low density in trees.

4.2.4 Water productivity

The WP of grape is mapped using yield and ETa map. Figure 4.15 shows the average WP of grape is 2.29 kg/m^3 with a CV of 0.17. Confirming previous findings with ETa and yield, there are no obvious trend in the distribution of WP for grape.

The WP of apple was produced but similar to yield, has to be taken with caution. The nominal WP of apple is 5.33 kg/m^3 with a CV of 0.18. As discussed above, the very low density of apple trees cause pixel level aggregated ETa and biomass to be lower than those of a *normal* apple orchard with higher tree density in a lager extent. The apple trees are growing in small patches with rather random distribution across the Nhon Hai project site. This causes a skewed distribution in WP results. It also has significant implications for organized irrigation water supplies, especially when investment in infrastructure is to be planned.

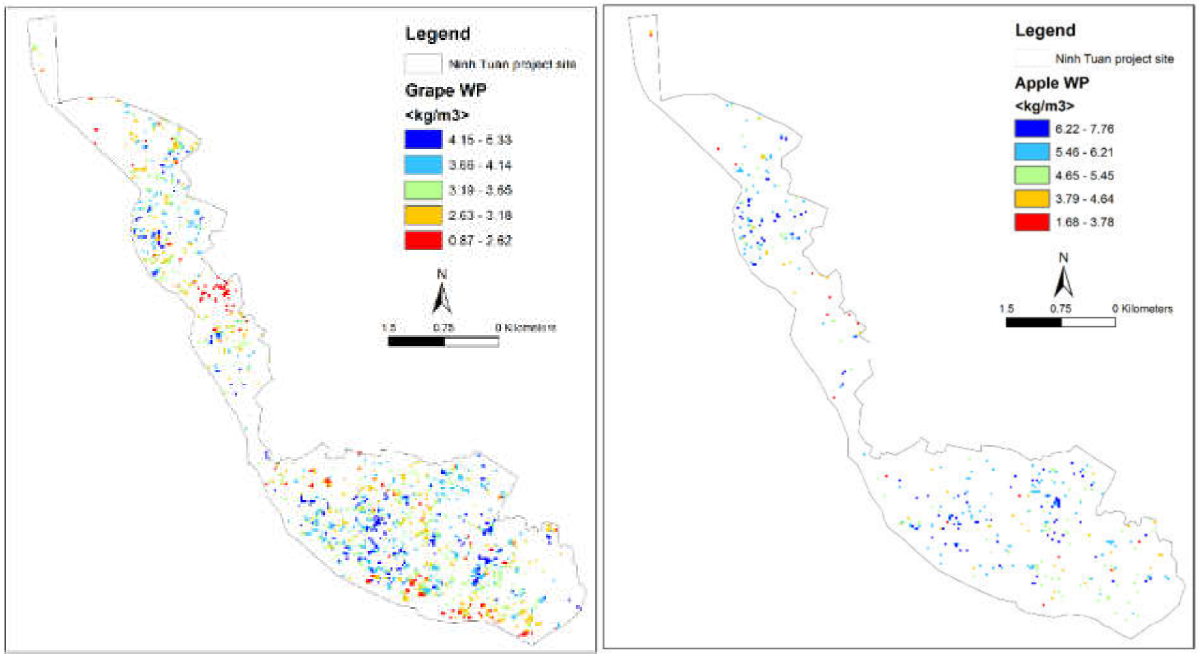

Figure 4.15 The WP of grape and apple at the Nhon Hai project site for the 2015-2016 season

The average WP of grape and apple is significantly higher than that of cereal crops. This is explained by a combination of high productivity and the moisture content of the products harvested. The yields of grape and apple are higher with very high moisture content in their fruits (70-80%).

The fragmented crop areas makes the setting of a reasonable baseline scenarios more cumbersome. The small farm plots create mixed pixels on the 30 m x 30 m Landsat images, and consequently the ET, yield and WP values are less accurate.

4.2.5 The delta paddy rice irrigation system

A field trip was designated to survey fields with rice. The number of GT points collected during an earlier field visit were insufficient to separate each of these mixed crops. Figure 4.16 shows the yield map and the histogram of the yield values. It should noted that while the centre of the histogram is close to 5 ton/ha, there are a large number of pixels with near zero yield values. These areas are no rice growing areas and the pixels were subsequently removed from further analysis. The yield map – in this case - serves as a validation of the land cover classification.

The average yield of a single rice growing season is reasonably high, albeit it has significant variations. The statistical mean, after removing the extreme non-rice pixels, is 5.4 ton/ha and the standard deviation is 1.4 ton/ha. There apears to be a double peak of rice yield, with one peak – large number of pixels – performing better than others. The real local heros with the highest produtivity are however those of the top 5%, whose yield is higher than 7.5 ton/ha. Most of these fields are at the southern part of the irrigation (the right) canal command areas, with a significant patch also found in the left canal command areas. The yield gap is 0.72 ton/ha or 13% of current yield values on average.

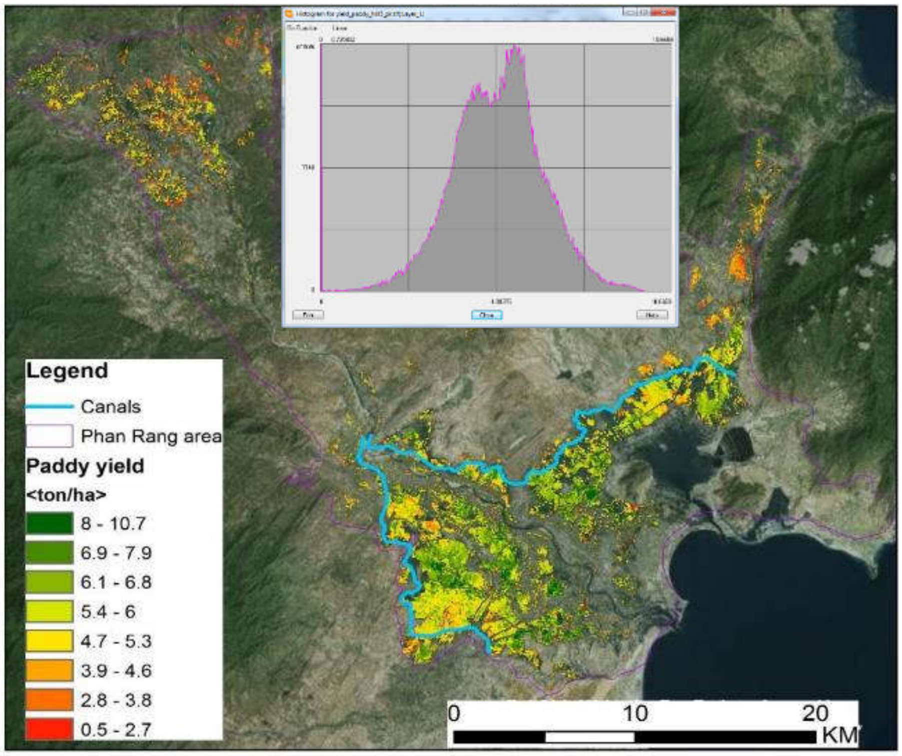

Figure 4.16 Paddy rice yield map and the historgram distribution of yield values (number of pixels (y-axis) corresponding to each yield value (x-axis)).

Seasonal ETa showed even bigger differences in the two command areas. The ETa values ranges from 104 mm to 688 mm, with an average ETa rate of 399 mm and a standard deivation of 61 mm. Following an international survey, Zwart and Bastiaanssen (2004) found the ETa of rice to vary typically between 400 to 900 mm/season. The ETa of the left canal command area is consistently higher than that of the right canal (about 100 mm higher). There are however, no statistically signifcant differences observed for crop yield along the main canal (head-tail of main canal), or the areas further away from the main canal (head-tail of teriary canals).

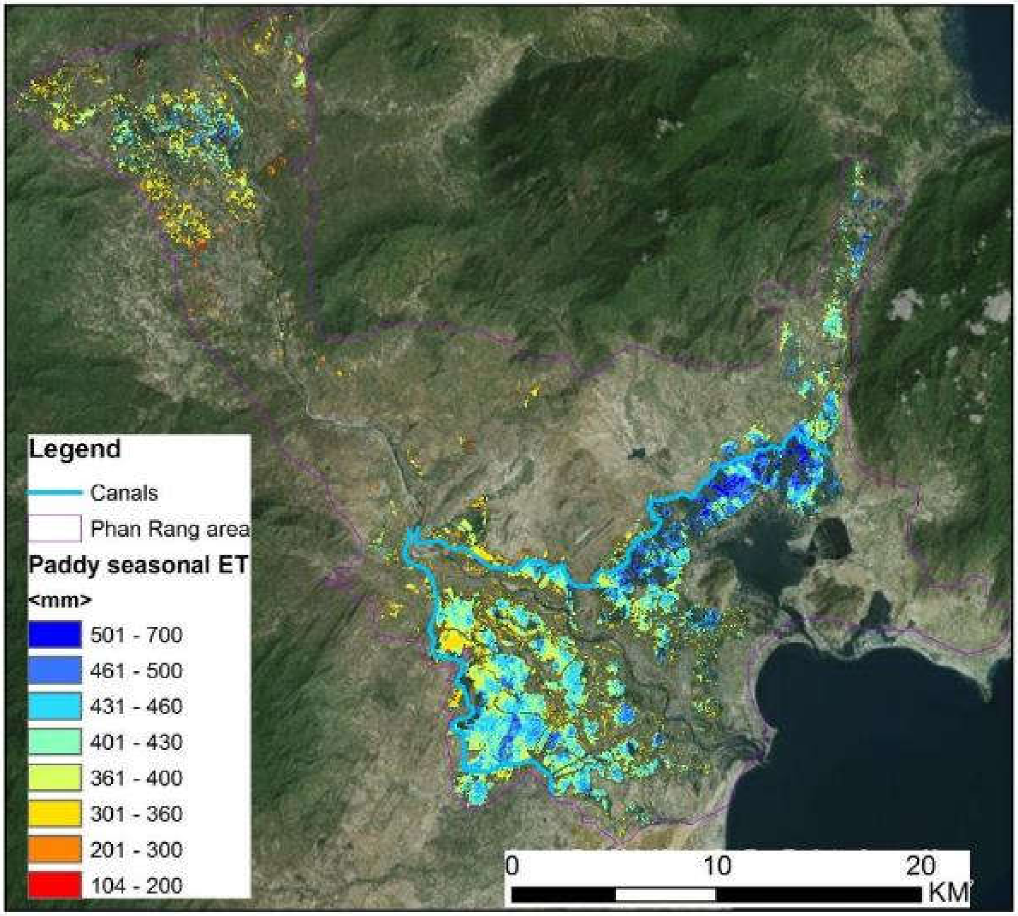

Figure 4.17 Seasonal ETa map of rice growing areas for the period 16 November 2015 to 31 March 2016

The rice WP map displays a somewhat different picture compared with ETa or yield alone. The average WP value is 1.5 kg/m^3 with a CV of 0.27. Higher WP is observed in the middle reaches of both left and right canals. This dismisses typical assumptions about head-tail water difference issues. The problem seems to be more one of on-farm water management practices. That is, for areas with high ET, the yield is moderate, and the WP tends to decrease as a consequence. It is in the middle reach areas where farmers managed to strike a good balance by consuming a modest level of water while simultaneously producing relatively high yields. These could be further disaggregated into two main categories: (i), areas where water consumption reduction should be the priority; and (ii) areas where yield improvement should be the priority. If upstream irrigation development occurs, some mild level of water stress will likely occur, and this may change the situation.

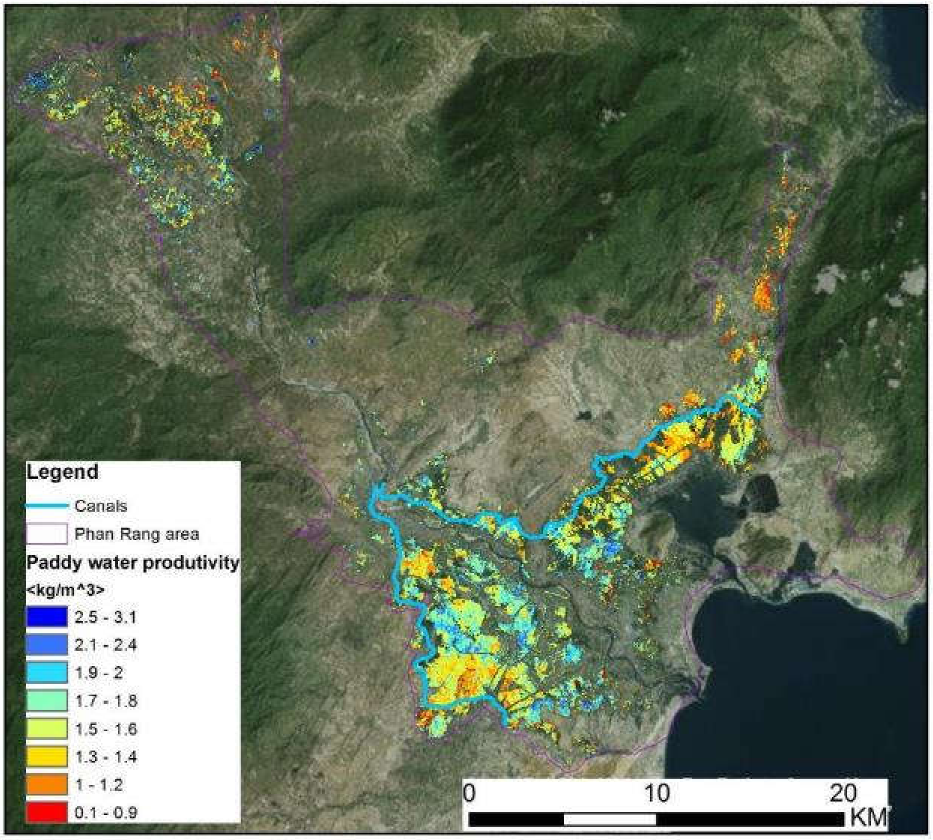

Figure 4.18 water productivity map of paddy rice of the existing irrigation system.

The severe drought in early 2016 had a more pronounced impact on ETa and agricultural production in other cropland areas. Water consumption and biomass production of other cropland areas are significantly lower compared with those of irrigated paddy rice. Unlike paddy rice, there are large number of pixels with zero or close to zero biomass production (Figure 4.16). In fact, 48% of the cropland areas are fallow with zero biomass production. There are 3, 410 ha, or 5% of cropland areas, with biomass production of 2 ton/ha or less. Part of this is attributed to fallow cropland; part of this is however, probably drought effects causing crop failure. When fallow cropland is excluded (removing pixels with biomass production of less than 0.5 ton/ha), the average biomass production is 6.4 ton. The standard deviation, at 2.9 ton/ha, also shows much higher variations.

4.2.6 Summary for Ninh Thuan sites

The main results of the WP assessment at the Ninh Thuan sites are summarized in table 4.4 below.

Table 4.4 Summary information for apple, grape and rice at the Ninh Thuan project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Rice	Dec - Mar	9892	197	399	18	0.47	39469	5.4	0.72	53417	1.36	7	0.27
Apple	Oct - Sep	14	594	555	145	0.19	78	30.2	8.15	190	5.33	64	0.18
Grape	Oct - Sep	21	594	602	145	0.2	126	22.2	11.9	466	2.29	32	0.17

The key recommendations generated from WP results and associated analysis for these sites are:

1. The target crops apple and grape have a very small cultivated area currently. Their distribution is highly fragmented, which makes it less ideal to represent current baseline situation. This is especially true at the Thanh Son site, where the density and total area are too low to establish any meaningful baseline situations;
2. The low apple and grape intensity poses challenges but also opportunities for developing new irrigation systems;
3. Perennial crops such as grapes (9680 m^3/ha) and apples (8540 m^3/ha) consume large amounts of water, and expansion of cultivated areas with these crops will significantly increase the irrigation water demands; Two rice crops are equal to one apple orchards
4. Over-irrigation occurs in large tracts of the left bank main canal. Simultaneously tracts with water deficit occur so the irrigation water distribution of the left bank canal is not uniform
5. Cautions have to be given to the upstream and downstream effects, especially with downstream delta paddy rice irrigation area to avoid potential water conflicts.

4.3 Du Du

4.3.1 Irrigation systems and crop area

The Du Du project site, in Binh Thuan Province, is heavily dominated with dragon fruits. Figure 4.19 shows the land cover and crop type map of the site mapped using Sentinel 2 image of February 2016. The total project area is about 3009 ha, of which 67% is cropland, 23% built-up areas, and the rest for forest, water bodies, and sand. Within the 2008 ha of cropland area, 1824 ha, or 91% of total cropland area, is cultivated with dragon fruit. Dragon fruits are relatively new in the region. Average ages of the trees are 7.5 years, with some as old as 16 years.

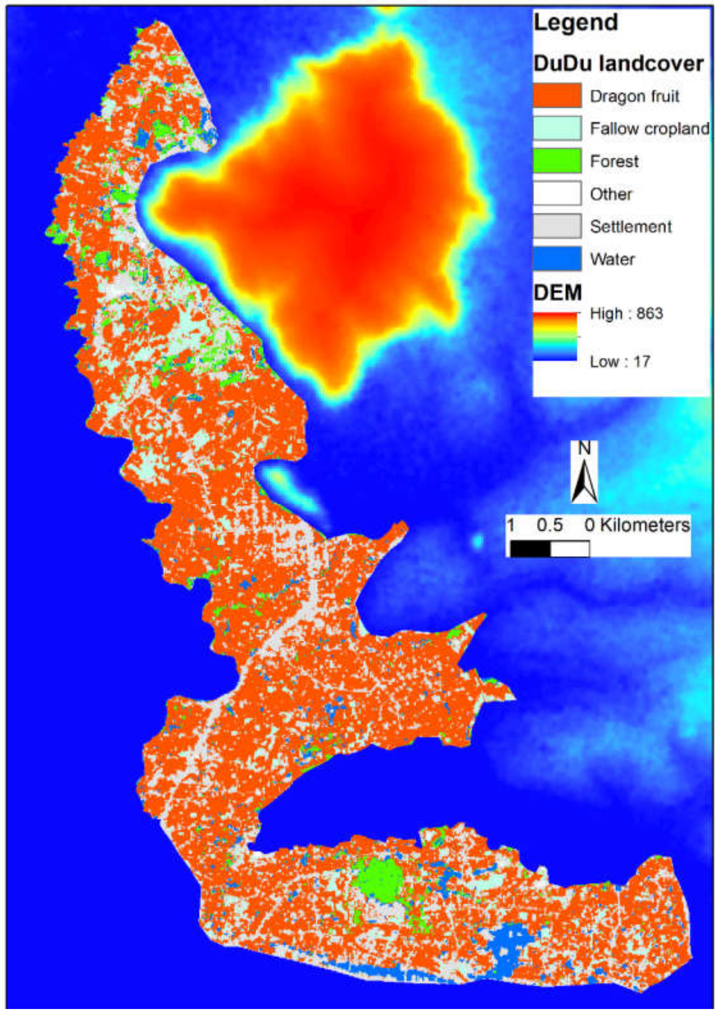

Figure 4.19 Land cover and cropland map (2016 Feb) of the Du Du project site

Table 4.5 land cover and cropland area of the Du Du project site

Class	Area (ha)	%
Cropland	2008	67
Dragon fruit	1824	61
Fallow	184	6
Forest	144	5
Water	145	5
Sand	7	0
Settlement	705	23
Total	**3009**	**100**

4.3.2 Water consumption

The annual ETa of dragon fruit is estimated for the period of 1 September 2015 to 31 August 2016. The average ETa for a dragon fruit orchard is 1059 mm/yr, with a CV of 10.3%. There is however a trend of strong geographic clustering effects of ETa: both high value pixels and low value pixels are found to group themselves at different parts of the study area (figure 4.20). There are no apparent reasons why ETa varies in such a manner and the first interpretation for this clustering is the presence of sediments from nearby rivers (hence soil fertility) and the age of the trees. These need to be identified through follow-up field works. But it certainly pin-points the need to understand both excessive ETa and low ETa values.

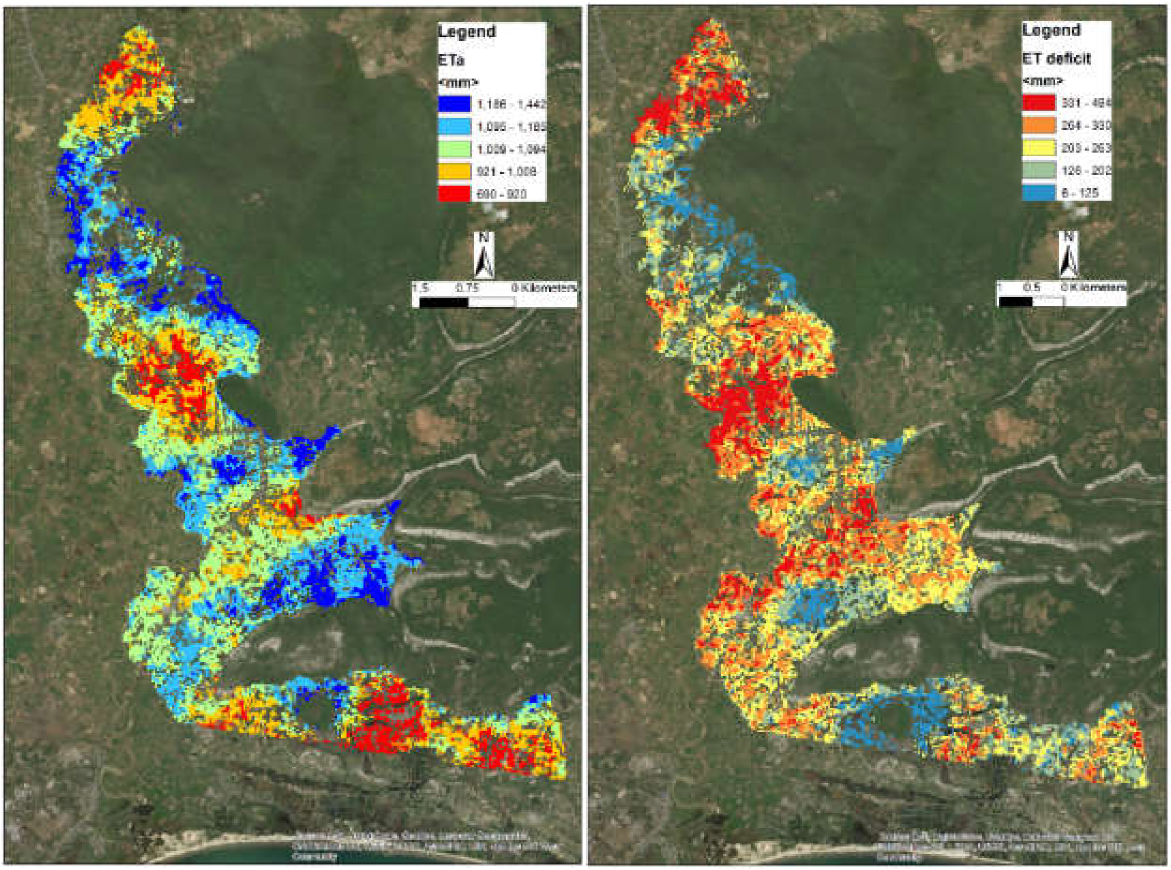

Figure 4.20 Annual ETa (1 September 2015 – 31 August 2016) of dragon fruit at the Du Du project site

The ET deficit map shows similar trend as ETa map, confirming that ETa variability is mostly affected by water supply. Most areas with zero deficit have a high ETa. The other way around is no always true. A high ET deficit occurs at both low and moderate ETa values.

The ETa of dragon fruit was further partitioned into Ta and Ea. Figure 4.21 shows the map of Ta and the ratio Ta to ETa. Average Ta for dragon fruit is 332 mm, with a CV of 0.31. Average Ta to ETa is about 32% only, representing a very low "beneficial consumption" ratio whereas most part is evaporated through open soil or canopy interception. Without further a priori information it is obvious that dragon fruits are exposed to flood irrigation. Because tree spacing is usually large for dragon fruits, evaporation from wet soil and ponding water surfaces can indeed occur. Significant potential for water savings exist by switching to drip or micro-sprinkler irrigation systems.

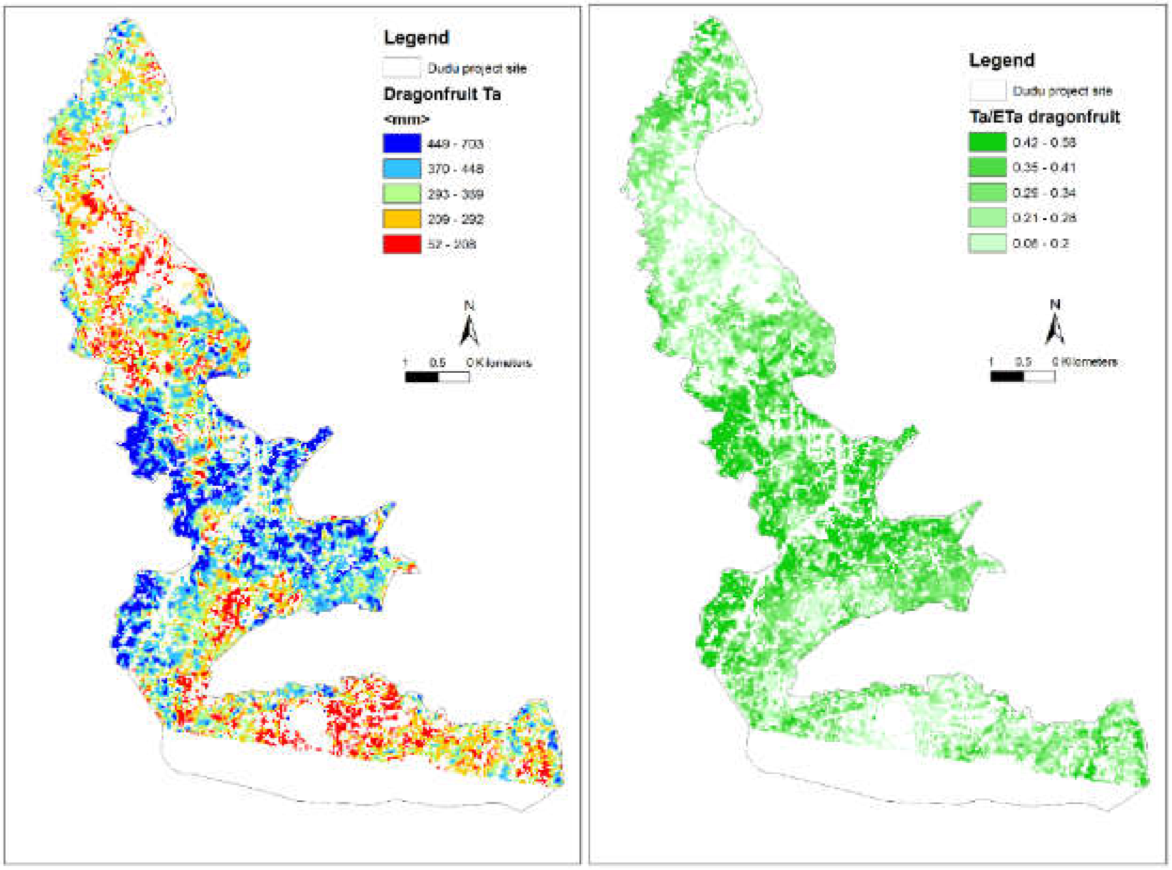

Figure 4.21 The actual annual transpiration (Ta) and Ta to ETa ratio of dragon fruit at the Du Du project site for the 1 October 2015 – 30 September 2016 harvest season.

4.3.3 Crop yields

Dragon fruit is a high value and high yield product with 2-4 harvests per year. The GT survey in March showed an average yield of 9.4 ton/ha for the last harvest. The annual average yield, as reported in statistical yearbook 2015, shows an average of 24 ton/ha. Figure 4.22 left shows the fresh yield of dragon fruit trees. The average yield was 24.1 ton/ha. Surprisingly, the yield map is inversely related to ET. Except for the southern part, where both ETa and yield are low, low ETa is often associated with higher yields, and vice versa. This could likely be related to negative feedback of flood irrigation practices and over-irrigation. If the entire field is flooded, the trees may experience oxygen deficits and they have a classical drainage problem. Dragon fruit yield seems to increase with T/ET, which suggests that yield and T are linear, being confirmed for many other crops.

The yield gap was computed from the difference between potential and actual yield, normalized for the potential yield. Figure 4.22 (right) shows the yield gap of dragon fruit at Du Du was 13.4 ton/ha, or 56% of current yield levels, implying significant potential for improvement. While bigger gaps are observed in low yield areas, it is observed that some high yield areas also have significant potential for improvement.

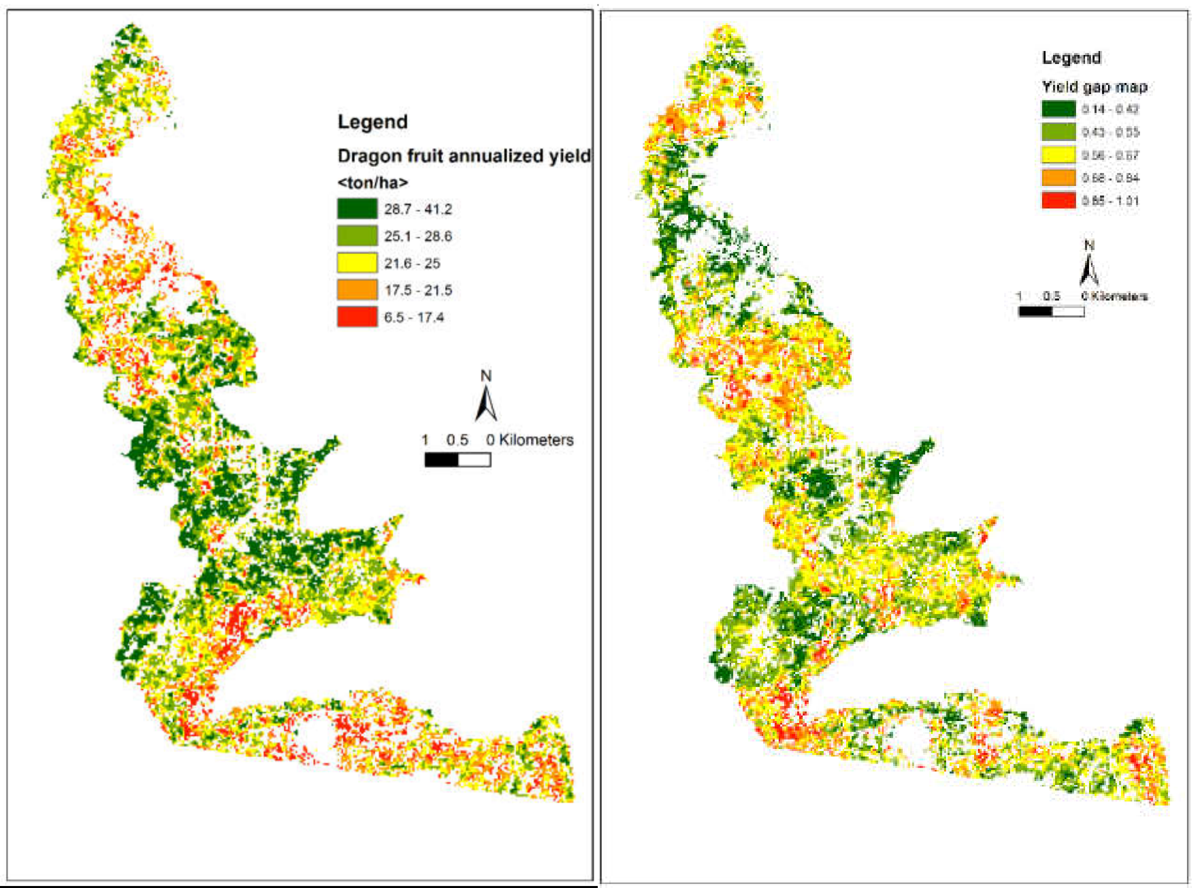

Figure 4.22 the map of dragon fruit yield (left) and the map of yield gap (expressed as the difference in actual and potential yield divided by potential yield)

4.3.4 Water productivity

Water productivity map was produced and provided insight into the combined effects of ETa and yield. The average WP of dragon fruit is 2.29 kg/m^3, or 28 thousand VND/m^3, with a CV of 0.2. The CV may not be high. However, the WP map clearly illustrates the “hot spots” and “bright spots”, or the so called “hero farmers”. The northern and the central parts show two clusters of high WP areas, while pockets of low WP areas are clustered in between.

The contrasted WP map, together with ETa and yield maps, provide clear indication of where interventions are required, and what these interventions should be targeting at by comparing with those “hero farmers”. For example, if the WP level could be brought up to a more uniform level by reduced floor irrigation practices. Yield improvement through more T could increase production by 36% by targeting interventions in areas with yield gap exceeding 55%.

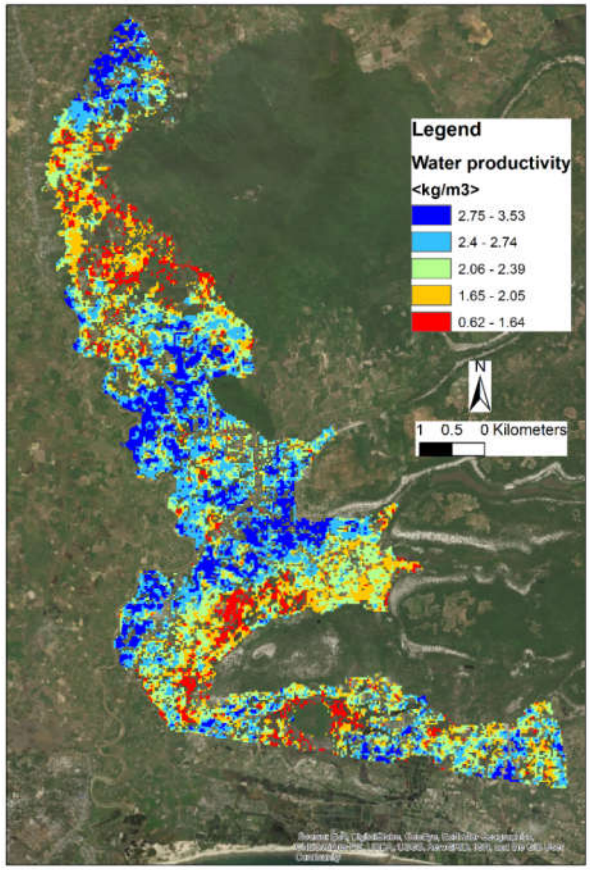

Figure 4.23 WP of dragon fruit for the Du Du project site for the 2015-16 season.

4.3.5 Summary for Du Du site

The main results of the WP assessment at the Du Du site are summarized in table 4.6 below.

Table 4.6 Summary information of dragon fruit at the Du Du project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Dragon fruit	Oct - Sep	1824	245	1059	239	0.31	19316	24.1	13.4	43958	2.29	28	0.20

The key recommendations generated from WP results and associated analysis for these sites are:

1. High water saving potential exists. Soil moisture conservation and switching to partial wetting irrigation methods to reduce open soil evaporation should be practiced. The T/ETa ratio should be targeted at say 0.7 instead of the current 0.32;
2. The negative trend between ETa and yield should be reversed and this can be accomplished by water conservation practices;
3. Water in this study area is not the main limiting factor for low yield areas. Attention is therefore drawn to non-water management factors such as soil fertility, levelling, diseases etc. Pockets with low and high productivity are likely related to river morphology;
4. The yield gap analysis shows great potential for farmers and agri-communities to increase their income.

4.4 Tra Tan

4.4.1 Irrigation systems and crop area

The Tra Tan is another site located in Binh Thuan Province. It's relatively small with a total area of 1722 ha. The site is served by a small reservoir to the north east. Most of the site area (89%) is developed for cultivation, of which 646 ha, or 42%, is cultivated with pepper, 82 ha with paddy rice and 808 ha for various other crops. It is one of the areas where high value crop have become common practice.

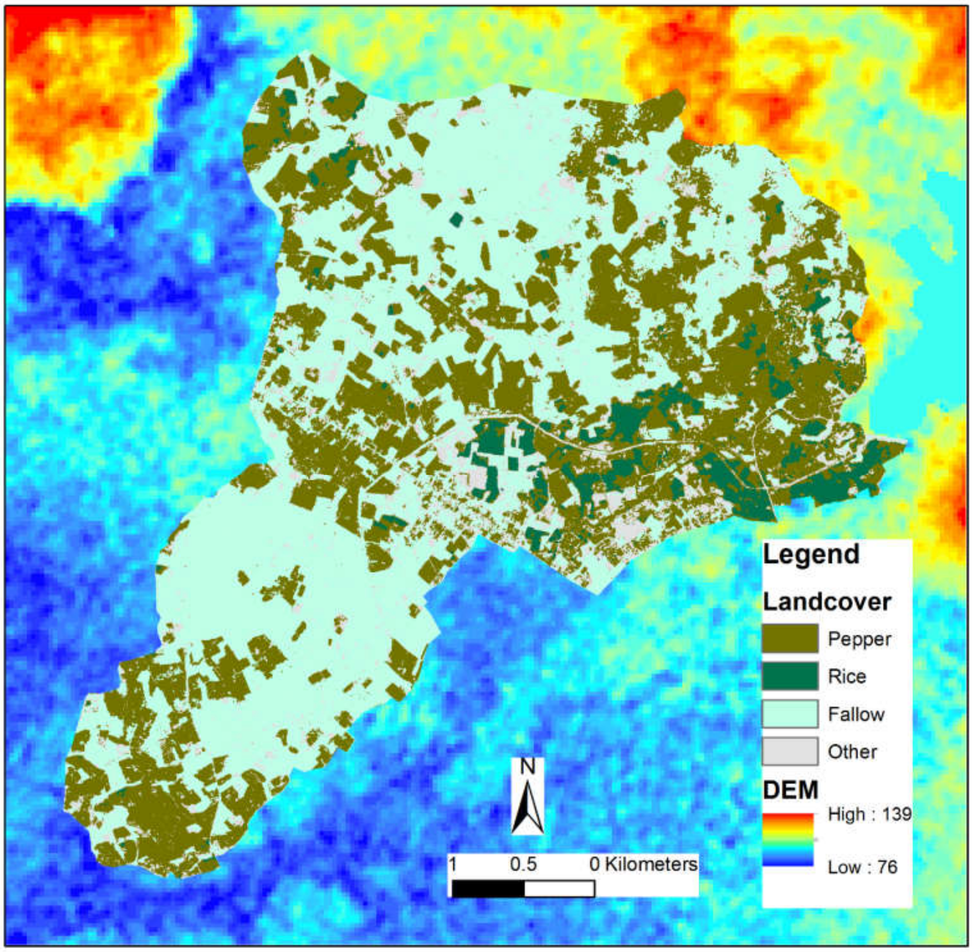

Figure 4.24 crop type map of the Tra Tan project site

Table 4.7 cropland areas of the Tra Tan project site

Land cover	**Area** [ha]
Cropland	1535
Pepper	646
Rice	82
Fallow	808
Other	187
Total	**1722**

4.4.2 Water consumption

The seasonal ETa for the period 1 September 2015 to 31 August 2016 is mapped for the entire project site. The average ETa for all land use classes is 1057 mm with two extremes in irrigated areas and non-irrigated areas. Figure 4.25 shows the ETa around some non-irrigated (fallow) cropland areas are very low, averaging about 700 mm for a year. These are drought affected areas where no crops were cultivated during the 2015-16 season. On the other side, the irrigated areas have annual ETa values of 1100 – 1400 mm, almost double that of dry cropland.

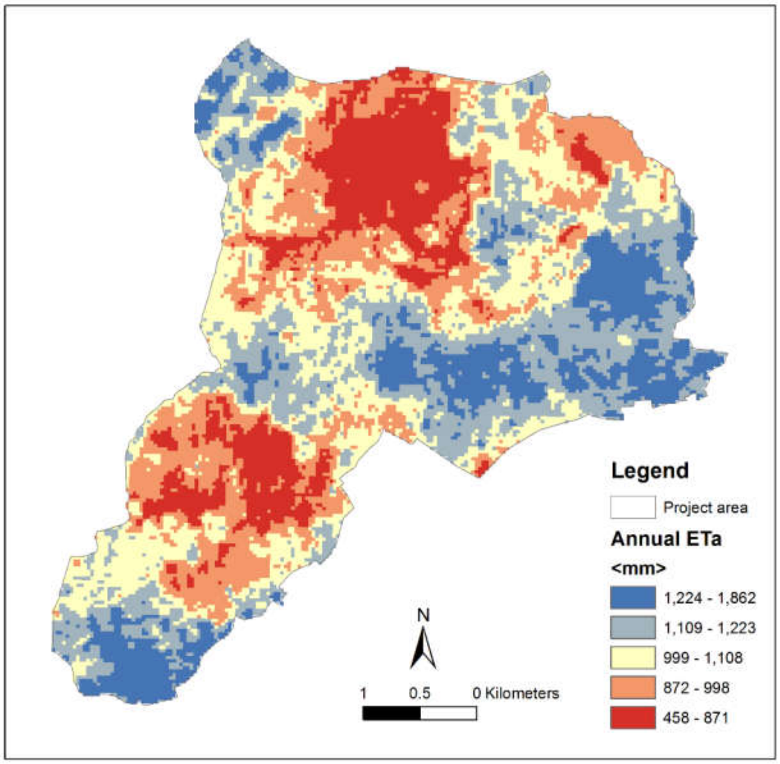

Figure 4.25 Annual ETa for the 2015-16 growing season at the Tra Tan project site

The average ETa of pepper crop for the season September 2015 – August 2016 is 1137 mm, with a CV of 0.1. The higher end of water consumption areas are found to be at three areas: the southern tip, the eastern side, and the northwest tip. The ETa values for pepper in these areas are as high as 1400 mm/yr. The low water consumption areas are more concentrated around one area, which is mostly covered with other rainfed crops.

Rice is mainly concentrated downstream to the reservoir areas. The average ETa of rice is 503 mm, higher than those found in other areas, but a very normal value for rice crop. While this was not been investigated in detail, variability in rainfall conditions (and other meteorological variables) are the major causing factor for ETa variability.

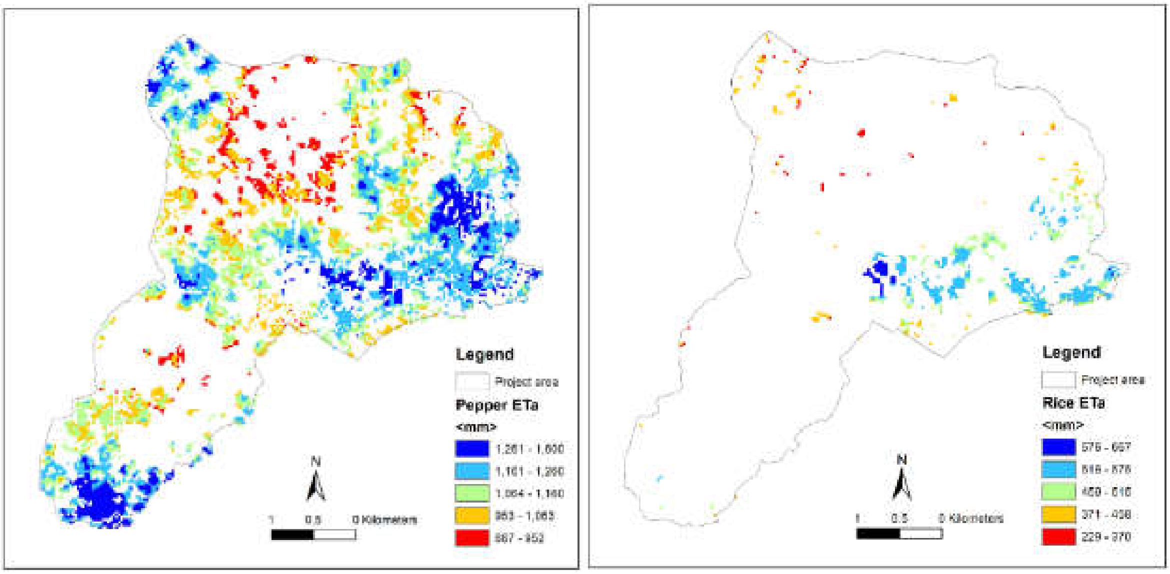

Figure 4.25 ETa of pepper and rice at the Tra Tan project site

4.4.3 Crop yields

The crop yields of pepper and rice are mapped separately for their own growing seasons (pepper from 1 September 2015 to 31 August 2016 and rice from 16 November 2015 to 31 March 2016). Average yield for pepper and rice are 2.4 ton/ha and 7.1 ton/ha respectively. The yield of pepper is low in areas where ETa is low and high where ETa is high. However, in areas close to paddy fields, where ETa of pepper is high, the yield of pepper is found to be low. The yield gap of pepper at Tra Tan is 0.89 ton/ha on average, or 37% of current yield values. The yield gap of rice is 0.4 ton/ha, the lowest compared with rice at all other sites.

The yield of rice has opposite trend to the ETa of rice. Overall when the ETa is more than 500 mm, the yield is lower than average. The worst case happens to the west side of the main paddy area, where ETa is more than 600 mm, while the yield is less than 5 ton/ha. Clearly excessive irrigation supply has led to decrease in rice yield, and further, the water productivity.

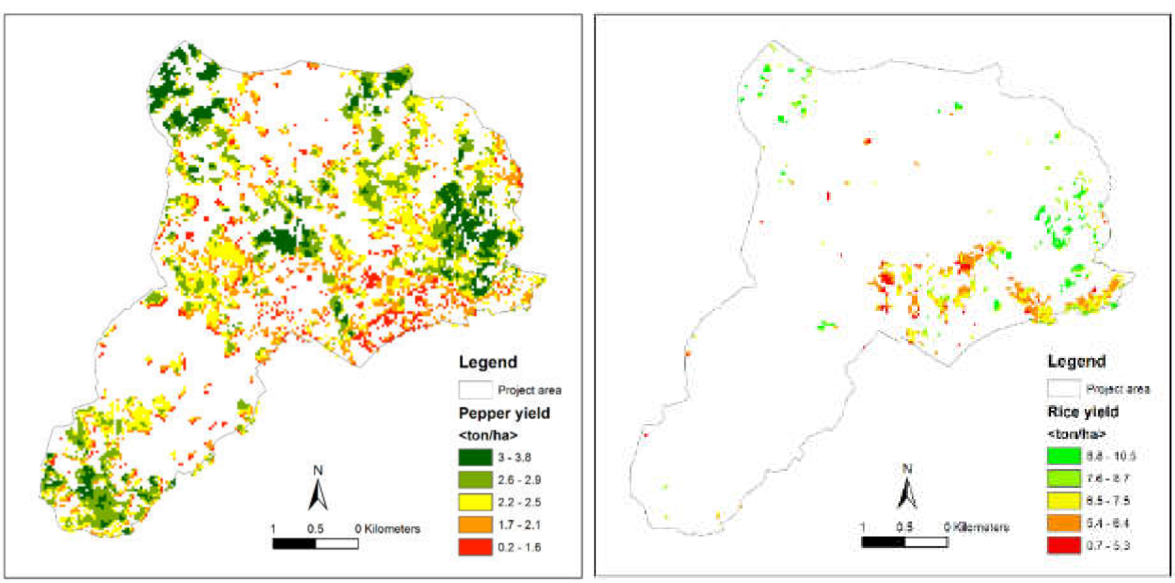

Figure 4.26 Yield of pepper and rice at the Tra Tan project site

4.4.4 Water productivity

The WP of pepper and rice are mapped separately. The average WP of pepper is 0.21 kg/m^3, or 29 thousand VND/m^3, with a CV of 0.18 and for rice it is 1.4 kg/m^3, or 8 thousand VND/m^3, with a CV of 0.26. The WP of pepper is very low. This is because pepper is a perennial crop growing throughout the year, the yield is however only around 2.4 ton/ha. Although the annual ETa is high (at 1137 mm), much of this is used to accumulate overall above ground biomass at a rate of 30 ton/ha/pear. The WP of rice is relatively high, which is mainly because of very high yield.

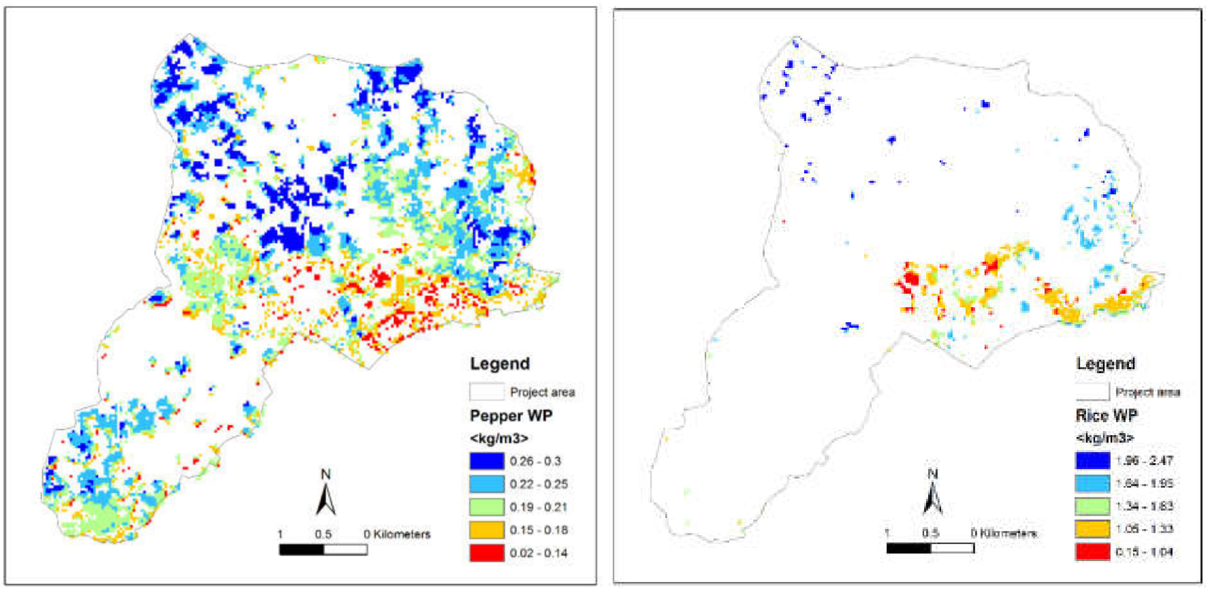

Figure 4.27 WP of pepper and rice

4.4.5 Summary for Tra Tan site

The main results of the WP assessment at the Tra Tan site are summarized in table 4.7 below.

Table 4.7 Summary information of pepper and rice at the Tra Tan project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Pepper	Sep - Aug	646	390	1137	213	0.41	7345	2.4	0.89	1550	0.21	29	0.18
Rice	Nov - Mar	81	73	503	44	0.43	407	7.1	0.4	575	1.44	8	0.26

The key recommendations generated from WP results and associated analysis for these sites are:

1. There are two dry islands inside the project site with well-established cropland but lack of water supply;
2. The yield and WP of pepper is low near the main paddy rice farming areas. The soil and excessive water maybe limiting factors and the suitability of pepper cultivation in these areas should be investigated;
3. The yield and WP of rice is high. However, too much water is drawn to the paddy rice areas, which is linked to yield reduction. Water regulating infrastructure and irrigation water management practices should be reviewed and improved;

4.5 Buon Yong

4.5.1 Irrigation systems and crop area

The Buon Yong project site is small but has a complex cropping patterns. Except from fallow land areas, a total of five crops were identified. They were coffee, pepper, rice, cocoa, and paddy. The area is dominated with coffee and pepper intercropping, which accounts for 317 ha out of 448 ha of total land. Separately, there are another 72 ha of coffee and 37 ha of pepper.

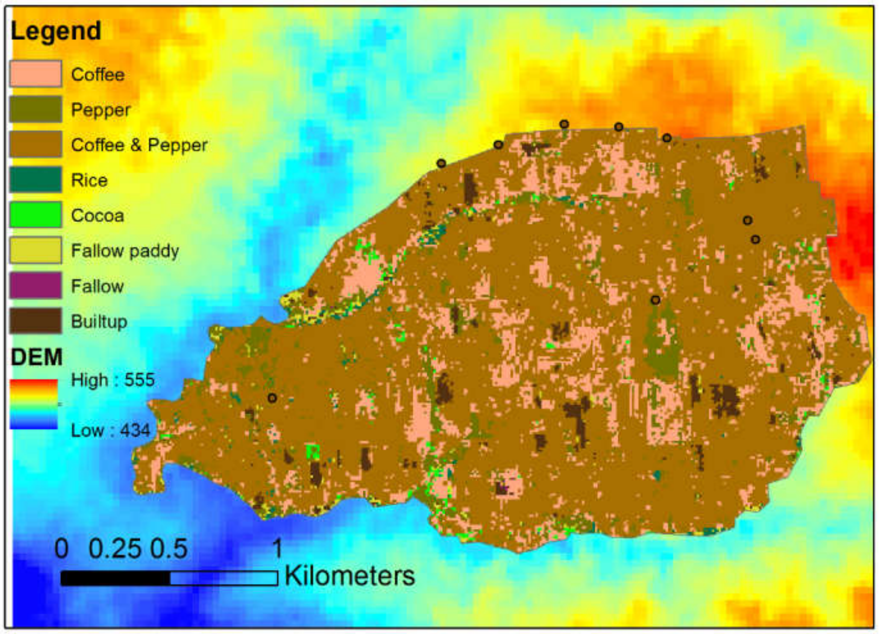

Figure 4.28 Land cover map of the Buon Yong project site

4.5.2 Water consumption and yield

The yield of the dominant coffee-pepper intercropping cannot be separated using satellite image. This section therefore presents only the ETa results, and the yield from the field survey. Figure 4.29 shows the average ETa of the intercropping is 1152 mm, with a CV of 0.14. The ETa of the intercropping is very similar to standalone coffee and pepper, perhaps because the ETa of the two are also very close. Similarly, the CV of the intercropping is not particularly high, although clear trend is observed for a high ETa belt in-between two low ETa zones.

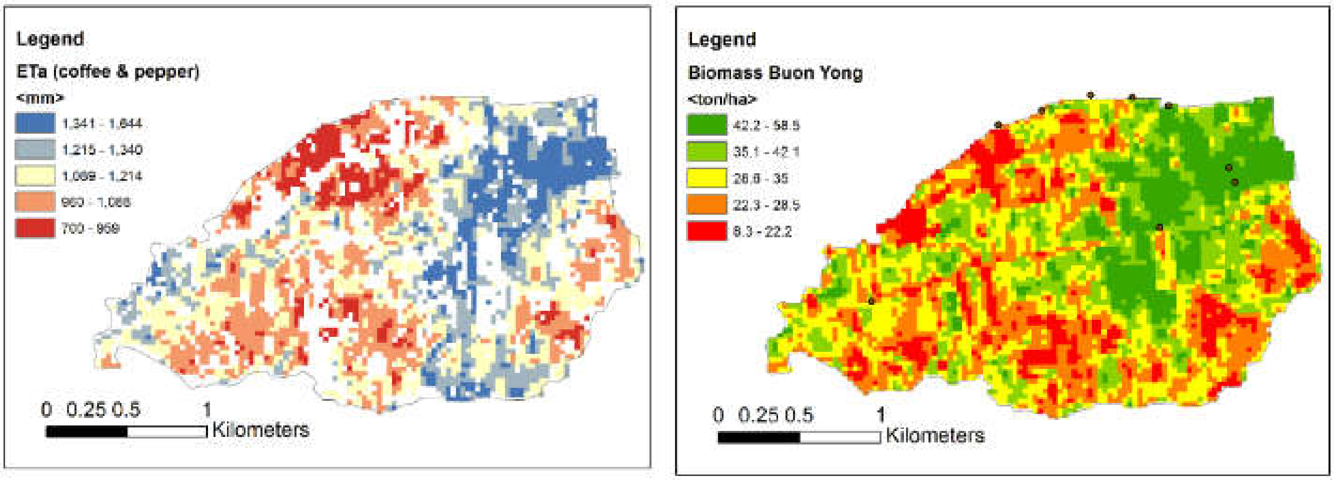

Figure 4.29 The ETa (left) and biomass (right0 map of the coffee-pepper intercropping at the Buon Yong project site for the period 1 February 2015 – 31 March 2016.

The crop yield of the intercropping cannot be mapped using satellite image but can be estimated from the field survey. There were in total six GT points with crop yields for the site. The average yield of coffee was 2.4 ton/ha, and for pepper it was 2 ton/ha. The yield of coffee is higher from these rather small sample size than other sites. The yield of pepper is however higher.

There is clearly a positive correlation between water consumption and crop biomass as shown on figure 4.30. Since biomass and crop yield has a linear relation. The crop yield also has a positive correlation with the ETa map. This represents the opportunity for irrigation rehabilitation to bring sufficient and reliable water supply to increase the productivity, hence water productivity, of the low yield areas.

4.5.3 Summary for the Buon Yong project site

The main results of the WP assessment at the Buon Yong site are summarized in table 4.8 below.

Table 4.8 Summary information of coffee-pepper inter-cropping at the Buon Yong project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]
Coffee-pepper intercropping	Feb - Jan	317	1535	1152			3657	-		-

The key recommendations generated from WP results and associated analysis for these sites are:

1. The coffee-pepper intercropping has a very similar water consumption patterns to coffee and pepper separately.
2. The low yield areas, more than half of the total area, experienced significant constraints on water consumption. Increasing water supply to these areas should therefore be a priority.

4.6 Thi Tran

4.6.1 Irrigation systems and crop area

The Thi Tran project site is dominated with coffee and pepper crops. There are 169 ha of coffee and 36 ha of pepper, which account for 91% of total areas of the site. No intercropping is observed here. Rather, the pepper clusters around one area to the east side of the project site.

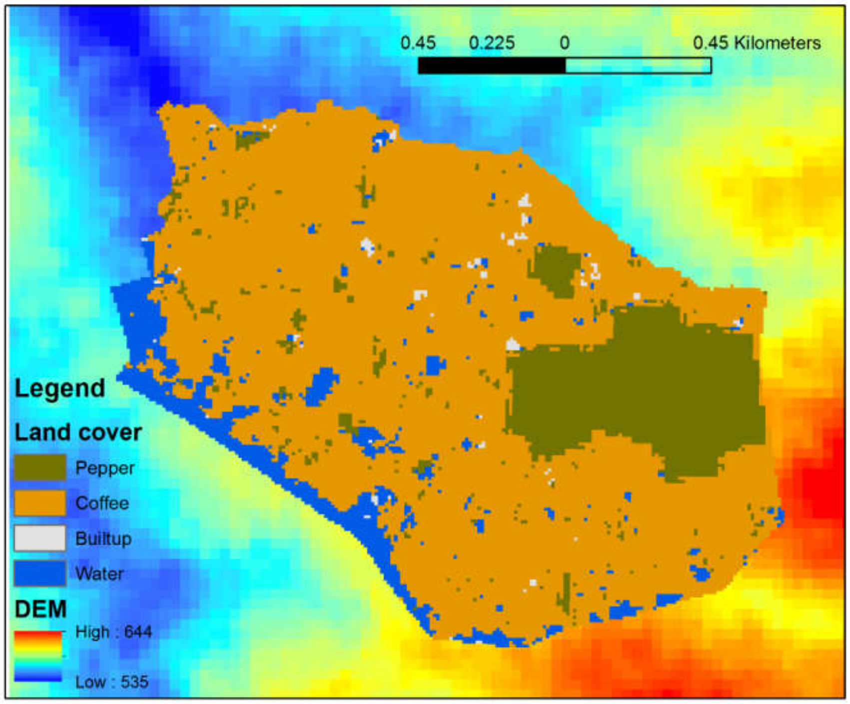

Figure 4.30 Land cover map of the Thi Tran project site

4.6.2 Water consumption

The water consumption of coffee and pepper at Thi Tran site is high. Average ETa is 1159 mm for coffee and 1459 mm for pepper. In fact there is a high ETa belt through the centre of the site covering part of coffee and most of pepper crop. This area is parallel to a river. The exact means of water withdrawals are unknown and should be further investigated to avoid duplication of investment.

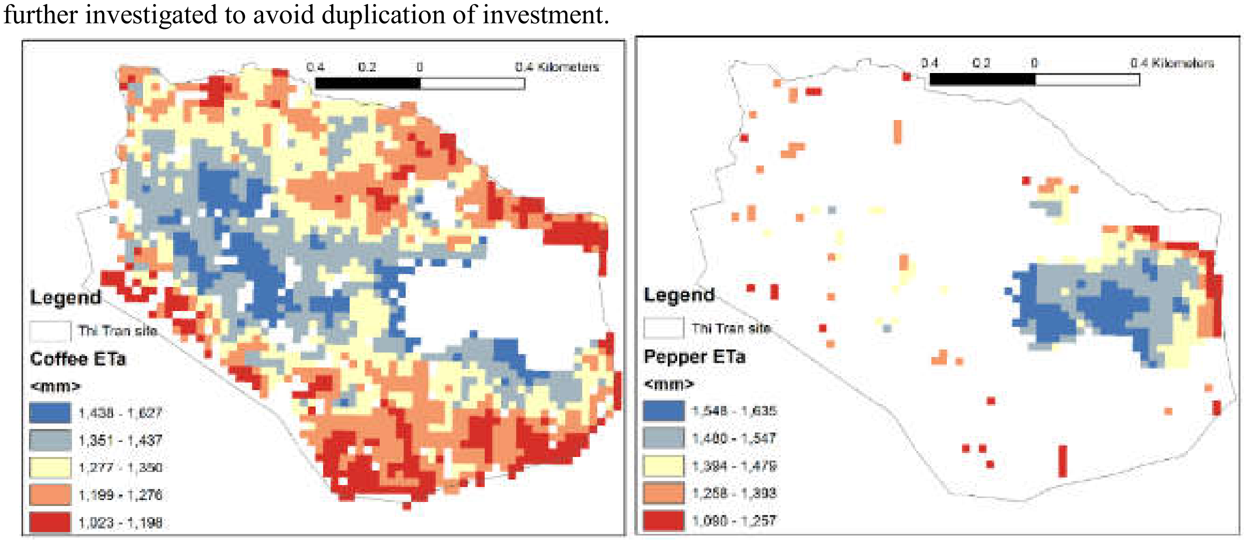

Figure 4.31 ETa of coffee and pepper crops at the Thi Tran site

4.6.3 Crop yields

The yield of coffee and pepper are shown in figure 4.32. The average yield of coffee and pepper are 1.1 ton/ha and 2.72 ton/ha respectively. The distribution of yield is somewhat different with that of ETa. High yields are loosely related with high ETa. But in some areas medium to low ETa also correspond to high yields. The yield gap for coffee and pepper at Thi Tran site were 0.4 and 0.39 ton/ha, or 36% and 14% of their current yields respectively.

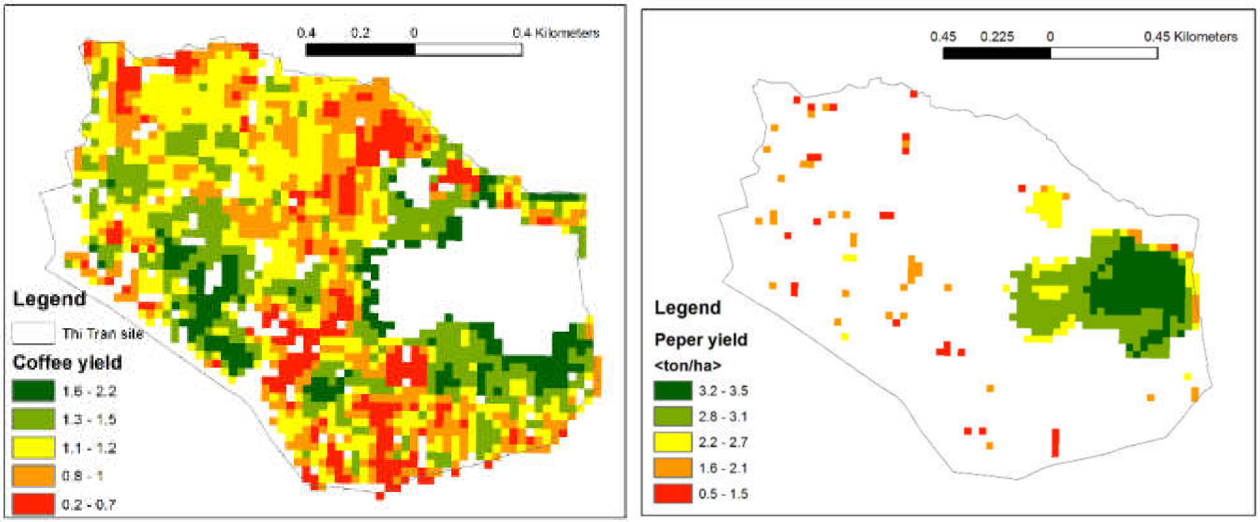

Figure 4.32 Yield maps of coffee and pepper at the Thi Tran site for the 2015-16 growth season

4.6.4 Water productivity

The WP of coffee and pepper were mapped. The average WP of coffee is 0.08 kg/m^3, 3 thousand VND/m^3, with a CV of 0.29. The WP at Thi Tran is the lowest compared with all other coffee sites. The main reason is explained with slightly low ETa but much lower average yield.

The WP of the main pepper area at the site has a gradual transition from medium to high. The average WP of pepper is 0.19 kg/m^3, or 27 thousand VND/m^3, with a CV of 0.21.

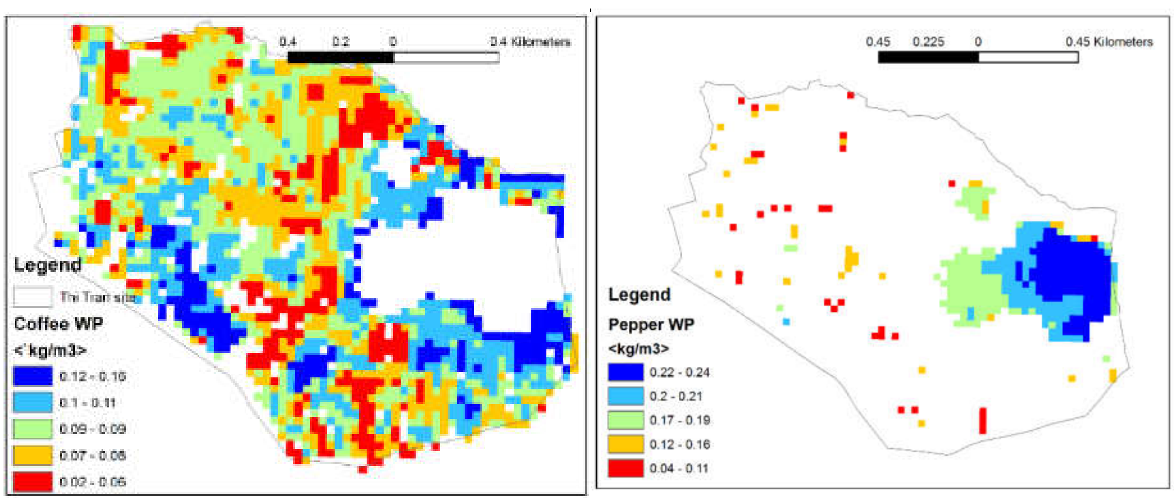

Figure 4.33 WP of coffee and pepper at the Thi Tran project site

4.6.5 Summary for Thi Tran site

The main results of the WP assessment at the Thi Tran site are summarized in table 4.9 below.

Table 4.9 Summary information of pepper and coffee at the Thi Tran project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Coffee	Feb - Jan	169	1535	1152	50	0.28	1947	1.11	0.4	188	0.08	3	0.29
Pepper	Feb - Jan	36	1535	1459	34	0.52	525	2.72	0.39	98	0.19	27	0.21

The key recommendations generated from WP results and associated analysis for these sites are:

1. A wet belt with high yield and high WP is found along the river. Further investigation is required to find out means of water extraction, and to bring into the design of the overall system;
2. Coffee yield at Thi Tran is very low compared with other sites. The increase in irrigation water supply with investment in infrastructure is necessary to improve yield of coffee.

4.7 Cujut

4.7.1 Irrigation systems and crop area

The Cujut project site has a narrow and long stretch. A reservoir (not included on map) is located to the west of the project site. Total area of the project site is 2422 ha. Most of the areas (89%) if cropland. Pepper is the dominant crop type with a total area of 1412 ha. Paddy fields cover a total area 726 ha, mostly close to the reservoir area. Paddy fields were cultivated in different seasons.

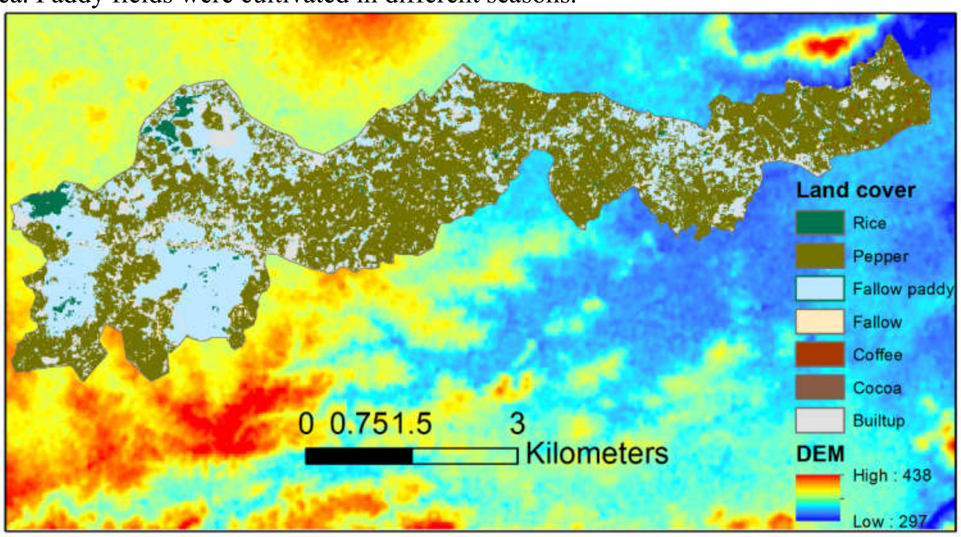

Figure 4.34 Crop type area of the Cujut project site

‘Table 4.10 Land cover and the areas of the Cujut project site

Land cover	Area [ha]
Cropland	2163
Coffee	7
Pepper	1412
Rice	53
Cocoa	1
Fallow paddy	673
Fallow	17

Builtup	259
Total area	**2422**

4.7.2 Water consumption

The shape of the project site indicates the challenges in supplying water evenly to upstream and downstream. The ETa map is shown in figure 4.25. Average ETa was 1246 mm, which is relatively high compared with other sites. Areas of low ETa are spread out but mostly found to the northern side.

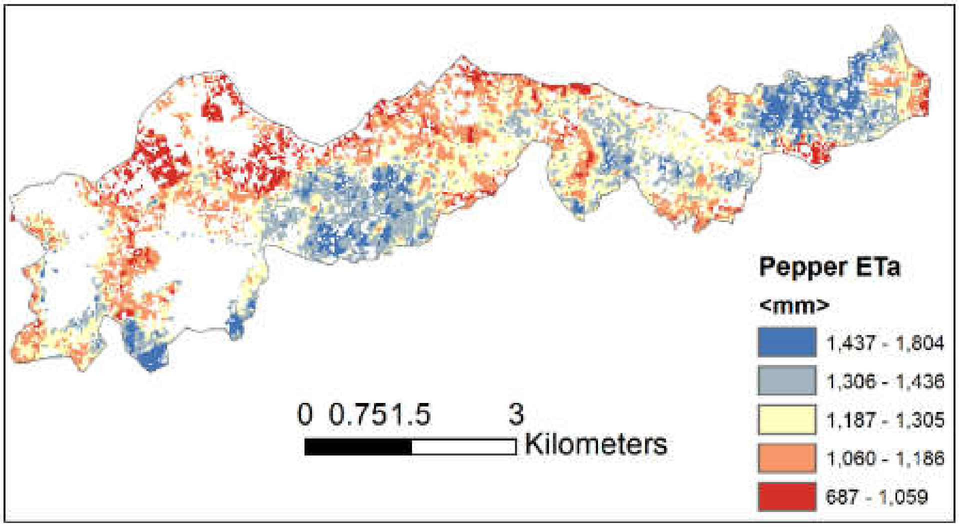

Figure 4.35 The ETa map of pepper crop at the Cujut site

4.7.3 Crop yield

The yield of pepper is shown in figure 4.36. The average yield was 1.64 ton/ha, relatively lower than other sites. Interestingly, most of the high yield areas (>4.5 ton/ha) are located at the further downstream area. The tail end also had high ETa, which explains the high yield. However, in another high ETa area, yield is on the lowest scale (around 2 ton/ha). The yield gap of pepper is 0.5 ton/ha, or 30% of current yield values.

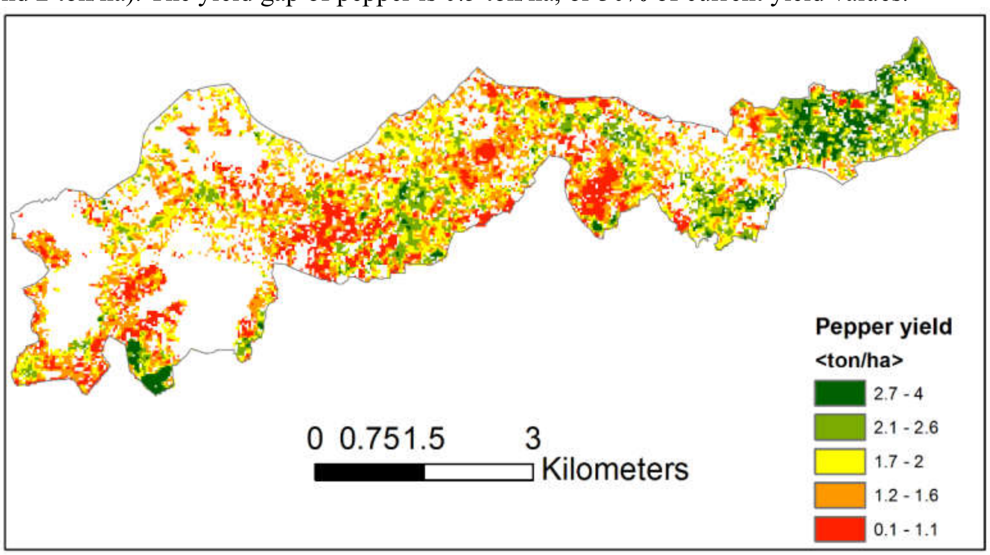

Figure 4.36 The yield of pepper at the Cujut project site

4.7.4 Water productivity

The water productivity of pepper is mapped and shown in figure 4.37. The average WP was only 0.13 kg/m^3, the lowest of all the sites with pepper crops. Although the WP in monetary is still high at 18 thousand VND/m^3. The relative low WP is partly explained with high ETa, and partly explained with low yield. The two negative factors together made the WP the lowest. The variability is also very high. The CV of pepper WP was 0.29, one of the highest of all crops at all sites. All these point to great potential in improvement.

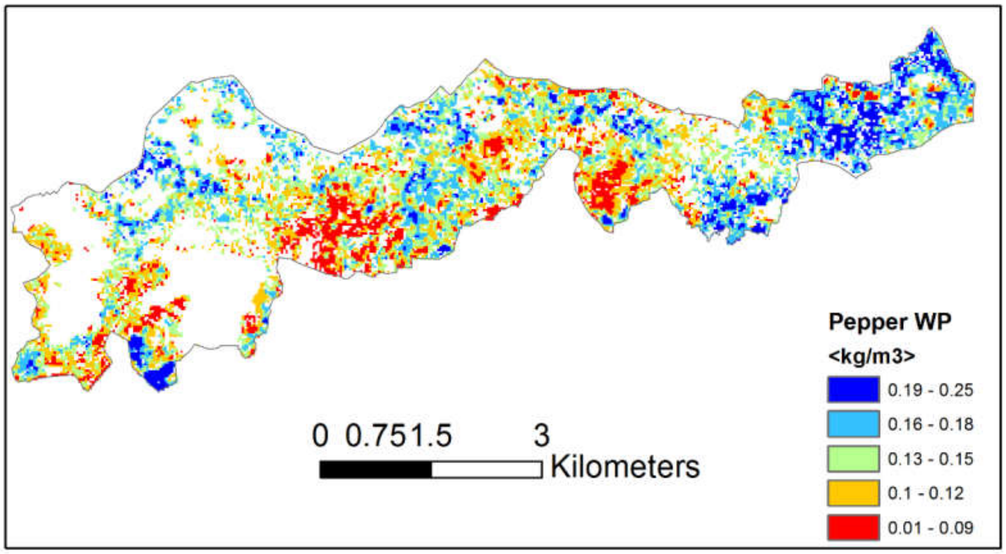

Figure 4.37 WP of pepper crop at the Cujut project site.

4.7.5 Summary for Cujut site

The main results of the WP assessment at the Cujut site are summarized in table 4.11 below.

Table 4.11 Summary information of pepper at the Cujut project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Pepper	Feb - Jan	1412	1535	1246	50	0.26	17594	1.64	0.5	2316	0.13	18	0.29

The key recommendations generated from WP results and associated analysis for these sites are:

1. The WP of the main crop pepper is very low at the Cujut site, which is explained with high ETa and low yields. Improving WP needs to target at both at the Cujut site;
2. The variability in WP is one of the greatest of all sites, indicating greater potential in improvement;
3. The downstream areas have good performance than other areas;
4. The northern side where ETa is low requires field based investigation to understand the reasons.

4.8 Dak Mil

4.8.1 Irrigation systems and crop area

The Dak Mil project site has a complex water supply system. It is served by a string of reservoirs from the west, and from the east, the Nam Xuan weir. The geographic area of the site was 5207 ha. There are 2685 ha of cropland, of which coffee covers 2084 ha. There are also significant built-up areas covering 1276 ha within the site. Coffee is mostly

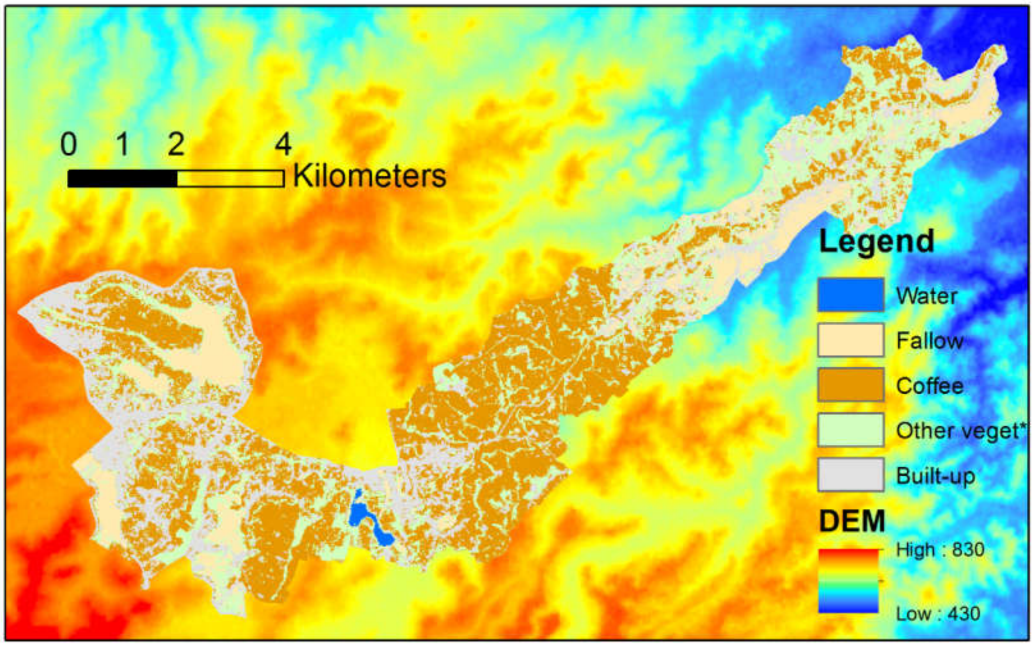

Figure 4.38 cropland area of the Dak Mil project site

Table 4.12 Land cover and the areas of the Dak Mil project site

Class	Area [ha]
Cropland	2685
Fallow	601
Coffee	2084
Other crops	1224
Water	23
Built-up	1276
Total area	**5207**

4.8.2 Water consumption

Water consumption of the main crop coffee is relatively low. Average ETa of coffee was 1017 mm. There is a clear trend that the ETa to the northern side of the river system, which runs roughly the middle of the long stretch, is much lower than those to the southern side.

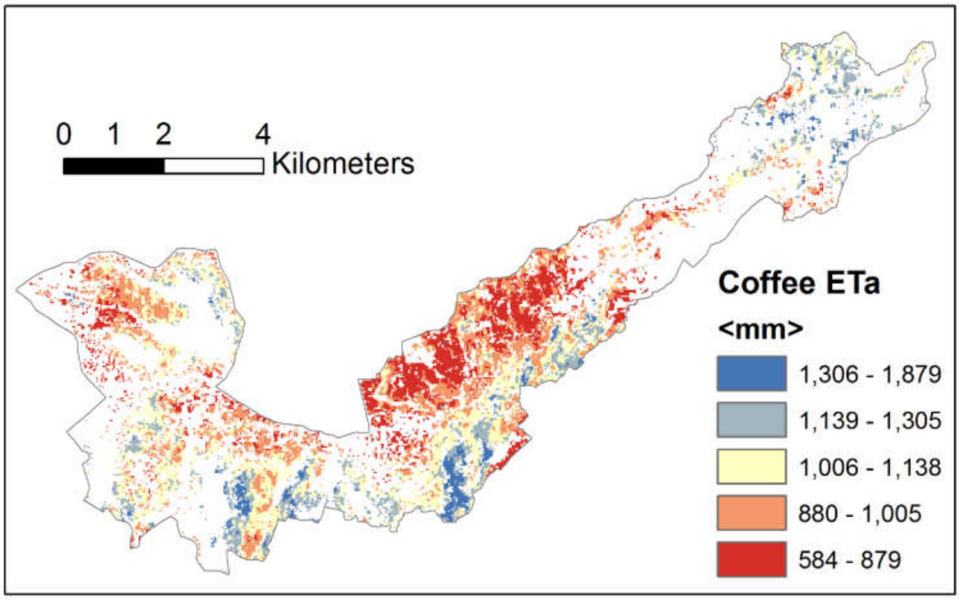

Figure 4.39 ETa of coffee crop at the Dak Mil project site

4.8.3 Crop yield

The yield of coffee is also low following that of ETa. Average yield was 1.2 ton/ha. Similar to ETa, the yields to the northern side of the river is much lower than that of the southern side. High yields are found around high ETa areas, implying significant role of water supply and consumption on final yields. The yield gap of coffee was 0.7 ton/ha, or 58% of current yield values. In line with other sites, coffee constantly shows high potential for yield improvement.

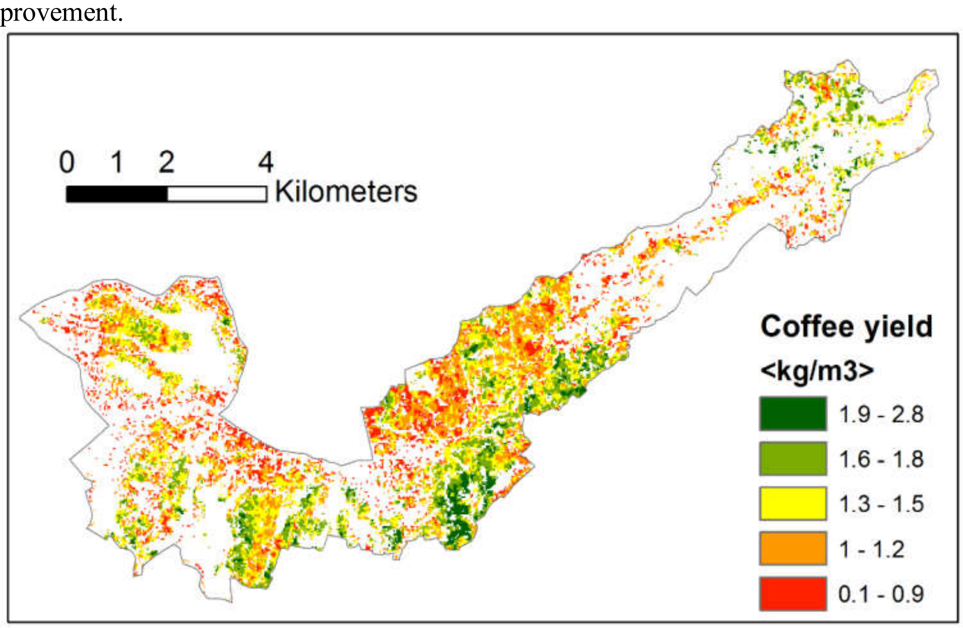

Figure 4.40 yield of coffee at the Dak Mil project site

4.8.1 Water productivity

The WP of coffee is low. Average WP was 0.12 kg/m^3, or 5 thousand VND/m^3, with a CV of 0.17. The areas where yield is high also have high WP. However some areas with low yields also have high WP. This is because the rate of decrease in water use was higher than the rate of yield reduction. These areas may not be very productive but they are still relatively water efficient.

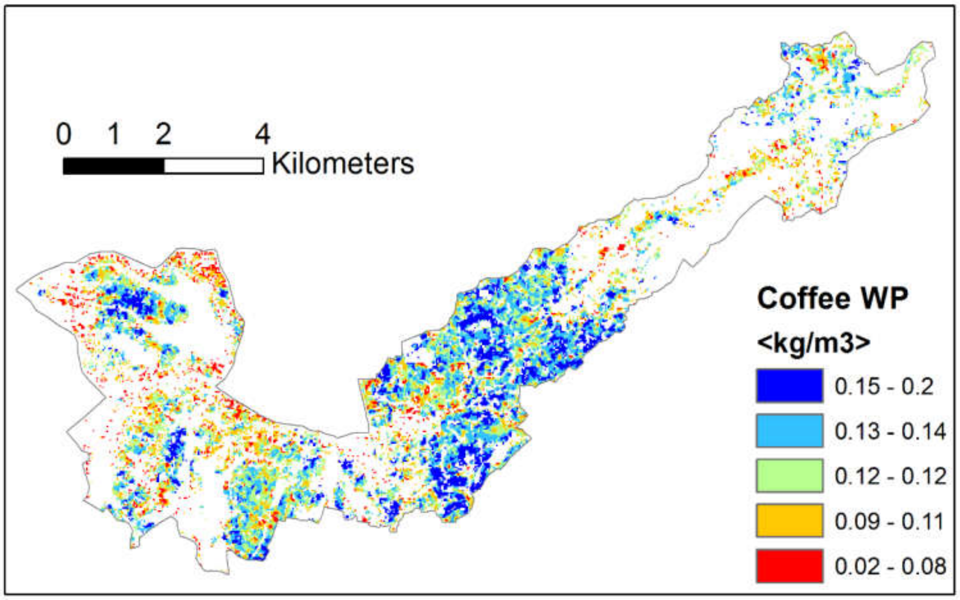

Figure 4.41 WP of coffee at the Dak Mil project site

4.8.2 Summary for Dak Mil site

The main results of the WP assessment at the Dak Mil site are summarized in table 4.13 below.

Table 4.13 Summary information of coffee at the Dak Mil project sites

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Coffee	Feb - Jan	2084	1603	1017	262	0.38	21194	1.23	0.7	2563	0.12	5	0.17

The key recommendations generated from WP results and associated analysis for these sites are:

1. Water use, yield, and WP to the northern side of the river are much lower than those of the southern side. It's probably due to lack of effective infrastructure;
2. The central part, including the low yield area, has high WP. The factors limiting WP is therefore likely non water related.

4.9 Doi, Krong Buk Ha, and Ea kuang (Dak Lak)

4.9.1 Irrigation systems and crop area

There are a total of six project sites clustered around cenral Dak Lak area. These sites, mostly small, have similar crops and growing conditions. Therefore they were grouped together to assess water use, yield and productivity.

The main crops of the sites are coffee and pepper. Coffee cover an area of 1316 ha while pepper covers 624 ha. In addition, there are about 231 ha of coffee and pepper intercropping. There are 395 ha of paddy rice, 68 of which is spring rice. Coffee is the dominant crop at the sites to the west, while pepper is dominant to the opposite side.

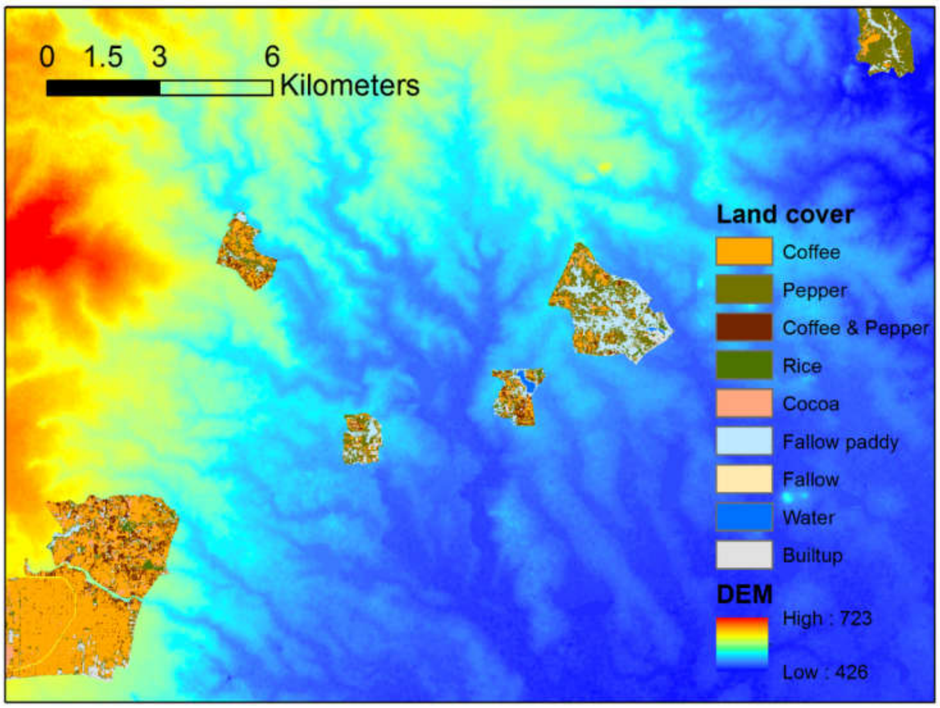

Figure 4.42 Cropland of the six Dak Lak project sites

Table 4.14 land cover and the areas of the six Dak Lak site

Class		Area [ha]
Cropland		
	Coffee	1316
	Pepper	624
	Coffee & Pepper	231
	Rice	68
	Cocoa	168
	Fallow paddy	327
	Fallow	9
Water		14
Built-up		152
Total area		2909

4.9.2 Water consumption

Water consumption of pepper at the Dak Lak is the lowest while that of coffee is the highest among all sites. Average ETa of pepper was 978 mm, significantly lower than those of other sites. Average ETa of coffee was 1190 mm, although not much higher than other sites. The average ETa of the intercrop was 1015 mm, about 12% lower than the same intercrop at the Buon Yong site.

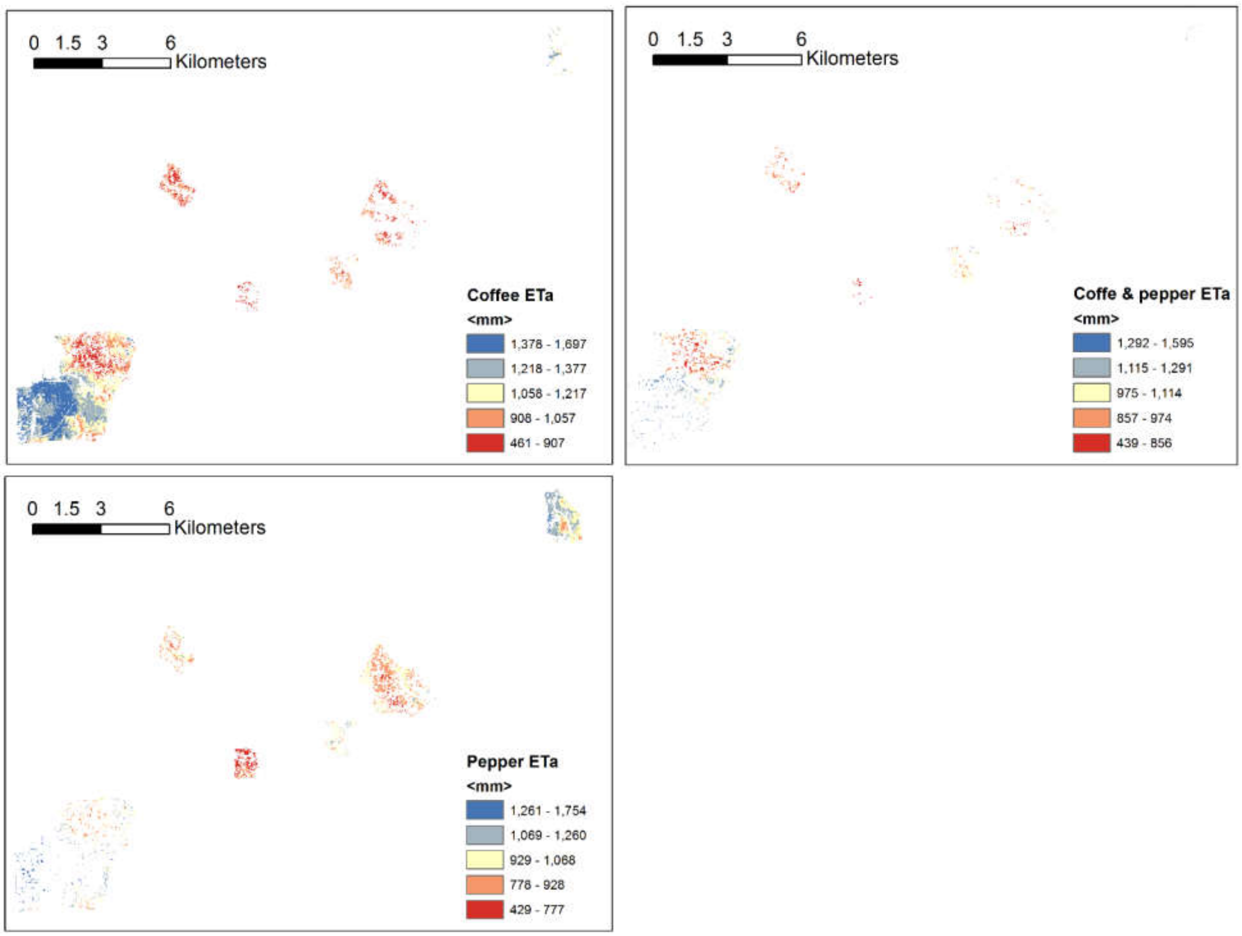

Figure 4.43 ETa maps of coffee, pepper and coffee-pepper intercropping at the six Dak Lak project sites

4.9.3 Crop yields

The yields are of pepper and coffee are shown in figure 4.44. Average yield of pepper was 1.6 ton/ha, the lowest of all sites as was with ETa. The average yield of coffee was 1.8 ton/ha, the highest of all sites. The high yield of coffee concentrate at a corner at the Ea Kuang site while other low density areas have lower yield. However, pepper yield at the Ea Kuang site is the lowest. The spatial variability of yield for coffee and pepper has two opposite trend as shown in figure 4.44.

Significant yield gaps exist at these sites. The yield gap of pepper is 0.94 ton/ha, or 59% of current yield values. The yield gap of coffee is 0.6 ton/ha, or 33% of current yield values.

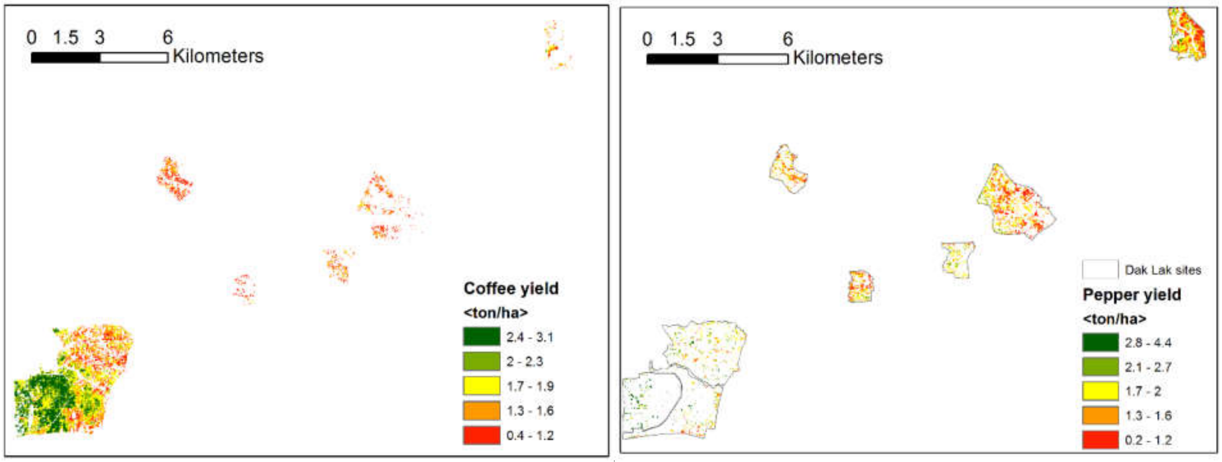

Figure 4.44 Yield of coffee and pepper at six project sites in Dak Lak

4.9.4 Water productivity

The WP of coffee and pepper were relatively low at the six sites. Average WP of coffee was 0.15 kg/m^3, or 6 thousand VND/m^3, with a CV of 0.13. The average WP was the highest for coffee among all sites, although not too much higher than other sites. It follows closely the trend of yield with the highest values found at the southwest corner of Ea Kuang site. The average WP of pepper was 0.16 kg/m^3, or 22 thousand VND/m^3, with a CV of 0.25. High CV indicates more differences in performance of different areas within the system, hence greater potential for improvement. The distribution of pepper WP is somewhat opposite to the distribution of yield. Low WP values are found for some high yield areas. Although these farmers are more productive than others, their water management is not as efficient.

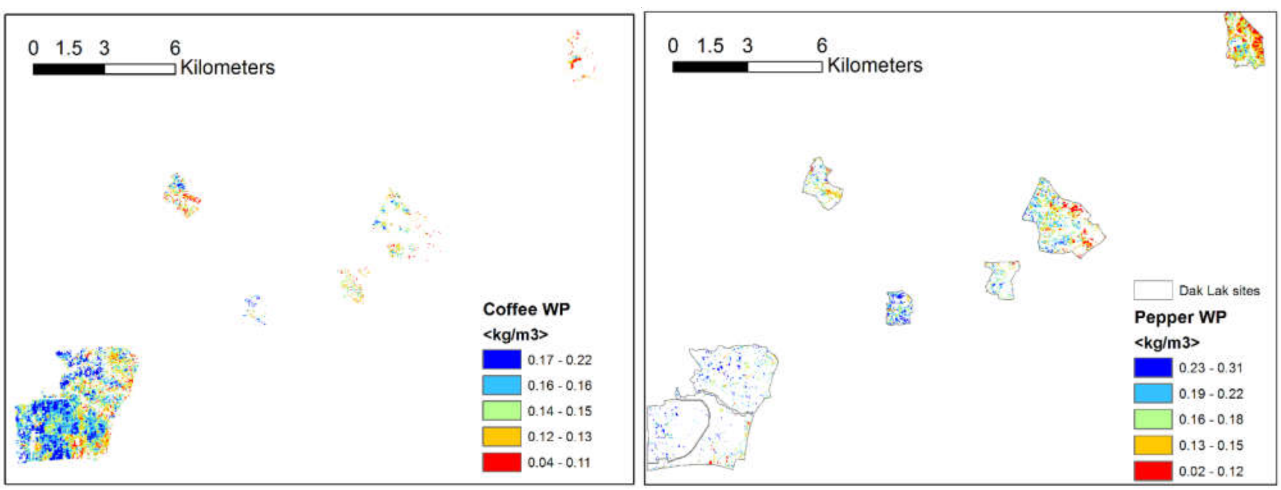

Figure 4.45 WP of coffee and pepper at the six project sites in Dak Lak

4.9.5 The impact of the existing large paddy rice irrigation system

The WEIDAP project aims to construct new pump stations and upgrade current irrigation water supply infrastructure in this area. That includes expansion of about 3,400 ha of irrigation and rehabilitation for another 9,670 ha within current command area. Paddy rice is a main crop in addition to coffee and pepper in this area. Figure 4.46 shows a total area of 7,324 ha for paddy rice downstream to a main reservoir, Krong Buk Ha, of the region. These paddy fields are major users of water resources and the effects with the newly planned project sites are unknown.

The distribution of crops are different in relation to the main reservoir Krong Buk Ha. The paddy rice is heavily concentrated along the canal command areas of the reservoir. Other major crops such as coffee and pepper are however mostly outside the command area.

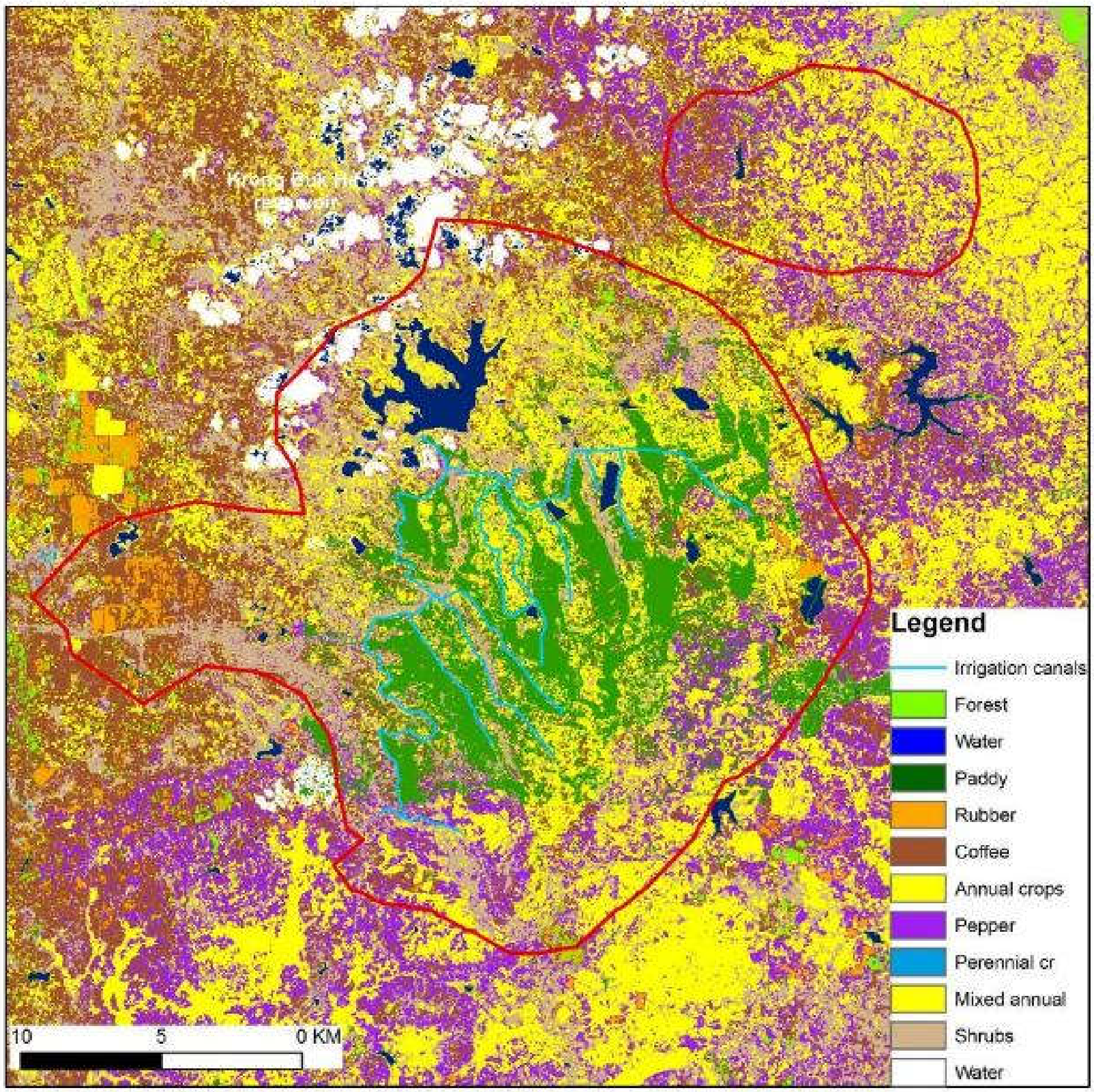

Figure 4.46 The crop type map of the Krong Buk Ha reservoir area

There was no vegetation detected for the period 16 Nov 2015 to 31 March 2016, contradicting a field based cropping calendar. Although field preparation and ponding water was observed towards March. It can only be assumed the rice in this system/region has different growing calendar, and it is unlikely that rice is cultivated in all three seasons (spring, summer, autumn), such as the case in coastal areas.

In spite of missing the rice growing season, significant ETa is observed from paddy fields. The average seasonal ETa is 510 mm with a CV of 8.8% (figure 4.47). This in fact is higher than rice ETa in coastal areas for the same period. The exact causes are unknown, but there seem to be substantial soil moisture residue, accompanied with prolonged water ponding period. As also shown on the right of figure 5.16, most pixels have an evaporation to ETa ratio closing to 1, which means non-existent or very low level of vegetation.

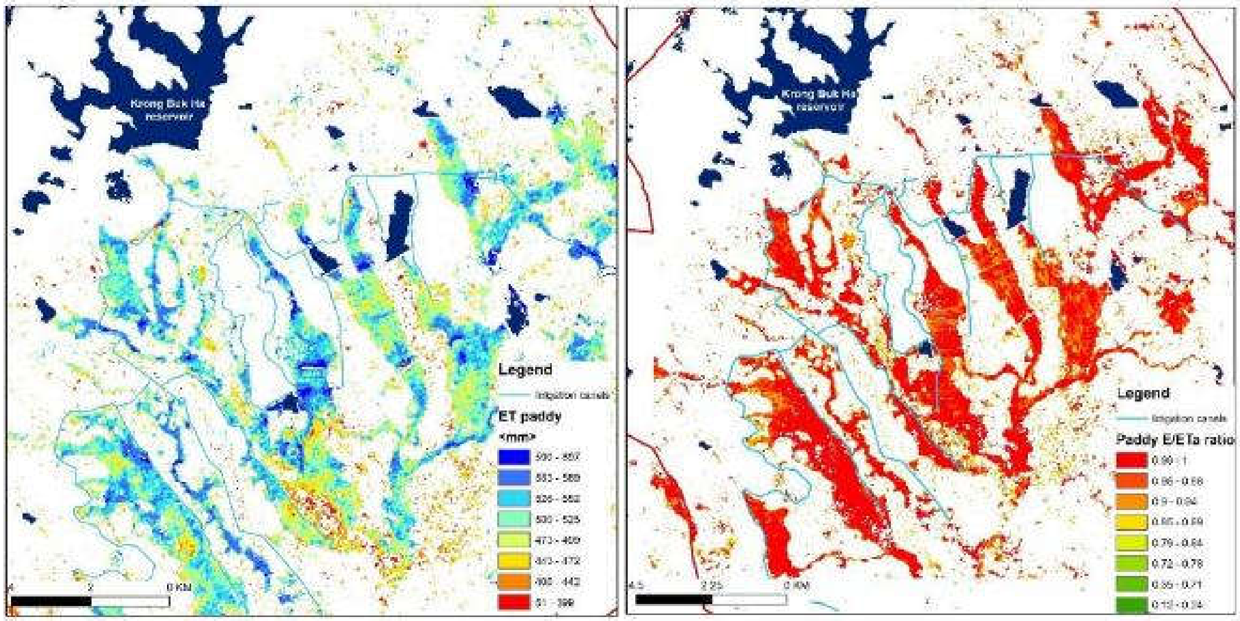

Figure 4.47. Seasonal ETa (left) and the ratio of evaporation (E) to ETa (right) of paddy fields for 16 Nov 2015 to 31 Mar 2016. No rice is growing in this period. The right figure shows the ETa is mostly through evaporation

The excess ET, in fact mostly evaporation as shown above, for no rice growing season may also be attributed to lack of drainage infrastructure and poor management practices. The paddy fields with most ETa are typically found along the river/drainage with puddles of ponding water. The existence of this water and saturated top soils causes water losses. If it continues to happen throughout rice growing season, may also negatively impact on plant growth and yield formulation.

4.9.6 Summary for Dak Lak site

The main results of the WP assessment at the Dak Lak sites are summarized in table 4.15 below.

Table 4.15 Summary information of coffee at the six project sites in Dak Lak

Crop	Season	Area	Rainfall	ETa	ET deficit	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP		
		[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Pepper	Feb - Jan	624	1535	978	181	0.31	6103	1.59	0.94	992	0.16	22	0.25
Coffee	Feb - Jan	1316	1535	1190	214	0.53	15660	1.76	0.6	2316	0.15	6	0.13
Coffee-pepper intercropping	Feb - Jan	231	1535	1015			2345	-	-	-	-	-	

The key recommendations generated from WP results and associated analysis for these sites are:

1. The sites have the lowest pepper ETa but the highest coffee ETa among all sites. As a result the coffee WP was also low, representing the greatest potential in water saving through coffee crop;
2. High pepper yields are associated with low pepper WP. Although average pepper ETa was low, significant scope exist in water saving at low WP areas;
3. The extensive paddy areas consume large amount of water, even at off-growing season. Attention should be given to these paddy areas to ensure sustainable expansion to the new sites without conflicts in water demand.

5. Summary and the way forward

5.1 Summary of WP assessment

The concept of WP helps irrigation mangers, agricultural extension workers, and policy makers to better understand whether water resources in agriculture are used efficiently. This pilot study introduce WP concept and demonstrates its applications to a wide range of Vietnamese stakeholders as well as ADB project officers. WP is a simple and attractive indicator to assess whether intended processes go well. More irrigation related performance indicators are needed to make a first diagnosis on how irrigation systems function. In this study, we introduced therefore also crop yield, yield gap, ET deficit and beneficial ET fraction (T/ET).

A novel yet practical remote sensing approach was applied to 11 project sites in Vietnam central highlands and costal area in a relatively short time span. The computations of crop production and crop evapotranspiration requires an energy balance model that converts available radiation from sun and earth into water and carbon fluxes. The updated Surface Energy Balance Algorithm for Land (SEBAL) model with automated calibration process was used for this purpose. This so called pySEBAL model is programmed in python language. pySEBAL was applied freely available high resolution data from the Landsat and Sentinel satellites. Hence, there are no costs involved to repeat and expand these type of analysis. It is a matter of available manpower and their skillsets.

The conversion from accumulated biomass production to fresh crop yield requires a map with the major crop types because every crop has its own harvest index. Image analysis complemented by smart phone based field surveys show that the region has a very diverse and high value cropping system. Paddy rice is dominant in only one irrigation system in the Dinh River delta area. All the other systems are dominated with high value crops including coffee, mango, pepper, and dragon fruit. Similar conditions can also be observed across the region. This presents an opportunity and need for irrigation development. Farmers are responding to market needs and cultivate more high value crops. Vietnam is praised for these frontier developments in Southeast Asia. These changes requires irrigation management and other basic infrastructure to catch up, along with agricultural extension services and related knowledge building. Remote sensing techniques are sufficiently mature for operational imbedding in water management improvement studies, such as WEIDAP.

The pySEBAL analysis reveal that crop water consumption and yield show high variability in the region. The seasonal average ETa rate across all sites for paddy rice ranges from 385 mm to 503 mm. These values agree well with other humid countries, and shows that a single rice season has a mild level of water consumption. Too often, rice is considered as a major water user because the amount of applied water is considered in the discussions, rather than the consumptive use. Consumed water is a better basis for evaluating water use because all non-consumed water originating from applied water will be reused downstream, sometimes by other water use sectors. Annual ETa for coffee crop, an important economic crop to Vietnam, varies from 1017 mm to 1190 mm in different irrigation systems. The average ETa of pepper, mango, and dragon fruit is 1200 mm, 1118 mm and 1059 mm respectively. These perennial tree crops have relatively high water consumption across an annual cycle. Moving from rice to perennial crops would typically increase the water demands and consumption and exacerbate water shortages, rather than controlling them. Because the economic and social benefits will increase steeply, the Government of Vietnam will continue to stimulate these changes. But at the same time, water management should become more stringent. A proper planning process requires more data on crop statistics, water consumption and the like, and this report describes methodologies on how to achieve that.

Table 5.1 summary table of crop area, ETa/water consumption, yield and WP at all Vietnam project site

Site	Crop	Season*	Area	Rainfall	ETa	ET def	T/ETa	Total Water consumption	Yield	Yield gap	Production	WP**		
			[ha]	[mm]	[mm]	[mm]	[-]	[1000 m^3]	[ton/ha]	[ton/ha]	[ton]	[kg/m^3]	000 VND/m^3	CV
Khanh Hoa	Mango	May - Apr	8,061	1,411	1,118	92	0.27	90,122	27.9	8.8	#########	2.52	110	0.20
	Rice	Dec - Mar	740	284	385	20	0.48	2,849	5.9	0.68	4,366	1.53	8	0.15
Nhon Hai	Apple	Oct - Sep	14	594	555	145	0.19	78	30.2	8.15	423	5.33	64	0.18
	Grape	Oct - Sep	21	594	602	145	0.2	126	22.2	11.9	466	2.29	32	0.17
Ninh Thuan Del	Rice	Nov - Mar	9,892	197	399	18	0.47	39,469	5.4	0.72	53,417	1.36	7	0.27
Du Du	Dragon fruit	Oct - Sep	1,824	245	1,059	239	0.31	19,316	24.1	13.4	43,958	2.29	28	0.20
Tra Tan	Pepper	Sep - Aug	646	390	1,137	213	0.41	7,345	2.4	1.59	1,550	0.21	29	0.19
	Rice	Nov - Mar	81	73	503	44	0.43	407	7.1	0.4	575	1.44	8	0.26
Buon Yong	Coffee-pepper	Feb - Jan	317	1,535	1,152			3,657	-		-	-		-
Thi tran	Coffee	Feb - Jan	169	1,535	1,152	50	0.28	1,947	1.11	0.4	188	0.08	3	0.29
	Pepper	Feb - Jan	36	1,535	1,459	34	0.52	525	2.72	0.39	98	0.19	27	0.21
Cujut	Pepper	Feb - Jan	1,412	1,535	1,246	50	0.26	17,594	1.64	0.5	2,316	0.13	18	0.29
Dak Mil	Coffee	Feb - Jan	2,084	1,603	1,017	262	0.38	21,194	1.23	0.7	2,563	0.12	5	0.17
Dak Lak	Pepper	Feb - Jan	624	1,535	978	181	0.31	6,103	1.59	0.94	992	0.16	22	0.25
all other sites	Coffee	Feb - Jan	1,316	1,535	1,190	214	0.53	15,660	1.76	0.6	2,316	0.15	6	0.13
	Coffee-pepper	Feb - Jan	231	1,535	1,015			2,345	-		-	-	-	-

* All crop seasons are in year 2015-16

** The WP in monetary term uses farmgate price in 2017 constant Viet Nam Dong (VND: 1 USD = 22,600 VND).

Significant variations are also observed within individual irrigation systems, among different canal command areas, and even within the same canal command area, which present water managers, irrigation rehabilitation planners and designers more insights in the problems and solutions they should focus on. The coefficient of variation (standard deviation/mean value) with certain systems is 0.15 to 0.30. The CV of crop yield is generally higher (up to CV= 0.4) and CV of ETa is lower. But surely also local ETa variability is sometimes the major issue of concern. The apple and grape areas in Ninh Thuan, for example, have high CV at 34% and 33% respectively, representing great uncertainty in water supply for these crops. Hence, poor and excellent water management practices occur simultaneously, and can sometimes be adjacent plots. A simple bulk computation of irrigation water requirements and crop water consumption with fixed management practices needs revision.

The crop WP brings together the effects of variability in both ETa and yield. Pixel to pixel variability has been quantified to demonstrate the opportunity of spatial data. Paddy rice is classically considered as a water intense crop, but perennial crops have ETa rates exceeding that of rice. Coffee has an annual ETa of 1150 to 1190 mm/yr and peppers reach up to 1250 to 1460 mm/yr (Table 5.1). The possibilities to impose some level of ETdefict and higher T/ETa fractions will create realistic opportunities to save water and make consumed water more efficient.

For the first time, the ETa and WP of coffee, pepper, mango, and dragon fruit is reported both at farm and system level using actual crop water consumption. The Coffee WP varies from 0.3 to 0.6 kg/m^3 in the four systems which have coffee production. The average WP of mango and dragon fruit is 0.3 kg/m^3 and 12.87 kg/m^3 respectively. The average WP of pepper is from 0.11 to 0.22 kg/m^3, the lowest of all crops included in this study.

The spatially distributed and geographically rectified data shows a wide variety of irrigation conditions. Mixed performance is observed for different crops with paddy rice having relatively high CWP at 1.37 kg/m^3. Fruits have higher CWP ranging from 2.29-5.33 kg/m^3, while coffee and pepper generally have low CWP at 0.13 and 0.16 kg/m^3 respectively. However, when converted to monetary terms expressed in 2017 constant Vietnamese Dong (VND), The CWP of mango stands out at 110 thousand VND/m^3, 15 times that of rice and 12 times that of coffee. Relatively high average coefficient of variation (standard deviation / mean value) on water productivity within a given crop ranges from 0.13 to 0.29. This implies that for most crops considerable savings in water consumption can be achieved (approximately 10 to 20%), together with increased productions (approximately 20 to 30 %).

A full economic analysis was no part of this study, but a conversion to WP in monetary terms were included. The WP expressed in 2017 constant Vietnam Dong (VND) exhibited even higher variability among different crops. The mango has WP in monetary term of 110 thousand VND/m^3, followed distantly by apple, at 64 thousand VND/m^3. Rice and coffee have the lowest WP with only 7 and 5 thousand VND/m^3 respectively. It's not surprising to see rice with low WP in monetary term. However, coffee is a main cash crop of the region. It's surprising to see that coffee WP is the lowest of all crops including paddy rice.

Table 5.2 Aggregated crop area, water consumption, production, and water productivity for seven crops. Sorted according to the crops with the highest WP to the lowest in monetary terms.

Crop	**Season**	**Area**	**Average ETa**	**Total Water consumption**	**Average yield**	**Production**	**Water productivity**	
		[ha]	**[mm]**	**[1000 m^3]**	**[ton/ha]**	**[ton]**	**[kg/m^3]**	**000 VND/m^3**
Mango	May - Apr	8,061	1,118	90,122	27.9	224,902	2.52	110
Apple	Oct - Sep	14	555	78	30.2	423	5.33	64
Grape	Oct - Sep	21	602	126	22.2	466	2.29	32
Dragon fruit	Oct - Sep	1,824	1,059	19,316	24.1	43,958	2.29	28
Pepper	Sep - Aug	2,718	1,161	31,567	1.8	4,956	0.16	22
Rice	Dec - Mar	10,713	399	42,725	5.4	58,358	1.37	7
Coffee	Nov - Mar	3,569	1,087	38,801	1.4	5,067	0.13	5

5.2 Assessing the potential and determining the priorities

A combined analysis of ET, yield and WP provides a comprehensive picture of the results and outputs of irrigation management. It is a vehicle for diagnosing management gaps and identifies directly the local potential for gaining more benefits (food, income, nutrition) from water resources. The practical interpretation of image analysis requires extensive field knowledge, and understanding of local water practices that cannot be seen on an image. The specific intervention analysis for solving problems in irrigation management can be achieved by combining the images produced with field visits to discuss the observations with local stakeholders, Such type of activity is beyond the scope of current assessment. However, an analysis into the Phan Rang delta irrigation system is illustrated to demonstrate how Vietnamese officials best can embrace these technologies.

Yield – often referred to as land productivity – and water productivity should both score high in an ideal situation. Figure 5.1 shows yield and WP of rice for every 30 m x 30 m field. The two dimensional plot shows most of the pixels fall in a shape that is defined by a straight line at the bottom, ad a curve-linear line on top. The bottom line is defined by the potential ET that is controlled by atmospheric conditions. The upper line is defined by local water management practices, including on-farm. This graph demonstrates vertical with farmers who produces the same yield but with low and high WP. This shows that a lower ET is not necessarily bad. In the verticals, farmers should move up from the bottom to the top. The horizontal show that a large group of famers are scoring high in WP, but their yield is low, and hence their income and perhaps even own staples. A yield of 2 ton/ha is very low, and they should target more on 5 to 8 ton/ha. In the case of the latter, assistance from agronomic extension officers is needed. Not all farms have the same potential due to soil, water, and other limitations. It is therefore often not possible to push all the farms towards the top-right corner of figure 5.1.

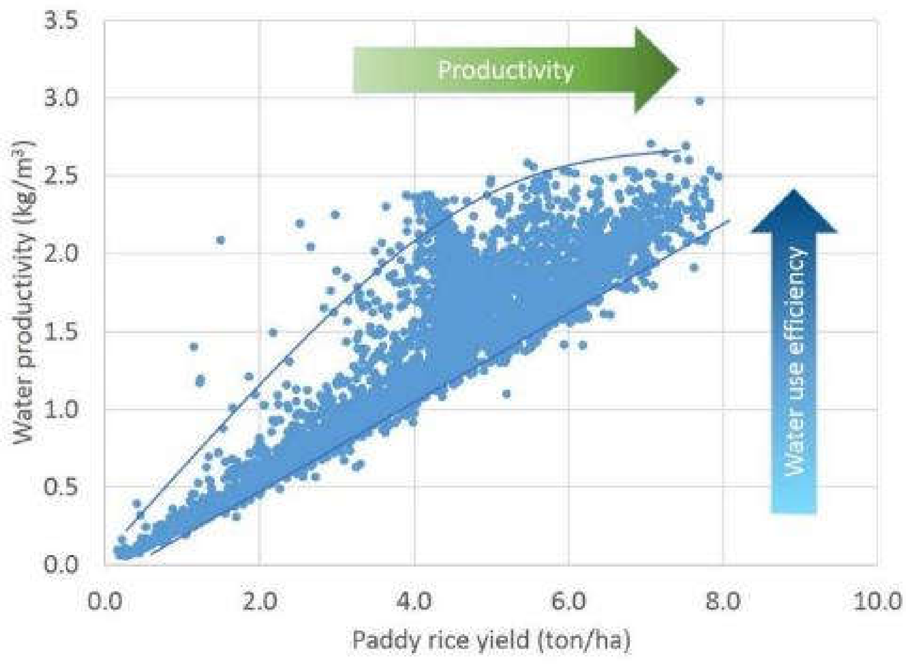

Figure 5.1 water saving and WP potential analysis by identifying water use efficient farmers and productive farmers. The paddy farmers in … were selected to demonstrate variability

Planning agencies need to have strategic data on total production, commodity export and staple food production in relation to water availability. Remote sensing can provided the statistical data required. Figure 5.2 illustrates the frequency distribution of paddy fields. In an ideal situation, the target could be set to the maximum value of 2.5 kg/m3. In this case the areas to be improved are marked in red (bottom right).

Full potential is not straightforward to achieve, and perhaps only on the longer run. The second best option could be to improve only the fields with a below average WP value. A lower target is therefore much more practical, especially for the shorter term planning. The areas requiring interventions to meet the average value is therefore much smaller (Figure 6.2 bottom left). The Government of Vietnam is advised to develop a phased approach to start working on the poor performing fields first, and design a 5 to 10 year plan, sothat by the passage of time, gradually all fields will produce more food from less water. This requires a special remote sensing unit to be fully trained up.

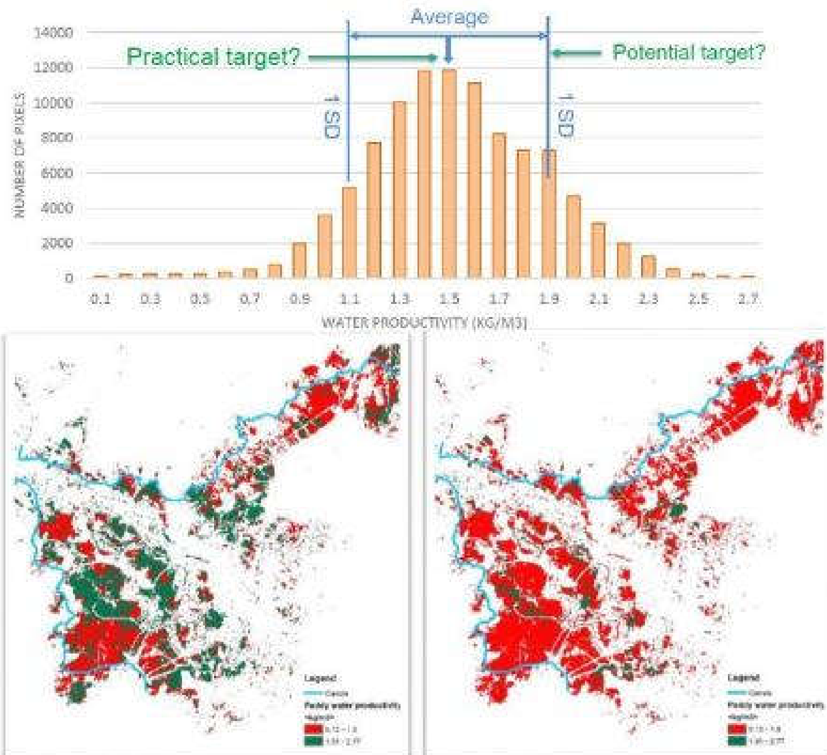

Figure 5.2 Determining the yield and water saving potential based on target values of WP. One possible target is to close the water productivity gap by aiming at the average WP + one standard deviation. A more realistic target is to aim at improving the lower than average farmers to the average value of the region.

5.3 Conclusions and the way forward

The demonstration study targeted eight sub-project sites of the Water Efficiency Improvement Project in Drought Affected Areas (WEIDAP) in five provinces: Dak Lak, Khanh Hoa, Ninh Thuan, Binh Thuan, and Dak Nong. Initially, only rice was targeted for the analysis which was then expanded for the inclusion of coffee, mango, pepper, and dragon fruit, in recognition the aim of WEIDAP project to promote high value crops. A ground truth campaign and cropland classification was carried out to map specific crops and their growing areas. Subsequently, crop water consumption yield and WP were assessed, which forms a powerful base for advanced analysis for improved irrigation investment and management.

This report presents the demonstration part of a capacity building project on integrating WP into irrigation development and management. The project introduces and demonstrates the concept of WP and using state-of-art remote sensing technology to assess WP in agricultural areas where ADB lending is helping the government and farmers of Vietnam to develop and rehabilitate irrigation projects. While rehabilitation and modernization are essential to keep pace with the rapid changes of crop selection, the effectiveness of investments depends on the major constraint to improve yield and WP. It is recommended to target in first instance on both improvements in land and water productivity.

A genuine shortage of water due to lack of rainfall and low storage in reservoirs or outdated pumping stations can be the primary reason for low productivity. Such situation will apply to an entire irrigation system, so all the pixels should then show lack of water. Most irrigation systems though, exhibit local variabilities in both yield and ET, and this typically reflects uneven distribution of canal water. Lack of maintenance of canals and hydraulic structures could be a contributing factor, but also the manual distribution of irrigation water by gatekeepers. It was detected that certain canal command areas are under-irrigated while others are over-irrigated. Without an analysis of the major causing factors of low WP, it will be difficult to achieve improvements. Hence remote sensing is excellent for detecting local situations, but follow-up investments should be initiated to define a package of measures that could upgrade the WP values.

Because spatial variability in both crop yield and crop water consumption are significant, the Vietnamese irrigation sector has scope to produce more food from less water resources. Such kind of policy will not only provide more benefits to farmers, it makes them also less vulnerability to erratic rainfall regimes.

Approach to identify problems

- Check first whether low yield or high ET is the source of under-performing WP
- If yield, then check on planting dates, soil preparation and crop protection
- If related to water, judge whether there is too much or too little
- In case of too little water, and a uniform pattern across the scheme, check the availability from the reservoir
- If reservoir has insufficient amounts, then increase storage capacity (or reduce irrigation water requirements if the catchment yields are low)
- If reservoirs contain sufficient amounts of water, and the fields are dry, then the canal network is malfunctioning and needs perhaps rehabilitation
- Identify whether practices with groundwater abstraction occur
- When pockets of low and high crop water deficit coincide (and it is not groundwater induced), canal water is not fairly distributed
- If the spatial variability of WP is very local, within field water management needs improvement

A total of 25 participants were trained during a one-week workshop to build up local remote sensing and WP assessment capacity. This capacity is meant to create awareness and interests. It does not seem to be of sufficient duration to transfer the full modelling capacity. The latter needs to be achieved during individual investment projects such as WEIDAP. In particular, emphasis should be given to diagnoses of the causing problems and monitoring of the irrigation system to detect improvements.

The key findings from the pilot study include:

- The region has a highly diverse cropping structure while irrigation infrastructure and management practices are yet to catch up with the market driven cropping changes;
- The crop water consumption of high value crops can be 1000 to 1400 mm/yr (10,000 to 14,000 m3/ha/yr). The supply depends on rainfall, but is also high. The conversion from rice to perennial crops does not save water;
- Water consumption and water productivity of rice is in the middle to higher range compared with literature. However, significant variations exist within individual irrigation systems and across the systems;

- WP of coffee, pepper, mango, and dragon fruit based on actual water consumption was mapped at system level for the first time. Comparison with international literature is rare, but cross systems and intra-system variability also provides an indirect way of identifying the gaps, and estimating site specific potential;
- The crop water deficit was also measured, and it shows areas with under-irrigation and over-irrigation. These spots could be identified and visited. One observation is that areas with a (mild) crop water deficit show a higher water productivity;
- WP assessment also reveals that in spite of drought conditions, the ET deficit or crop water stress of perennial crops is little. Due to larger rooting depths, perennial crops seem to be resilient in coping with droughts;
- The new open access SEBAL modelling approach has big potential in irrigation performance evaluation, and diagnosing investment needs and management options.

The pilot study is also limited by its scope and there are a number of further steps recommended:

- WP assessment be expanded for more crops in more details. The methodologies posed in this pilot study could be copied to other areas;
- Cloud cover remains to be a major problem. SEBAL is now expanded to inclusion of daily 100 m satellite data that can first be made cloud free by special techniques;
- Collecting field information (e.g., irrigation and drainage water levels, soil type and fertility, on-farm management practices) to conduct comprehensive factor analysis in order to develop locally relevant recommendations;
- Assess the consequence of moving from rice to high value crops in terms of crop water requirements and consumptive use. More water is consumed, but the socio-economic value is very favourable;
- Involve the water accounts that are produced in a parallel ADB study to assess the maximum sustainable water withdrawals from surface and groundwater resources;
- Define clear targets of WP for the next 5 to 10 years using the frequency distributions available;
- Induce mild crop water stress levels that will boost the WP in the verticals of Fig. 5.1;
- Involve agricultural extension officers to boost the yield in the horizontals of Fig. 5.1;
- Build technical capacity to apply WP assessment to larger areas, and the facility to repeat the assessment annually for the sake of monitoring and evaluation;

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