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1 Acknowledgments

We would like to express our appreciation to all local farmers, commune extension staff and Vietnam collaborators from Binh Dinh, Ninh Thuan and Quang Nam provinces.

We would also like to express our appreciation to the contribution of Departments of Agriculture & Rural Development (DARD) of the provinces of Binh Dinh, Ninh Thuan and Quang Nam.

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2 Executive summary

This research took place in the coastal region of South Central coastal Vietnam (SCC VN) where low income levels on farms are related to the natural constraints of infertile sandy soils together with a long dry season (7-9 months). The aim of this project was to identify, test, demonstrate and facilitate adoption of crop management practices and technologies for sustainable and profitable crop production systems well suited to the conditions of the SCC VN region.

This project focussed on increasing crop productivity of low fertility sands through improved water and nutrient use efficiency for groundwater-dependent smallholder farming systems in SCC VN by:

1. assessing groundwater utilisation and quality in targeted areas within Binh Dinh and Ninh Thuan provinces;
2. evaluating methods to improve on-farm water use efficiency and to overcome soil constraints; and
3. determining profitable soil and water management technologies for adoption by farmers and developing scale out and communication programs for SCC VN.

Objective 1 Assessing groundwater utilisation and quality:

The effects of land use and land use change on groundwater resources are best examined through the lens of a catchment water balance. For understanding SCC VN groundwater use, a water balance was determined under land use and rainfall scenarios for the La Vi catchment in Binh Dinh, which comprises almost 10,000 ha of mostly sandy soils with underlying granite basement geology. Groundwater quality was assessed in the La Vi catchment as well as in coastal unconfined shallow aquifers in Phu Yen and Ninh Thuan provinces.

A methodology was developed for agricultural areas in the La Vi study area for assessing groundwater resources quantity and quality, including the determination of the sustainability of groundwater use under different agricultural development scenarios. An extensive program of data collection was setup for obtaining basic hydrometeorological, hydrological, hydrogeological, landuse, soil, and other geographical data. The collected data is now available (archived at Flinders University) and can be accessed for further studies on evidence-based management of land and water resources. The challenge of working in La Vi catchment is that it is ungauged. The approach developed has broader relevance across landscapes in Vietnam and SE Asia since most catchments are ungauaged.

In the La Vi catchment, Binh Dinh,during 2015 to 2017, both surface and subsurface water quality generally complied with the Vietnamese water guidelines for drinking and irrigation purposes with relatively low concentrations of nitrate and phosphate except close to point sources of nitrate pollution from households and animal holding pens.

In the wet season in Phu Cat district, Binh Dinh, nutrient levels could be quite high near areas of domestic and stock use (nitrate levels typically 150-200 mg/L but up to 1000 mg/L in the groundwater beneath areas where stock are penned), otherwise nitrate in the groundwater was typically low at 1-2 mg/L. Moreover, nitrate levels decreased quickly over a 200 m monitored transect between a farm and a riparian area and were always low in the riparian area. Simple mixing calculations show that 80 % of the reduction of nitrate concentration from the farm towards the riparian area can be attributed to the high recharge from rainfall along the transect. This is due to sudden and substantial changes in the groundwater level during the shift from the dry to the wet seasons and the high hydraulic conductivity of the sandy aquifer. Hence, further investigation of water quality around settlements and its impacts on households is warranted in the La Vi catchment but not those due to cropping practices.

In the coastal zone of Ninh Thuan rainfall is low (500 to 700 mm) in comparison to provinces such as Binh Dinh (~1,900 mm).High salt (0.2-13.5 dS m^{-1}), nitrate (0-417 mg L^{-1}) and phosphate (0.01 to 5.35 mg L^{-1}) levels in groundwater were measured, particularly in the Ninh Hai district in 2015 where rainfall was less (500 mm) than average (800 mm). However, lower levels of salt, nitrates and phosphates were observed during normal rainfall years of 2016, 2017 and 2018. In a particular year, the levels of salt, nitrate and phosphate in the groundwater varied with season and were generally higher during dry periods (March to September) than during the wet season (November to January). While there was significant dilution of nitrate in groundwater due to monsoon-season rainfall, concentrations exceeded Vietnam drinking water standards(< 6 mg L^{-1}) in 75 % of cases in Ninh Hai commune. By contrast, surface water samples collected from lakes and rivers were within the Vietnam water quality limits. Farmers growing vegetables, grapes or jujube in Ninh Thuan tend to apply very high rates of nitrogen fertilisers (ranging between 375-680 kg of urea /ha) and phosphate fertilisers (ranging between 300-690 kg di-ammonium phosphate /ha) and this is the most likely factor in elevating nitrate and phosphate concentrations in the groundwater. High salt levels in groundwater may be due to intrusion by sea water, accentuated by groundwater abstraction for irrigation.

In the La Vi catchment, there was considerable exchange between groundwater from agricultural fields and the adjacent river. Calibrated models estimated increasing streambed fluxes along the length of the river, with highly variable fluxes up to 1.6 $m^2\ h^{-1}$ upstream and 0.2 $m^2\ h^{-1}$ downstream during the rainy season decreasing to low fluxes of 1.0 $m^2\ h^{-1}$ upstream and 0.15 $m^2\ h^{-1}$ downstream in the dry season before flow ceased.

Maps of expected low and high groundwater tables and whole-basin water extraction were developed for the La Vi catchment in Binh Dinh based on information obtained from surveys of farmers. Generally, intensive groundwater abstraction was reported during the dry season (from January to August), particularly for the main cropping period from the end of December to the beginning of April, accounting for up to 70% of total annual abstraction. The basin-wide water extraction was compared to estimated water use based on the land use classifications and crop water requirements, which showed a total annual extraction for the base scenario (S0 which represents the current land use and water balance) of 40.5 x $10^6\ m^3$/yr.

Simulation of groundwater recharge showed that it was highly seasonal. High net recharge was estimated for the rainy season, from September to December, with an average net recharge for the whole catchment of about 100–160 mm per month. Total net recharge for the four months of the wet period was 497 mm, accounting for 81 % of the annual recharge in the base scenario (S0).

The completed temporal assessment of land use combined with knowledge on the agriculture sector as obtained in this project, allowed for formulation of scenarios of agricultural development. The landuse mapping of 2005, 2010 and 2016 shows a significant decrease in bare soil and rice paddy fields and a strong increase in other cropped areas. In total, 12 land cover scenarios were developed representing different land uses to the current base scenario. The first eight scenarios involve the introduction of water-saving irrigation techniques in combination with changes in cropping. The next three scenarios looked at the conversion of water-intensive crops, paddy rice and peanut, to the water-efficient crops, maize and cassava, respectively, as well as the replacement of bare land by non-irrigated cassava. The final scenario, is based on the prediction of a growing market for vegetables. From the 12 scenarios, five were selected, which had the largest range of associated groundwater extractions. Those five scenarios, as well as the base case, were simulated for assessment of the sustainability of groundwater use.

A coupled water balance (WetSpass-M) model and groundwater flow model (MODFLOW) was set up and applied for the base case conditions of the catchment. It was concluded with respect to the sustainability of the groundwater resources, that in wet years (>2,572 mm annual rainfall equivalent to the 90th percentile of rainfall) groundwater pumping is less than 46 % of the recharge, which is generally important for maintaining minimum ecological conditions in river valleys. In a year with average precipitation (1,838 mm), the groundwater pumping increases to 75 % of recharge. In dry years with low precipitation (<1,239 mm annual rainfall equivalent to the 10th percentile of rainfall), the groundwater pumping exceeds the natural recharge, i.e. 116 %, thereby reducing the baseflow to practically zero and effectively reducing groundwater storage by about 7 x $10^6 m^3$/yr.

A SWAT daily surface water model for the La Vi catchment was developed, and successfully calibrated and validated. It is also coupled to the groundwater flow model. The results confirm that recharge into the aquifer occurs principally between November and February. Groundwater contributions to river flow mainly occur during the wet season. Moreover, the results show that groundwater pumping cause significant reductions in the groundwater storage between February and June. This transient flux pattern confirms the presented average water balance results of the above base case scenario.

A comparison is made of the base case and the five simulated agricultural development scenarios in terms of the sustainability of the used groundwater resources. Groundwater balance fluxes for each scenario for dry, average and wet year climate conditions were simulated with the coupled WetSpass-M – MODFLOW model. It shows that the recharge to the groundwater does not vary a lot among the scenarios, but much more among the climate conditions. Groundwater pumping varies significantly over the scenarios, with five scenarios having an abstraction higher than the recharge to the aquifer system, hence depleting the groundwater system. Eight scenarios have an abstraction between 100 and 50 % of the recharge, while five scenarios have an abstraction less than 50 % of recharge. Further analyses of the sustainability shows that the only sustainable development scenarios are those in which the cropping patterns favoured a shift to dryland crops like cassava or land use was not changed compared to the base scenario, but the amount of water consumed for irrigating peanut and mango was reduced by 50 % (i.e. the full adoption of water-saving irrigation similar to that developed by the present project). These are the only scenarios, which under wet and average climatic conditions are in a 'safe' groundwater management space, while being close to this under dry climatic conditions. Replacing irrigated rice with lower water-use crops like maize did not achieve a safe groundwater outcome but was no worse than the base case which would be expected to experience groundwater drawdown in the 10 % of driest years.

Objective 2 Evaluating methods to improve on-farm water use efficiency and to overcome soil constraints:

Soil testing shows that sands in Binh Dinh and Ninh Thuan were generally deficient in potassium (K) and sulfur (S). Hence, nutrient management research focussed on these two elements.

The optimum K fertiliser rate for irrigated peanut yield was determined from multiple field experiments to be 50-75 kg K/ha. At these rates K inputs were still below outputs resulting in depletion of soil K. Most of the net loss of K was attributed to the removal of shoots of peanut from fields for use as a cattle feed.

The optimum S fertiliser rate was determined from multiple field experiments to be 20-30 kg S/ha for peanut. At these rates, S inputs were approximately equal to outputs.

Our findings on improved irrigation technologies (sprinklers based on mini-pan evaporation rates) and balanced use of nutrients (75 kg of K/ha and 30 kg of S/ha) in Binh Dinh, showed water use decreased on average by 25 to 47% and peanut yield increased by 16-26 % in comparison to farmer's hose irrigation practice. Negative balances of K, and to a lesser extent of S were observed on different sandy soils of Binh Dinh with farmer's practice of applying N and P fertilisers only (i.e. little of or no application of K and S) in combination with hose irrigation. In 2018, to determine whether negative balances of K and S could be reversed we tested the effects of sprinkler and mini pan irrigation technology on K balances under peanut production in Binh Dinh. In the 3 experiments in 3 communes (Cat Hanh, Cat Hiep and Cat Lam) of Binh Dinh, increasing K rates from 75 to 90 kg/ha had no effect on peanut yield, however, positive balance of nearly 19 kg K/ha was obtained with 90 kg K/ha irrigated by sprinkler guided by mini pan. The K balance results suggest the need for re-adjustment of rates of K (between 75 and 90 kg K/ha) for peanut production, especially with the use of improved irrigation technologies.

The profit margins for irrigated peanut varied among sites, but the mean value was 19 million VND/ha (AUD 1,308/ha)[1] higher where mini-pan and sprinkler irrigation was used together with application of 75 kg of K/ha and 30 kg S/ha in comparison to farmer's irrigation and fertilizer practice.

The improved sprinkler irrigation and nutrient management technologies developed in Binh Dinh were tested in 2018 and 2019 in Quang Nam, the province to the north of Binh Dinh with similar climatic conditions and sandy soils but lower peanut productivity (<2 t/ha). Initial results from a double-pot experiment showed N, K, S, Zn, Cu and B deficiencies could limit peanut productivity. Field experiments were conducted in 2 communes (Binh Sa and Binh Trung) of Quang Nam to test the effect of sprinkler and mini pan irrigation technology in combination with balanced nutrients (75 kg K + 30 kg S/ha) on peanut productivity. Peanut at Binh Sa commune performed better than Binh Trung commune with yields of peanut being 4.71 and 2.85 t/ha, respectively. Potassium was the main limiting element that restricted yield of peanut under both the irrigation practices (farmer's practice and sprinkler with mini pan). Application of 75 kg K/ha and 30 kg S/ha increased the yield of peanut by 11 to 12 % in both communes. The amount of irrigation water applied by the sprinkler and mini pan was 28 to 33 % less relative to farmer's practice. Sprinklers guided by mini pan decreased the number of irrigations required during peanut growth from 26 with farmer's practice practice (hose irrigation and 4 tonnes of FYM + 30 N + 29 P + 33 kg K + 300 kg lime/ha) to 21.

In An Hai commune of Ninh Thuan province, experiments on onion were conducted to evaluate farmer's irrigation practice using sprinkler in combination with farmer's fertilizer practice (100 kg N, 70 kg P, 80 kg K and basal fertilizers) against sprinkler with mini pan with reduced rates of N (25 and 50 % less), P (25 % less) and K (25 % less). Although, different irrigation technologies showed no significant effect on yield, use of sprinkler alone with 25 % reduced rates of P, increased the yield of spring onion by 13.5 %, while with 25 % less P, sprinkler guided by mini pan irrigation increased yield by 21.6 %. The net profit margins varied between 132 (sprinkler irrigation with 25 % less P applied) to 196 million VND (sprinkler guided by mini pan with 25 % less P applied), however, the profit margins are dependent on the price at the time of selling the produce, which varies significantly.

Amendment materials such as sugarcane straw, bentonite, clay-rich soil and manure were also trialed in Ninh Thuan to assess the impact of these materials on yield of onion and water use efficiency. Sugarcane straw and bentonite increased yield of vegetables by 30-167 % while also improving water and nutrient use efficiencies. At the current price of bentonite (2.2 million VND/t with an application rate of 60 t/ha) three consecutive onion crops did not recover the cost of investment but after three consecutive years, bentonite was highly profitable. This emphasises the need for arranging credit access for farmers to take up this technology.

From 4 years of experimental results on a 16-year-old mango orchard established on infertile sands of Binh Dinh, we can conclude that despite the yield of mango varying from 16 t/ha in good years to 5 t/ha in alternative-bearing years; the use of a mini-pan to guide irrigation scheduling with drippers saved 46-70 % of irrigation water and increased yield of mango fruit by approximately 2.6 t/ha (26-32 %). However, there were negative balances for K under all irrigation methods (farmers practice, sprinkler and drip and mini pan). The

[1] *1 Australian dollar = 14, 527 on 7 April 2020*

cost of irrigation technologies varies based on the irrigation technology used. For example, farmers practice of using hose may cost only 1 million, however, the cost related to labour can be very high (200,000 VND/day/labour). The cost of large sprinklers is ~3 million, but the operating cost with labour and power is also high. Cost of sprinkler (~ 25 million/ha) and drip (~35 million VND/ha) systems are high, but there are significant savings in operating and labour costs. Comparing farmer's practice against sprinkler and drip irrigation system, farmers can generate 15 and 45 million VND extra income /ha, respectively. Drippers with mini pan generating 45 million VND increase in profit against farmers' practice suggests that farmers could recover the cost of investment in approximately one year. In addition, saving of 46-70 % water by using drip technology conserves water when supply is limited especially during the peak season of flowering and fruiting.

Given that both nutrients and water are critical for mango production, in 2018 and 2019, the project examined the effect of fertigation (to supply both water and nutrients) on a 9-year-old mango orchard. Fertigation increased the proportion of grade 1 fruit (good quality and higher price) by 5 % which would increase profit.The water savings (57 %) were similar to the drip irrigation system but applying nutrients by fertigation further reduces the labour required for fertilizer application.

Objective 3 Determining promising soil and water management technologies for adoption by farmers:

On the basis of the research and demonstration results of the Project, ASISOV submitted proposals to the Department of Agriculture and Rural Development (DARD) Binh Dinh to approve new peanut and mango irrigation technologies. These were approved for use in Binh Dinh in 2018.

Large on-farm demonstrations (1 ha each) were conducted in 2018 and 2019 in three communes (Cat Hanh, Cat Hiep and Cat Lam) of Phu Cat district in Binh Dinh to compare use of sprinklers guided by min-pan with farmer's hose irrigation practice for peanut. On average, 30 % less water was pumped using sprinklers guided by min-pan . In addition, 12 % higher peanut yields, varying between 4.5 to 4.65 t/ha, were achieved using the project's new sprinkler irrigation technology against farmer's practice. On-farm demonstrations also showed higher profit margins (~55 million VND/ha) with an increased cost to benefit ratio of 1.24 relative to farmer's practice. Labour was the main cost (~55 %) of the total input costs (57.2 million VND) associated with farmer's practice, whereas, the labour cost using irrigation technology was 42% of the total input costs (45 million VND). The cost of irrigation system, mini pan, pump and energy use accounted for 30 million VND, which is 13.6 % of the total input costs. Given that profit margin from a single peanut crop using sprinkler irrigation technology is approximately 47 million VND, the cost of investment in irrigation technology can be recovered from two peanut crops.

Summary and outcomes

The main highlights and learning from our collaboration are:

1. Application of balanced rates of fertilisers and organic inputs, after diagnosis of soil constraints and in combination with the use of water-efficient irrigation technologies, have enormous potential to achieve sustainable groundwater resource use and help in alleviating the poverty of small landholders in SCC VN.
2. With integrated water and nutrient management technologies, improved profit from peanut and mango in Binh Dinh and from vegetables (onion) in Ninh Thuan was in the order of 47.0 (AUD 3,235), 118.6 (AUD 8,164) and 58.5 (AUD 4,027) million VND/ha, respectively, as against farmer's practice.
3. Water balance modelling in La Vi catchment, Binh Dinh showed that under current land use, over-extraction of groundwater is likely in years of low rainfall and that in an average rainfall year, 75 % of the recharge is currently extracted for irrigation. Attempts to expand irrigation using groundwater will exacerbate the severity and frequency of water shortages. Rather the focus should be on reducing

groundwater use in the present land use scenario (e.g. using water saving technologies from the present project) or land use change to low water-use crops (e.g. mango) or non-irrigated crops (e.g. cassava). Water balance modelling identified the vulnerable parts of the La Vi catchment to over-exploitation of groundwater, and land use scenarios that would be more sustainable due to lower requirements for groundwater pumping.

4. Groundwater in agricultural land showed no evidence of nutrient pollution in Phu Cat district of Binh Dinh. By contrast, in the coastal zone of Ninh Thuan groundwater quality was impaired by salinity, high nitrate and high phosphate concentrations: however, the levels varied depending on season and the total rainfall. Nitrate, phosphate and salt levels were high in the groundwater during the drought year of 2015. By contrast, in 2017, when the total rainfall was > 1,200 mm, the levels of salt, nitrate and phosphate were comparatively low. Groundwater in the dry season (Jan-Sept) normally had higher levels of salt and nutrients in comparison to the wet season (Oct-Dec).
5. Use of amendment materials (sugarcane straw, clay-rich soil, bentonite etc), together with water saving irrigation technologies have the potential to improve water use efficiency and nutrient use efficiency, which can help in overcoming unsustainable irrigation practices on deep sands that are currently used by farmers. Bentonite clay addition at 60 t/ha and clay-rich soil at 200-300 t/ha improved both water and nutrient use efficiency. Sugar cane residue at 30 t/ha also improved both water and nutrient use efficiency. Lower cost through economies of scale in the supply chain, subsidised prices for farmers or improved access to credit for purchase of amendments would make them more attractive options, especially as the effects persist for many years. However, farmers currently use cow manure as it is easily available and cheap and they should be encouraged to continue this practice.
6. For onion production in Ninh Thuan with sprinkler irrigation, reduced rates of P fertilizer improved yield of onion suggesting there is further scope for reducing the input costs and nutrient leaching to groundwater.
7. Small landholders in the project study areas recognize the benefits of using the tested technologies, however, there is a history of farmers waiting for Government subsidies before adopting new technologies. Leadership from national and provincial levels of the Government of Vietnam in demonstrating and extending these technologies to other coastal provinces and in supporting the adoption of the technologies can help in rural poverty alleviation in SCC VN.
8. The value of water savings reported consistently from our irrigation experiments will have added significance for farmers when water pricing policy comes into effect by 2020. In addition, given that labour costs are increasing over time, labour-saving irrigation technologies will become more attractive in the farming community of SCC VN.
9. The value of the improved irrigation and nutrient management technologies have been shown to apply in Quang Nam province, in addition to the original findings in Binh Dinh and Ninh Thuan provinces. Hence, these technologies are ready to be tested, validated and scaled out in other coastal provinces of South-Central and North-Central Vietnam on sandy landscapes.

3 Background

This project aims to improve profitability and sustainability of water use in groundwater-dependent smallholder farming systems in SCC VN. The shallow, unconfined groundwater resource in SCC VN is vulnerable to overexploitation and to pollution due to nutrient and contaminant leaching or saline water intrusion. Improving knowledge of groundwater resources will improve planning and regulation of their use and boost livelihoods on farms through more productive water and nutrient use. Improving the productivity and sustainable management of low fertility sands through improved water and nutrient use efficiency are common priorities for SCC VN and Western Australia (WA).

Biophysical constraints on >330,000 ha of low fertility sands that experience climatic extremes, present challenges for agricultural production and poverty alleviation in SCC VN. Groundwater dependent farming systems in SCC VN are mostly established on sands and are frequently affected by water shortages during the seven to nine-month dry season. The main focus of this project was on Binh Dinh (BD) and Ninh Thuan (NT) provinces, with further testing of technologies in Quang Nam province (QN). The climatic conditions of each province are described in Fig. 3.1, Fig. 3.2 and Fig. 3.3.

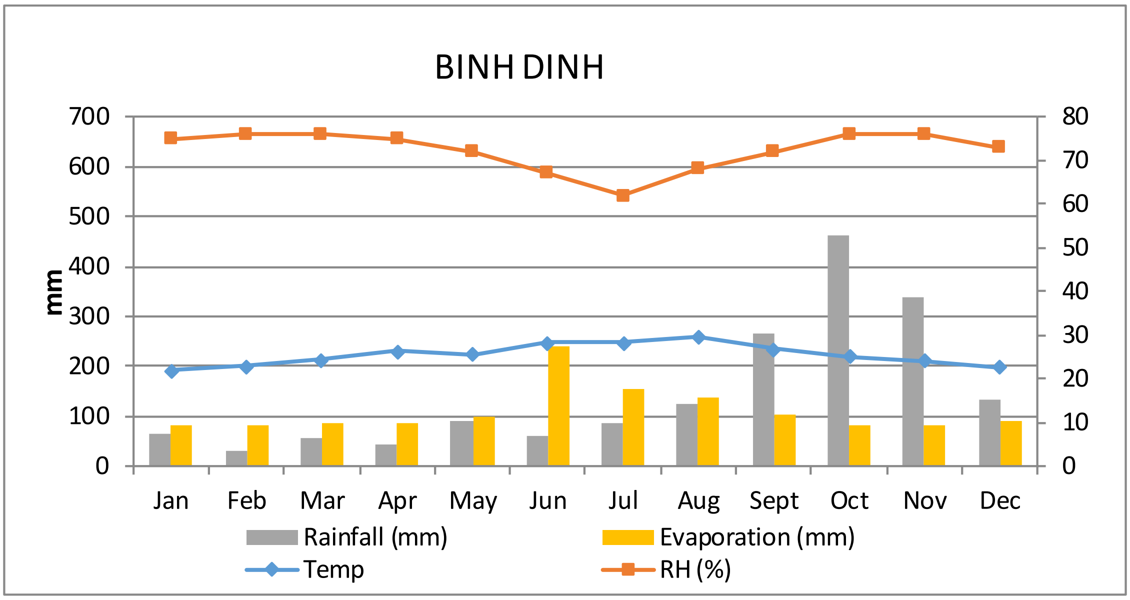


Fig. 3.1 Climatic conditions in Binh Dinh Quy Nhon station, 2011-2014)

Major irrigated crops in these groundwater-dependent areas are peanut, mango and vegetables with cropping seasons (Fig. 3.4). Rice is also irrigated but often from surface water sources and so is not examined in the present study. Cassava is an important non-irrigated crop in BD. Crop productivity is constrained by soil physical limitations and nutrient deficiencies associated with the sands (Hoang et al. 2015). Integrated water, soil and nutrient management is a key to improving their productive capacity (Bell et al. 2015). Priorities and strategies for the project were developed through consultations with Vietnamese research, planning and extension agencies and the findings of a prior ACIAR commissioned small research activity (SRA SMCN 2012/017) where the concerns raised were mainly for management of groundwater resources and the crops that are dependent on its use.

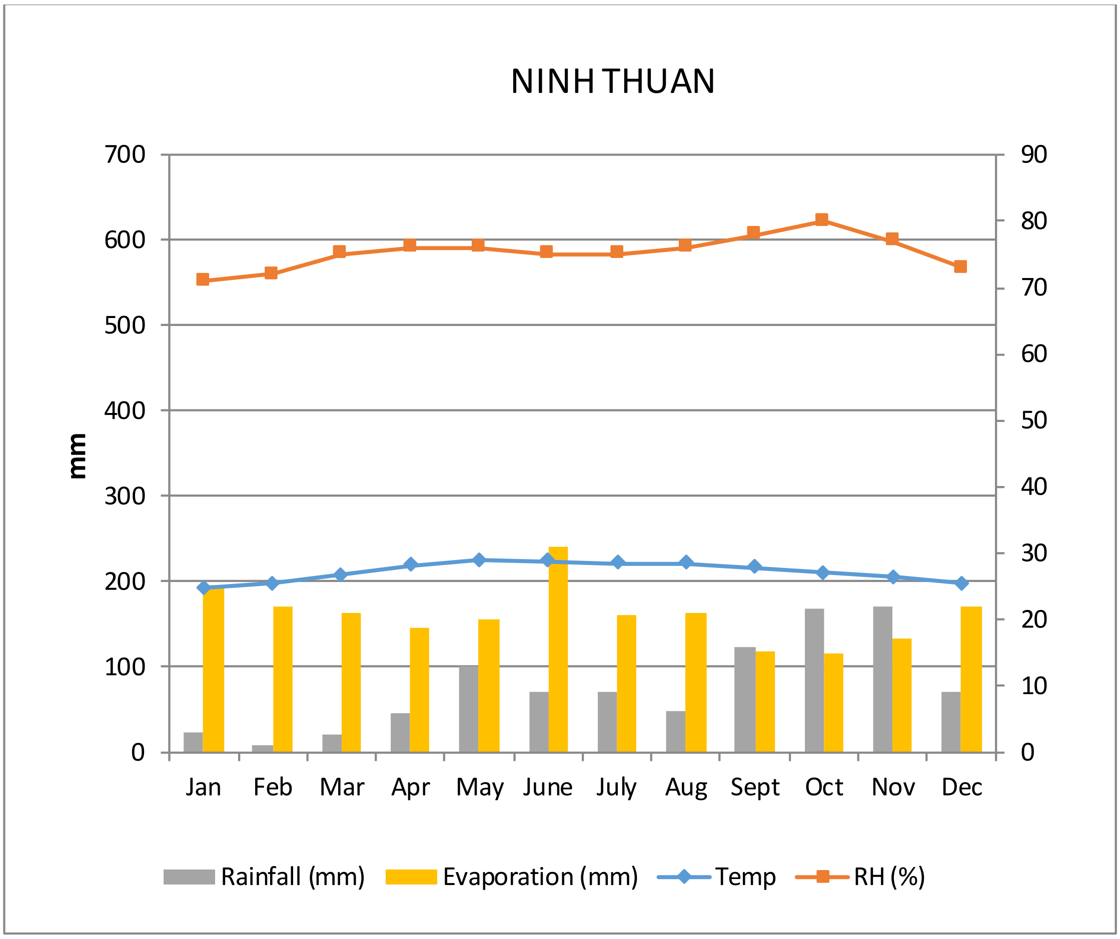


Fig. 3.2 Climatic conditions in Ninh Thuan (Phan Rang station, 2011-2014)

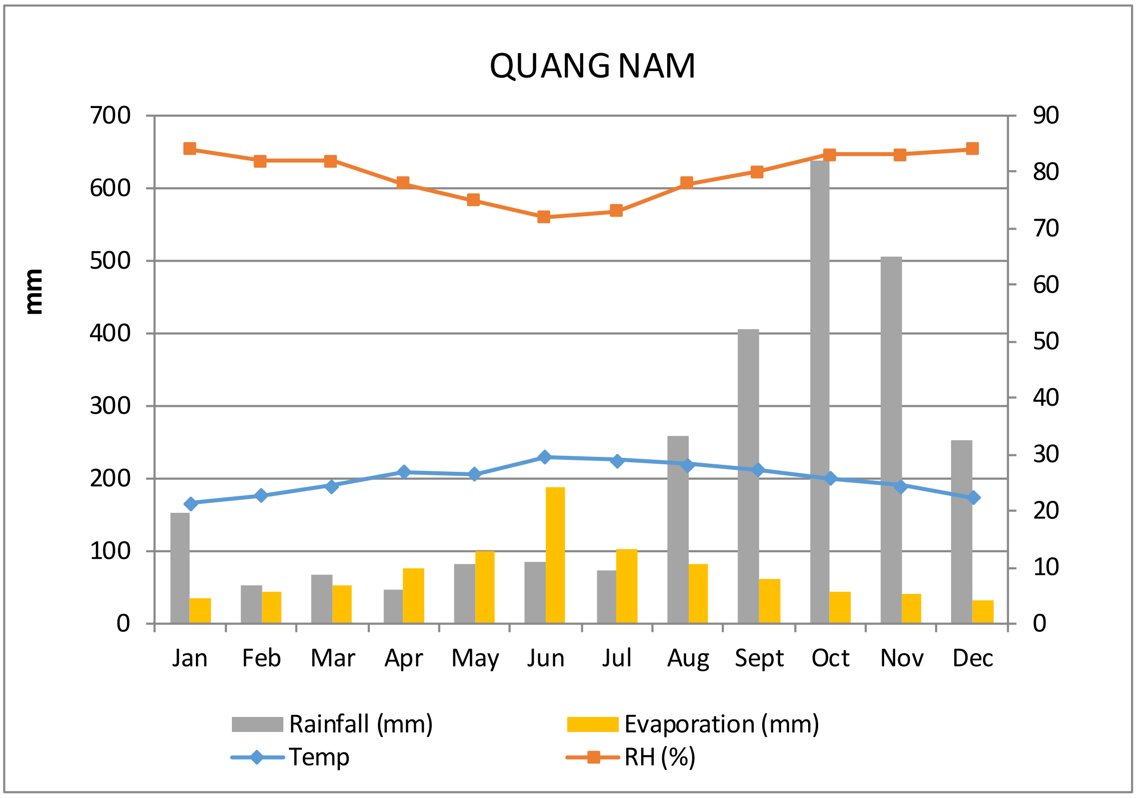
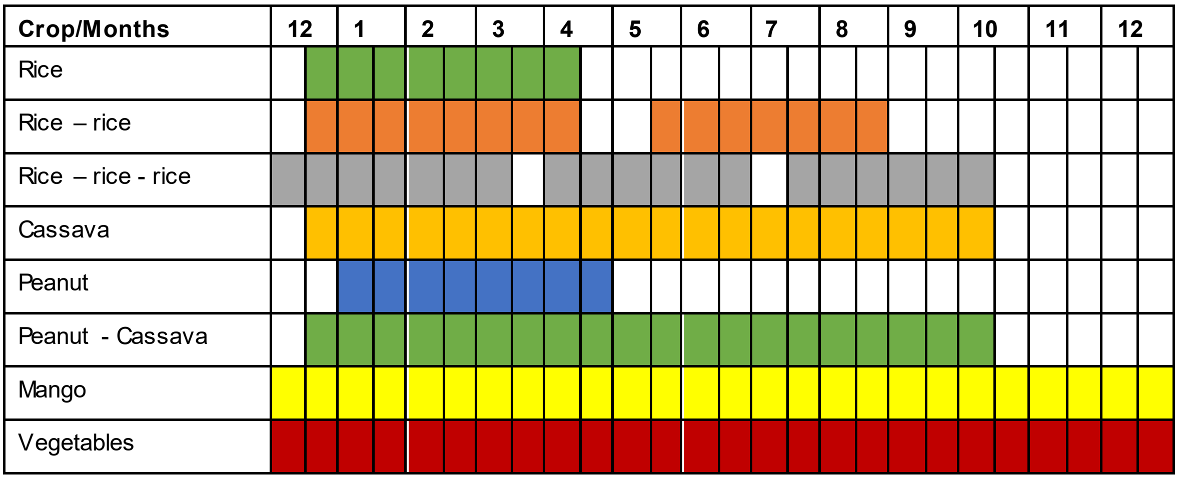


Fig. 3.3 Climatic conditions in Quang Nam (Tam ky station, 2011-2014)

Source: (MARD, 2017) average data for 2011-2014, http://thongke.mard.gov.vn/, access 12/25/2017

Communes in BD (Cat Hiep, Cat Hanh, Cat Lam and Cat Thinh) and NT (An Hai and Ninh Hai) provinces were chosen as the main study areas to improve profitability of crops like peanut, mango and onion by small landholders dependent on groundwater use to irrigate their crops during the dry periods of the year. The main focus of the study was to predict the impact it may have on the groundwater resources and how the impact could be minimized through the use of irrigation technologies to sustain this valuable resource which otherwise is under threat due to droughts, climate variability and change, and pollution.

Fig. 3.4 Major cropping patterns and seasons in Binh Dinh



Before the original completion of the project in June 2018, ACIAR agreed to an one and a half year extension of the project to address delays and gaps identified during 2014-18 and to extend findings to a neighbouring province,QN (Fig. 4.1). The extension is also designed as an exit strategy for ACIAR from SCC VN region that had been a focus region over the last decade.

The extension phase included additional activities:

I. to organize and participate in a Water forum/workshop/conference in Vietnam
II. to conduct training on irrigation scheduling, design, and equipment;
III. to simulate the water balance in La Vi catchment under different scenarios by modeling (SWAT/MODFLOW),
IV. prepare a manual that could be used by researchers to model other catchments of the SCC VN region;
V. to extend and demonstrate the use of irrigation technologies from BD to other provinces (QN and NT) of SCC VN; and
VI. in collaboration with DARDs (BD, NT and QN), conduct experiments, demonstrations, trainings, field days, workshops to gather support from provincial and central governments to promote scaling out to a larger farming community.

4 Objectives

4.1 Objectives and research questions

This project contributes toward the goal of improving livelihoods for smallholder farmers in SCC VN and to sustainable soil management in WA. The specific aim for the project is to identify and facilitate adoption of technologies and strategies for sustainable groundwater utilization and to develop options for improving crop productivity in soils of SCC VN and WA.

The main objectives of the project are to:

1. Assess groundwater utilisation and quality in targeted areas within BD and NT provinces in SCC VN;
2. Evaluate methods to improve on-farm water use efficiency and to overcome soil constraints and reduce nutrient leaching in SCC VN and WA;
3. Determine promising soil and water management technologies for adoption by farmers and develop scale out and communication programs for SCC VN.

To achieve the afore said objectives, the research questions that were addressed are:

1. How can groundwater abstraction for irrigation be managed to fit the available supply?
2. What are the most practical and cost effective solutions to overcome soil constraints and alleviate soil nutrient deficiencies in SCC VN and WA?
3. What technologies and practices can be utilized by groundwater-dependent farmers in SCC VN to improve on-farm water use efficiency and reduce nutrient losses?

4.2 Focus area

The SCC VN stretched from Danang in the north to Binh Thuan in the south (Fig. 4.1). The three provinces in which this project work represent the northern (QN), central (BD) and southern sections (NT) of SCC VN. They have contrasting climates (Figs 3.1, 3.2, 3.3).

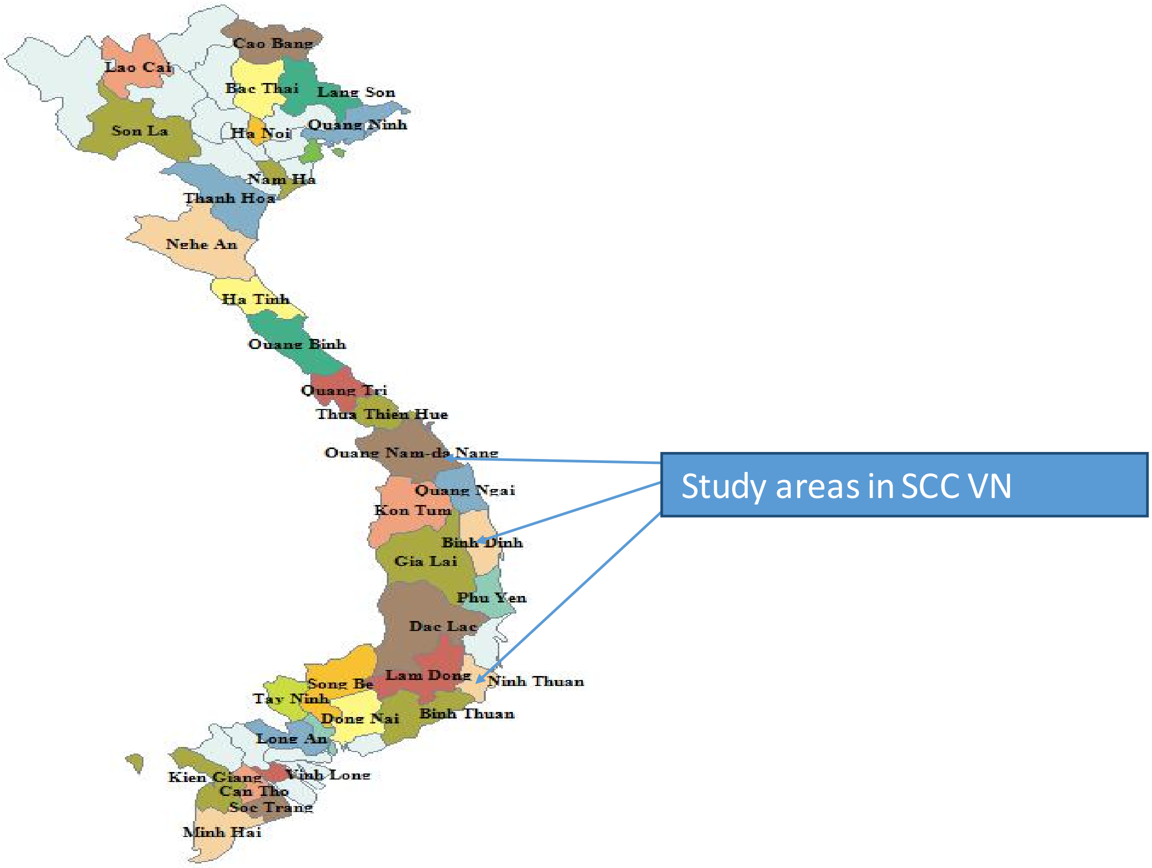


Fig. 4.1 Map of all provinces in Vietnam with study sites in SCC VN provinces (Binh Dinh, Ninh Thuan and Quang Nam)

4.3 The primary outputs including the extension phase

- Groundwater model and improved knowledge of the regional groundwater balance and its economic value for agriculture in SCC VN, now and into the future;
- Resource sustainability evaluation of reduced agricultural water use and scenario analysis through modelling water balance;
- A case study that can be documented as a manual and followed through by other researchers to assess other areas (NT/QN) for sustainable water use, and also for policy development;
- Integrated water, soil and nutrient management training modules for Vietnamese farmers;
- Irrigation, fertiliser and soil management options for overcoming soil constraints to increase soil productivity in SCC VN together with soil management options for overcoming soil constraints for increased soil productivity in WA;
- Economic analysis of the farm benefits and costs of implementing promising new technologies including differences in pumping and labour costs;

- Large scale demonstrations to encourage adoption of promising technologies and practices and proposals to secure central and provincial government approval and funding for expanding scale-out programs in SCC VN;
- Communication to influence policy and initiatives aimed at improving groundwater sustainability in SCC VN;
- Practices developed for fertigation (water and nutrient) through drippers as a management option for mango production.

5 Methodology

5.1 Water balance assessment

A scientific methodology is required for assessing groundwater utilisation and quality in targeted areas within BD and NT provinces in SCC VN, and for being able to answer the research question:

How can groundwater abstraction for irrigation be managed to fit the available supply?

In order to make this methodology generally applicable for other areas as well, a Manual was developed as one of the outputs of objective 1 of this project (Loi and Liem, 2019). In section 5.1 a summary of the general methodology is presented.

5.1.1 Defining a water balance problem

Assessment of the water balance of an area is one of the traditional goals of most hydrological studies. However, it is at the same time a complex problem as it requires estimating most, if not all, components of the hydrological cycle of an area. In its most simple form, a water balance equation for an area can be represented as:

Input - Output = Change in Storage (5.1.1)

In order to define properly a water balance problem, first the area needs to be defined. Although, a water balance assessment can be performed for any delineated area, mostly a surface watershed delineation is used. Using a topographic watershed divide generally assumes that all river water at the outlet of the catchment is derived from rainfall in the basin, which flows via surface streams and via groundwater recharge and discharge within the basin to the outlet of the catchment.

The detail of the hydrological processes entailed in a water balance assessment can be variable, from very simplified to highly physically detailed: it can focus on only surface water related processes, or only groundwater related processes or a combination of both. It can also be spatially lumped or spatially distributed, and finally the model can be temporally long term averaged or yearly, monthly, daily or hourly based. The choice for this conceptualisation in a water balance study depends a lot on the particular hydrological spatial and temporal process dynamics and understanding that one would like to obtain from a system.

5.1.2 Setting a goal for water balance modelling

Water balance assessments or modelling are generally set up in support of particular goals, such as understanding and or managing better available water resources, as needed for the agricultural sector, energy production, domestic or industrial water supply and in support of sustaining ecological conditions in an area. The type of water used, surface or groundwater, or both, and the spatial and temporal demand for water should determine the approach taken for the water balance modelling. Here, we describe, use and discuss two approaches for surface water balance modelling (WetSpass-M and SWAT) and one approach for groundwater balance modelling (MODFLOW). But, we also describe and test coupled uses of surface water and groundwater balance models.

5.1.3 Required data and data collection

Any water balance model assessment is dependent on the availability of field data on climate, surface water, groundwater, hydrogeology, soil, land use, topography, water use, etc. In many developing countries, there is a severe paucity of such data.

One of the most used data sets in water balance modelling is surface water discharge time series. If this data is not available for a catchment, hydrologists say such a catchment is 'ungauged'. However, if in a catchment, the water use is strongly groundwater dependent, lacking data on groundwater levels makes that the catchment also, from a groundwater perspective,is 'ungauged'. Simulating the water balance under ungauged conditions is scientifically still a huge challenge (Hrachowitzet al., 2013). Hence, collecting and maintaining measurement stations for crucial hydrometeorological, hydrological and geographical field data is of utmost importance.

The most important typical data required for water balance assessments are listed inTable 5.1, and have been collected in this project from field measurements but also from existing meteorological stations, maps, and remote sensing. They have been obtained by different researchers involved in this project, but have also been provided by a number of Vietnamese Agencies. Obtaining input datafor some parameters,with still limited generally available datasets, has been the hardest and most time-consuming effort for Objective 1 of the project.

Table 5.1 Data supporting water balance assessment and collected in this project for Objective 1.These data sets have been archived by Flinders University (Prof Okke Batelaan) for future use.

Parameter	Description	Location	Period	Resolution	Source
Discharge	River flow gauging: At Tan Hoa bridge: using ADCP At Ba Lang and Xom Tay: using propeller	3 stations: Tan Hoa (Downstream), Ba Lang (upstream) and Xom Tay (right tributaries)	Dec 2015 to Mar 2016; Nov 2016	16 meas. per station	Field measured by Central Vietnam Division for Water Resources Planning and Investigation (CEWRPI)
Surface water levels	Using pressure transducer;	3 stations: Downstream (Tan Hoa), Midstream, and Upstream (Ba Lang)	Oct, 2015 to Feb, 2018 (gaps due to failure of loggers)	20 min interval	Field meas. by Manh Hai Vu
Groundwater level	Time-series data logged at monitoring wells using pressure transducer	14 wells	Oct, 2015 to Feb, 2018 (gaps due to fails of loggers)	Scattered points throughout the catchment, 20 min interval	Field meas. by Manh Hai Vu
Groundwater level	Once off measurements at surveyed wells	77 wells	Oct, 2015	Scattered points throughout the catchment	Field meas. by CEWRPI
Water usages	Interviews of farmers on their water usage	77 wells and 35 surface water locations	Oct, 2015	Scattered points throughout the catchment	Field meas. by CEWRPI
Precipitation	Tipping bucket rain gauge	2 stations: Tan Hoa and Xom Tay	2016 to 2017	hourly	Nong Lam University (NLU)

Parameter	Description	Location	Period	Resolution	Source
Precipitation	Meteorological station	Phu Cat	1998-2015	Daily	South Central Hydro-Meteorological Centre
Precipitation	Meteorological station	An Nhon	1987-2018	Monthly	South Central Hydro-Meteorological Centre
Temperature, wind, relative humidity, solar radiation	Meteorological station	Quy Nhon	2008-2015	Daily	South Central Hydro-Meteorological Centre
Topographic map (DEM)	Microstation format, scale 1:10,000	Whole catchment	-	raster 10 x 10 m	Binh Dinh Department of Natural Resources and Environment
Riverbed longitudinal profile	Topographical elevation meas. with a Total station	Along the main streams	-	a point meas. every 300 m	Field meas. CEWRPI
River cross-sections	Topographical elevation meas. with a Total station	3 locations for measuring river discharge	-	a point meas. every 10 m	Field meas. CEWRPI
Geophysics	Electrical Resistivity Tomography (ERT) for aquifer thickness	Whole catchment	2017	100 meas. along 5 transects (2 km x 0.5 km)	Field meas. CEWRPI
Hydraulic conductivity (K)	Obtained from pumping test analyses	Whole catchment	2018	40 wells	Field meas. CEWRPI
Land use maps	Landsat and Sentinel imagery	Whole catchment	2005, 2010 and 2016	Raster 30x30 and 10x10 m resp.	Satellite based raster maps classified by NLU
Soil map	MapInfo format, scale 1:100,000	Whole catchment		Polygon map	Central Sub-Institute of Agricultural Planning and Design; updated by NLU

5.1.4 Methodological options for water balance modelling

WetSpass-M

WetSpass-M is a water balance model for estimating spatially distributed, monthly evapotranspiration, surface runoff and recharge (Abdollahiet al., 2017). The model uses raster data exported from a geographical information system (GIS) (Batelaan and De Smedt, 2001, 2007). The model has often been applied to study the influence of long-term effects of land cover changes on the water regime in a basin (Batelaan et al., 2003). By using monthly average standard hydrometeorological parameters as inputs, the model simulates the temporal dynamics and spatial differences of surface runoff, actual evapotranspiration, and groundwater recharge. Since evapotranspiration from shallow groundwater can be significant, especially in valley areas, the position of the groundwater table should be taken into account in the estimation of recharge. Therefore, WetSpass-M can be coupled to a groundwater model, to provide a recharge boundary condition.

The model treats a basin or region as a regular pattern of raster cells. Every raster cell is further sub-divided into vegetated, bare soil, open water, and impervious surface fractions, for which independent water balances are maintained. This allows for accounting of sub-cell land cover heterogeneity, depending on the resolution of the raster cell. Multi-resolution remote sensing classification offers possibilities to quantify sub-cell information. The bare soil fraction of a raster cell is also used to describe the part of the surface, which is not fully covered by vegetation. Especially, in the non-growing season this percentage can increase considerably for certain covers. The hydrological processes in each cell are simulated monthly, by assuming a cascading of the precipitation, interception, runoff, evapotranspiration and recharge processes.

SWAT

The Soil and Water Assessment Tool (SWAT) is a physically-based, semi-distributed hydrological model used for the simulation of surface and groundwater quality and quantity. SWAT is a robust hydrological modelling tool, which effectively simulates hydrological processes at the spatial scale of small catchments up to regional scale basins (Neitsch et al., 2011). SWAT is frequently used in scenario modelling of environmental impact of land use, effect of various land management practices, and climate change. SWAT is a public domain software (https://swat.tamu.edu/) and was originally developed by the USDA (Agricultural Research Service). It has become the most popular semi-distributed hydrological model and is scientifically well accepted particularly for surface water hydrology and nutrient transport modelling capacity.

In order to run a SWAT model, five principal climate input data are required; rainfall, temperature, wind speed, solar radiation and relative humidity. Other ancillary data required include land use, soil data and digital elevation model (DEM). SWAT can delineate the catchment or basin area based on the DEM and then divides the catchment or basin into sub-basins based on the river channels and tributaries. These sub-basins are further discretised into hydrological response units (HRU), which are made up of unique combinations of land cover, soil type and slope. The HRU discretisation method used by SWAT allows the model to simulate the sub-basin processes in detail, which is an advantage in understanding the interaction and response of the HRU's to hydrological processes.

SWAT outputs a large suite of catchment processes including stream/river discharge, evapotranspiration, groundwater recharge, nitrate and phosphorus loading. The SWAT model is often calibrated to observed stream/river discharge data as this is often the most readily available data. However, the model can be calibrated to any observed data which SWAT simulates.

The SWAT model can be coupled to MODFLOW using the SWAT-MODFLOW coupling tool to create a robust catchment hydrology ensemble.

MODFLOW

The MODFLOW model (https://www.usgs.gov/mission-areas/water-resources/software) is the global industry standard for modelling groundwater flow. It is developed and maintained as an open-source model by the United States Geological Survey (USGS). Its strong advantage is that it is public domain and continuously further developed. The main purpose of setting up a MODFLOW model is to simulate groundwater heads, fluxes and a groundwater balance for a specific conceptual hydrogeological setting. Such a simulation can be done in 2D (dimensions) cross-section, 2D layer or in 3D with multiple layers representing the hydrogeology of an area. It can simulate steady state or transient conditions. The numerical method used in MODFLOW for solving the partial differential equations, which mathematically describe the groundwater flow, is the finite difference technique.

For running a MODFLOW model typically the hydrogeology needs to be conceptualised in a number of layers vertically and raster cells horizontally. As input data to the model, hydrogeological data, boundary conditions and model parameters are required. Hydrogeological data are hydraulic conductivities, specific yield and specific storages. MODFLOW has been built as a modular model allowing theuse of a large set of different boundary conditions formulated as 'packages', each with its own data requirements. MODFLOW boundary packages exist for taking into account RECHARGE, WELLS, EVAPOTRANSPIRATION, RIVERS, DRAINS, etc. Model parameters are required for spatial, temporal discretisation, for the numerical solver, and for various processes in the calculation schemes of the boundary condition packages. For calibration and confirmation of the simulated results (see also section 5.1.5) generally measured groundwater heads are used, but it is also possible to use measured fluxes of e.g. groundwater-surface water interaction or evapotranspiration.

MODFLOW really only calculates heads and fluxes. Therefore, many pre- and post-processing tools and models have been developed and are generally freely available from the USGS (https://water.usgs.gov/software/lists/groundwater/). Examples are a graphical user interface (ModelMuse), post-processing models for particle tracking (MODPATH) and contaminant transport (MT3D-USGS). As MODFLOW only simulates saturated groundwater conditions, many couplings with models that can simulate unsaturated or surface water conditions have been developed. In the next section two of these couplings are described.

Coupled surface-groundwater modelling

One of the important boundary conditions and input variables for a groundwater flow model, like MODFLOW, is the recharge. Groundwater recharge is very difficult to measure and hence it is often roughly parameterized. Thereby it mostly does not reflect the spatial variability as would occur in reality as a result of different land covers, soil types and meteorology. The WetSpass-M model can be coupled with the MODFLOW model. The recharge as calculated by WetSpass-M in a spatial continuous raster format and at a monthly time resolution can be used as a boundary condition (input) for a MODFLOW groundwater flow model. The advantage of such a coupled model is that it takes into account the different land use/cover and soil conditions and therefore allows groundwater balance assessments for changing land use/cover conditions by scenario analyses with different recharge scenarios calculated with WetSpass-M and coupled to MODFLOW.

A more advanced coupling between surface water and groundwater can be achieved by the SWAT-MODFLOW combination. The SWAT-MODFLOW model is an ensemble made up of three hydrological models; SWAT, MODFLOW and RT3D. SWAT runs the operations associated with land surface, soil and surface water hydrology, while MODFLOW runs the model operations associated with groundwater hydrology and surface water – groundwater interactions. The SWAT and MODFLOW models have been described in previous sections, RT3D is a reactive transport 3D model used to simulate the transport of chemical compounds in groundwater. Unlike SWAT and MODFLOW, RT3D is an optional module in the coupling of the SWAT-MODFLOW; it is only required where contaminant transport is an objective. Fig. 5.1 shows the interaction of the three models and the processes they each perform in a SWAT-MODFLOW coupled model.

The development of the SWAT-MODFLOW model is underpinned by the need for improved groundwater flow and solute transport processes in the SWAT model. Although the SWAT model is widely accepted as a versatile and robust surface water, soil hydrology and land surface nutrient transport model, the SWAT inbuilt groundwater hydrology module is not as comprehensive as the industry standard, MODFLOW.

The SWAT-MODFLOW model was developed by updating the SWAT model code to bypass the inbuilt SWAT groundwater hydrology module and instead to read in the results of a pre-developed MODFLOW model over the same catchment or basin. The SWAT and MODFLOW models interact by passing surface water-groundwater interaction variables between them, which are then used in developing the coupled hydrological model. The output files include the groundwater hydraulic head files for each MODFLOW grid cell, the recharge into each HRU and MODFLOW grid cell, the river channel depths, and the volumetric exchange rates between the river and aquifer over each sub-basin and river cells for every time step.

A graphical user interface for the SWAT-MODFLOW (QSWATMOD) has recently been developed on the QGIS platform for easier processing and viewing of model results.

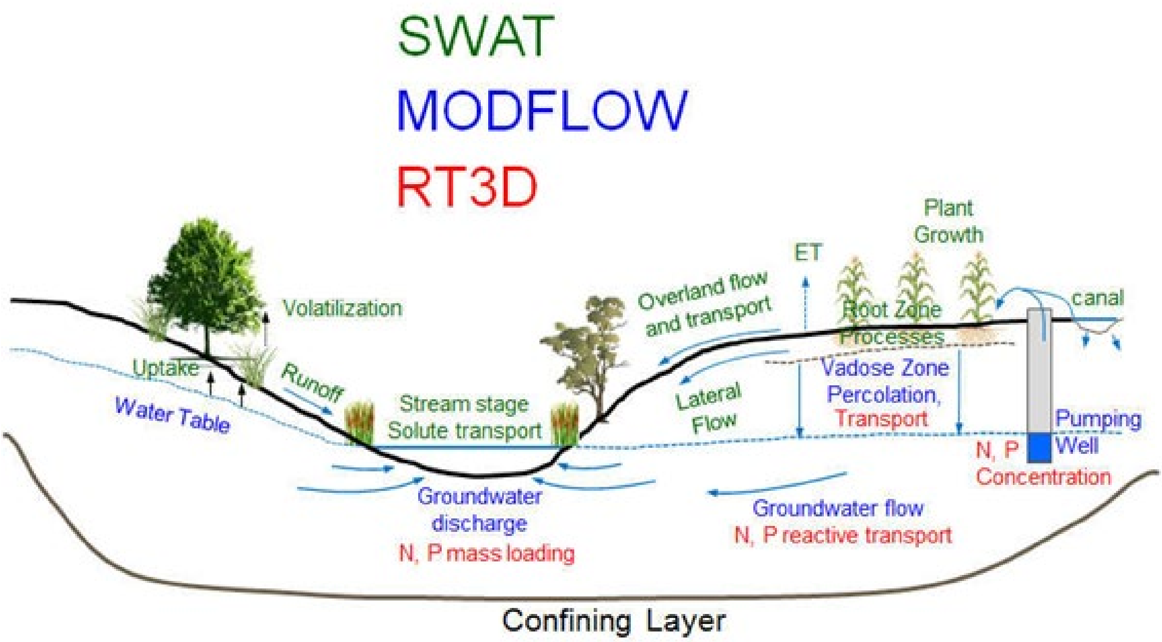


Fig. 5.1 SWAT-MODFLOW: SWAT, MODFLOW and RT3D operations in green, blue and red respectively (Chunn et al. 2019)

5.1.5 Calibration and validation

Calibration is the process of improving the parameterization of a model to fit a given set of observed data for a specific time period while validation involves the demonstration that the same set of parameters used in the calibration process are able to produce acceptable results when compared with observed data for another time period. The validation exercise can be viewed as the testing of the calibration parameters using observed data not previously used in the calibration exercise. Usually, observed datasets are split into two with one set used for calibration and the other for the validation exercise.

The calibration and validation processes are necessary in hydrological modelling to identify and determine the dominant processes driving a hydrological system. Good calibration and validation exercises should include dry, average and wet periods to ensure the parameterisation is applicable across a wide spectrum of hydrological conditions. The inclusion of various hydrological condition in the calibration and validation exercises allows for evaluation of the seasonal influence of the determined parameters in the hydrological system.

There are several statistical methods used in evaluating calibration and validation exercises. These methods often use thresholds to determine if calibration and/or validation exercises are satisfactory or unsatisfactory.

5.1.6 Applied modelling and presentation methods

Table 5.2 presents the applied modelling activities for Objective 1, the study area, the partners involved and the methods used.

Results of water balance modelling assessments can be presented in a large variety of graphs and tables. However, typically a table or bar chart showing the different water balance components flowing into and out of the area are displayed. Plots comparing anthropogenic water use versus natural inflow, e.g. groundwater recharge can be revealing with respect to the sustainability of water resources.

Table 5.2 Applied methods for major project activities of Objective 1 in different study areas

Activity	**Study area**	**Responsible (supporting) partner**	**Methodology**
Surface water modelling	La Vi	NLU (CWRPI-Div7, Flinders)	Daily surface water components simulated with SWAT for a part of 2015-2017. Model calibrated and validated with SWAT-CUP.
Water balance modelling	La Vi	Flinders (CWRPI-Div 7)	WetSpass-M distributed monthly modelling for 2017 of surface runoff, evapotranspiration, recharge; providing input to MODFLOW and compared with SWAT.
Groundwater modelling	La Vi	Flinders (CWRPI-Div 7)	Monthly groundwater heads, fluxes and balance simulation with MODFLOW for 2017. Model calibrated using observed groundwater levels.
Coupled surface water – groundwater modelling	La Vi	Flinders, NLU	The calibrated MODFLOW model is coupled to the WetSpass-M model and SWAT model for 2017. Recharge from WetSpass-M and SWAT is input to MODFLOW, and vice versa baseflow for channel routing (in SWAT).

Water quality

Besides the water balance (quantity) assessment methods developed in this project, water quality investigations were also conducted in both BD and NT provinces. These water quality investigations were performed to understand better the nutrient contributions to water quality conditions over time and how they relate to agricultural inputs. The main nutrients of interest were nitrogen (NO_3^-) and phosphorus (PO_4^{3-})as they are commonly used by farmer's in large quantities and their chances of leaching to groundwater through the sandy profiles are high. In addition, EC, pH and other soil properties were also monitored to see if there is any relationship between different parameters.

Samples of surface and groundwater were collected from open wells, bores, streams in La Vi catchment, Phu Cat district, BD province where most of the nutrition experiments on peanut and mango were carried out. In NT province, Ninh Hai and Ninh Phuoc districts were chosen as the main locations as these areas are used for intensive vegetable production and the project carried out experiments on peanut and onion.

Initial water quality investigations in BD targeted the whole La Vi basin to identify areas of excess nutrient loads or high salinity that could be tied to agricultural practices, livestock, or domestic practices. A total of 36 groundwater bores and 16 river samples were analysed for each field campaign: in April 2015, October 2015, and April 2016. The low nutrient concentrations throughout the La Vi catchment, despite intense agricultural and domestic use of surface and groundwaters, prompted subsequent sampling focused on a few sites but at a weekly sampling frequency. Three groundwater and two river sites were sampled for nutrients for 8 weeks (with a few pauses) beginning 8 December, 2016.

In An Chan commune of Phu Yen province, 32 agricultural (vegetable and rice) sites were selected to collect surface (streams, irrigation channels) and groundwater (tube and open wells) samples to investigate the level of contamination (NO_3^- and PO_4^{3-}) from fertilizer or animal sources (Do et al. 2015).

In another study conducted in NT during 2015, groundwater sample collection was conducted at 27 sites in six villages of the An Hai and Nhon Hai communes from areas around intensive vegetable production and areas planned for further expansion. This was followed in 2017 when groundwater samples were collected every two months along two transects in Ninh Hai and river water samples in the Cai River to investigate interannual variability.

5.2 Methods to improve on-farm water use efficiency, to overcome soil constraints and to reduce nutrient leaching

5.2.1 Identifying, overcoming and improving nutrient use efficiencies (NUE)

Glasshouse double pot method to identify nutrient deficiencies and nutrient supplying capacities of the soils

The double-pot method, developed in SMCN/2007/109 (Hoang et al. 2015), involves growing the test plant in a small amount of soil in a container suspended above a nutrient solution; the plant roots can access nutrients from the soil and from the nutrient solution. By selective omission of the nutrients from solution, the relative nutrient supply capacity of the soil can be directly assessed. This method was used to identify nutrient deficiency and the supplying capacity of all the soils from BD, NT and QN provinces where field experiments or demonstration trials were conducted for peanut, mango and vegetables with soil properties as presented in Table 5.3.

Nutrient experiments to test and verify the rates and forms of deficient nutrients (K and S) using different fertilizers for optimum growth of peanut, mango and onion on farmer's fields

K and S were previously identified as major limiting nutrients in sandy soils of BD for peanut production. Thirteen experiments since 2015 were carried out by using different rates and forms of K and S. These experiments had farmer's practice (FP) as control to compare peanut yield performance against different rates of K and S (Table 5.4).

Binh Dinh: In BD, farmers normally apply 10 tonnes of FYM, 40 kg N, 40 kg P, 50 kg K and 500 kg of lime for peanut production. Soils are normally prepared by carrying out tillage operations followed by sowing using 100 kg peanut seeds/ha not in rows but randomly.

Quang Nam: In QN, farmer's normally apply 4 tonnes of FYM + 30 N + 29 P + 33 kg K + 300 kg lime/ha.

Table 5.3. Soil properties in each location of omission nutrient experiments

Location	pH_{KCl}	OC (%)	N (%)	P_2O_5 (%)	K_2O (%)	K^+ (cmolc/ kg)	S (mg/kg)
1. Binh Dinh province (peanut fields)							
Cat Hiep commune	4.7	0.53	0.017	0,023	0.05	0.05	2.0
Cat Hanh commune	4.7	0.84	0.012	0.023	0.10	0.05	1.9
2. Binh Dinh province (mango field)							
Cat Hanh commune	4.2	0.83	0.013	0.023	0.11	0.05	1.6
3. Ninh Thuan province							
Truc, Thinh experiment	5.5	1.03	0.016	0.017	0.45	0.06	2.3
ASISOV experiment	4.7	1.07	0.012	0.008	0.43	0.05	2.8

4. Quang Nam province

Location	pH_{KCl}	OC (%)	N (%)	P_2O_5 (%)	K_2O (%)	S (mg/kg)	Cu (mg/kg)	B (mg/kg)	Zn (mg/kg)
Binh Sa commune/QN	4.77	0.67	0.047	0.030	0.07	13.7	1.03	1.56	11.0
Binh Trung commune/QN	4.14	0.42	0.014	0.010	0.05	68.5	0.99	1.23	6.26

The experimental sites were located at Cat Hiep (14°03′05″N and 109°99′52″E) and Cat Hanh communes (14°05′46″N and 109°00′16″E), Phu Cat district, BD province in SCC VN. The soils are deep sands with >95 % sand, < 5 % clay and are classified as Haplic Arenosols (Bell et al. 2015a). The climate in this region is tropical savannah with long dry periods (January to August) and high evaporation rates (~100 mm/month) with monsoonal rainfall (average 1,900 mm/year) concentrated over a short period (September to December) with average temperatures varying between 27-35 °C. Soils at these two sites are acidic in nature (~4.8 pH_{KCl}), low in total organic carbon (~0.6 %), total N (~0.02 %), total P (0.01 %), total K (~0.05 %) and had 0.05 cmolc exchangeable K kg^{-1} and extractable S (2 mg/kg soil) (Table 5.3).

Table 5.4 List of experiments conducted to determine appropriate rates and forms of K and S for peanut production in sandy soils of Binh Dinh

Name of Experiments	Treatments	Location	Year	No. of experiments
K fertilizers experiments for peanut with perforated hose to irrigate	(K rate: 0, 50, 75, 100 kg K/ha) x (Form of K: KCl, K_2SO_4, K40%)	Cat Hanh and Cat Hiep communes, Phu Cat - Binh Dinh	2015	2

Name of Experiments	Treatments	Location	Year	No. of experiments
S fertilizers experiments for peanut with perforated hose to irrigate	(S rates: 0, 15, 30 kg S/ha) x (Forms of S: $(NH_4)_2SO_4$, K_2SO_4, NPK 16:16:8:13S)	Cat Hanh and Cat Hiep communes, Phu Cat - Binh Dinh	2015	2
Organic and K fertilizer combination experiment with perforated hose to irrigate	(Organic matter: Nil, 8 tonnes manure, 10 tonnes Rice husk biochar /ha) x (K rate: 0 kg K, 50 K (KCl), 50 K (K_2SO_4)	Cat Hanh and Cat Hiep communes, Phu Cat - Binh Dinh	2015	2
K and S fertilizers experiments for peanut with sprinkler + mini pan for irrigation	(K Rate: 0, 50, 75, 100 kg K/ha) x (S rate: 0, 15, 30, 45 kg S/ha)	Cat Hanh and Cat Hiep communes, Phu Cat - Binh Dinh	2016	2
K and S fertilizers balance experiments for peanut with sprinkler + mini pan for irrigation	(K Rate: 0, 75 kg K/ha) x (S rate: 0, 15, 30 kg S/ha)	Cat Hanh and Cat Hiep communes, Phu Cat - Binh Dinh	2017	2
K fertilizers balance experiments for peanut with sprinkler + mini pan for irrigation	(K Rate: 50, 75, 100 kg K/ha)	Cat Hanh and Cat Hiep and Cat Lam communes, Phu Cat - Binh Dinh	2018	3
	Total			13

5.2.2 Testing irrigation technologies to improve water use efficiencies (WUE) for groundwater dependent crops

Irrigation technologies such as mini pan (MP), sprinkler irrigation (SI), drip irrigation (DI), micro-sprinkler (MS) and fertigation (F) were tested and verified for their use in farmer's fields to improve water use efficiencies (WUE) for peanut, mango and onion relative to current farmer's practice (FP).

Peanut irrigation

Six experiments using different types of irrigation technologies were tested and assessed under peanut production to compare their effectiveness and WUE efficiencies (Table 5.5).

Table 5.5 List of experiments conducted for peanut production with different types of Irrigation technologies (FP, MP, SI)

Treatments	Location Commune/district/province	Year	No. of experiments
T1 Irrigation according to Farmer's Practice (FP)	Cat Hanh and Cat Hiep/ Phu Cat/Binh Dinh	2015	2
T2 Irrigation according to FP + mini pan (MP)	An Hai/Ninh Phuoc/Ninh Thuan	2015	1
T3 Sprinkler irrigation (SI)	Cat Hanh and Cat Hiep/ Phu Cat/Binh Dinh	2016	2
T4 SI + MP	An Hai/Ninh Phuoc/Ninh Thuan	2016	1
Total			6

Integrated irrigation and nutrient management for peanut

Nine experiments were conducted on combined effects of integrating irrigation and nutrient technologies in Binh Dinh and based on the results from these experiments in Binh Dinh, 2 more experiments were conducted in Quang Nam (Table 5.6). The treatment combinations tested were:

Type 1: K rates: 50, 75 kg K/ha + Irrigation (FP, SI + MP)

Type 2: S rates: 20, 30 kg S/ha+ Irrigation (FP, SI + MP)

Type 3: Basal: (4 tonnes of FYM, 30 N, 26 P, 300 kg lime + 33 kg K) x Irrigation (FP, SI + MP)

Type 4: Basal: (4 tonnes of FYM, 30 N, 26 P, 300 kg lime + 75 kg K) x Irrigation (FP, SI + MP)

Type 5: Basal: (4 tonnes of FYM, 30 N, 26 P, 300 kg lime + 75 kg K + 20 kg S) x Irrigation (FP, SI + MP)

Type 6: Basal: (4 tonnes of FYM, 30 N, 26 P, 300 kg lime + 75 kg K + 30 kg S) x Irrigation (FP, SI + MP)

Table 5.6 List of integrated irrigation and nutrient experiment types for peanut

Experiment type	Location Commune/district/province	Year	No. of experiments
T1, T2	Cat Hanh and Cat Hiep and Cat Lam/ Phu Cat/Binh Dinh	2017	3
	An Hai/Ninh Phuoc/Ninh Thuan	2017	1
	Cat Hanh and Cat Hiep and Cat Lam/ Phu Cat/Binh Dinh	2018	3
T3, T4, T5, T6	Binh Sa and Binh Trung/Thang Binh/Quang Nam	2018	2
Total			9

Potassium and sulfur leaching were assessed by analysing K, S in the soil leachate. Leachate samples were collected 3 and 25 days after K and S application from the 25 cm diameter plastic bucket fitted with mesh to prevent soil entry into the bucket and placed 30 cm below the soil surface. A plastic tube was fitted to the bottom of the bucket to withdraw the leachate using a syringe. Leachate was collected at each sampling time and the volume of leachate was measured using a cylinder. Leachate samples were filtered and analyzed for K by flame photometry and soluble S by ion chromatography.

Mango irrigation

Four experiments using different types of irrigation technologies (Types 7, 8, 9 and 10) were tested and assessed under mango production to compare their effectiveness and water use efficiencies (Table 5.7). Before the onset of rainfall, 30 kg of manure was applied under the canopy of each tree and incorporated in the soil.

Type 7:Irrigated by FP

Type 8: Irrigated by FP + MP

Type 9:Drip Irrigation (DI) + MP

Type 10: Irrigation by micro-sprinkler (MS) + MP

Table 5.7 List of Irrigation experiments for mango

Types of experiments	**Location Commune/district/province**	**Year**	**No. of experiments**
Type 7, 8, 9	Cat Hanh/Phu Cat/Binh Dinh	2015	2
		2016	1
Type 7, 8, 9,10	Cat Hanh/Phu Cat/Binh Dinh	2017	1
Total			4

Integrated irrigation and nutrient management for mango

Two experiments (Table 5.8) were conducted on combined effects of integrating irrigation and nutrient technologies. Experiment types and their treatments were:

Type 7: Irrigated by FP

Type 9: Drip Irrigation (DI) + MP

Type 11: DI + MP + fertigation (F) + fertilizer rates (NPKS 0.48: 0.48: 0.74: 0.39 kg /tree)

Type 12: DI + MP + fertigation (F) + fertilizer rates (NPKS 0.48: 0.48: 0.94: 0.39 kg /tree)

Table 5.8 List of integrated irrigation and nutrient experiments for mango

Type of treatments	**Location Commune/district/province**	**Year**	**No. of experiments**
Type 7, 9, 11	Cat Hanh/Phu Cat/Binh Dinh	2018	1
Type 7, 9, 12	Cat Hanh/Phu Cat/Binh Dinh	2018	1
Total			2

Integrated irrigation and nutrient experiments for onion

Two integrated irrigation and nutrient experiments were conducted for onion in Ninh Thuan province where farmers used high doses of fertilizers for vegetable production increasing the cost of input as well as contributing to leaching of nutrients to groundwater as was evident from assessment of ground water quality in Ninh Thuan (Table 5.9). The hypothesis for these experiments was that reduced nutrient rates of N, P and K could reduce leaching of nutrients (N and P) without having an impact on yield of onion as well as decrease the cost of fertilizers applied. Most farmers in Ninh Thuan use 5 t of manure/ha as basal soil amendment and sprinklers to irrigate onion crops, however, they do not use mini pan to guide irrigation scheduling. Hence, the treatments that were tested were sprinkler irrigation guided by mini pan and reduced rates of N, P and K as follows:

I1: Irrigation by farmer'spractice (FP- Sprinkler):

I2: FP + MP

F1: FP (fertilizer 100 kg N + 70 kg P_2O_5 + 80 kg K_2O + 5 t manure)

F2: F1-25 % N

F3: F1- 50 % N

F4: F1-75 % P_2O_5

F5: F1- 75 % K_2O

F6: F1- 50 % P_2O_5

Table 5.9 List of integrated irrigation and nutrient experiments for onion

Treatments	Location Commune/district/province	Year	No. of experiments
I1, I2, I3, F1, F2, F3, F4, F5, F6	An Hai/Ninh Phuoc/Ninh Thuan	2018	2
Total			2

5.2.3 Optimisation of mini pan to guide irrigation scheduling for groundwater dependent crops

The mini-pan (Fig. 5.2) is a simple device used to guide irrigation scheduling based on water evaporation, evapotranspiration, crop factor and climatic conditions (temperature, humidity, wind speed, sunshine hours). The mini pan determines suitable time interval for re-irrigation to ensure that root zone soil water has no negative effect on growth and development of crops.

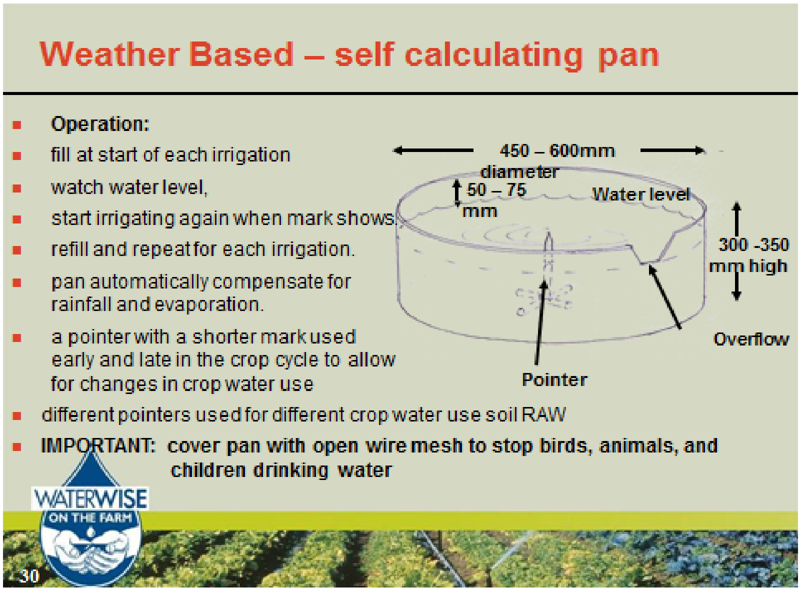


Fig. 5.2 Schematic diagram of the mini pan and its operation

The pan is placed in the field at the end of the rainy season for perennial crops and at the sowing time for annual crops to monitor soil moisture at the time of germination. The mini pan is placed on a flat cultivated surface of the field at a place where there is no shading at any time of the day. It also needs to be placed at a spot where animals are unable to drink water out of the mini pan.

Operating the mini-pan

To begin, fully fill the mini-pan with water after setting it up and observe the level of water on the vertical scale installed in the mini-pan. Trigger water level in the mini-pan is based on types of crop, cropping season, weather etc and when the level of water drops down to threshold level, it is time to re-irrigate. Once the crop is irrigated, re-fill water in the mini-pan to the overflowing point and repeat till the end of the cropping season. Optimisation in a particular environment is based on the data collected by the regional weather station and calculated accordingly by the formulas mentioned below. Normally, FAO guidelines have estimates of the crop factors based on data gathered throughout the world, however, optimisation of mini pan is adjusted based on the region, climatic conditions and crops to be irrigated. It is also essential to monitor moisture levels of soils to the depth of active root zone by using a soil moisture meter to make sure that the active root zone remains at field capacity for the soil where the crops are to be sown.

Developing time schedule to irrigation for crops

A suitable schedule of irrigation for crops will ensure the supply of enough water for growth and development of crops without over supplying water. The amount of water required depends on many factors such as weather (temperature, humidity, wind speed, day light time), soil texture and growth stage of crops. In this method, the amount of water required for a crop is approximately equal to amount of water that transpires from crops and that lost through evaporation (Etc). The Etc value equals to the amount of available water in soil and the scale is adjusted accordingly to indicate the time to re-irrigate in sufficient amount to restore the readily available water (RAW) in soil, calculated according the Formula:

ETc = Kc x ETo (1)

where:

ETc: transpiration-evaporation of crop

ETo: transpiration-evaporation of reference value (for example, amount of transpiration-evaporation of 1 unit area of grass cultivated in a standard conditions).

Kc: coefficient value of crop (depends on type of crops, growth stage)

ETo = Kp x Ep (2)

where :

Ep: amount of water evaporated from the mini-pan

Kp: coefficient of pan

From (1) and (2) we have:

ETc= Kc x Kp x Ep

When the amount of water lost through transpiration-evaporation of crop is equal to the amount of readily available water (RAW) then it is a right time to re-irrigate for crop.

RAW = Kc x Kp x Ep (RAW (Readily Available Water)

Ep = RAW/ Kc x Kp

Kc and Kp depend on weather factors and geography, and need to be adjusted as in formulae (1) and (2)

Step 1 : Estimate ET of weather parameters

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where:

ET_o: reference evapotranspiration [mm day^{-1}],

R_n: net radiation at the crop surface [MJ m^{-2} day^{-1}], G: soil heat flux density [MJ m^{-2} day^{-1}],

T: air temperature at 2 m height [°C],

u_2: wind speed at 2 m height [m s^{-1}],

e_s: saturation vapour pressure [kPa],

e_a: actual vapour pressure [kPa],

e_s-e_a: saturation vapour pressure deficit [kPa],

Δ: slope vapour pressure curve [kPa $°C^{-1}$],

γ: psychrometric constant [kPa $°C^{-1}$].

5.2.3 Use of amendment materials to improve soil buffering capacity, water and nutrient use efficiency on sands in farmer's fields

Use of amendment materials (30 t of sugarcane residue/ha, 200-300 t of clay-rich soil/ha, 60 t of bentonite/ ha etc), together with water saving irrigation technologies have the potential to improve WUE and NUE of crops. The amendment materials are incorporated in the sandy soil to a depth of 10-30 cm depending on crop type and their root depth. Most farmers currently use cow manure as it is available because most farms in the study are as retain livestock.

5.2.4 Training project staff to develop QA/QC protocols and skills to analyse water, soils, plant and fertilisers

In the last five years while Murdoch University has collaborated with ASISOV and HUAF, the project team from Murdoch assisted in the preparation for QUATEST 3 to establish quality control systems and gain ASISOV accreditation under the Vietnam Laboratory Accreditation Scheme (VLAS).

5.2.5 Use of Farm Economic Model (FEM) to calculate economic efficiency

The model was developed by Mr Peter Gartrell during the previous project, SMCN 2007-109, which also provided training to the current project participants on the use of FEM to calculate economic efficiencies under different systems. Comparing farm enterprises by isolated gross margin analysis is of limited value in understanding farming systems comprising diverse activities particularly where labour and cash are limited. The spreadsheet-based FEM was constructed to allow comparison of farming systems, to test desktop scenarios and to consider compatible activities with regard to labour utilisation and cash flow. The model is run by incorporating all the input and output parameters to estimate the economic efficiencies under different practices. The model uses input costs like quantity and price of fertiliser etc, total amount of water used, cost of energy, labour, cost of irrigation system, and durability of system to determine depreciation. Output parameters include yield and selling price to calculate profit margins, return on investment (ROI), internal rate of return (IRR) and net profit value (NPV) etc. However, there were difficulties in using FEM for mixed farming systems and in estimating the economic efficiency of long duration perennial crops (mango) due to variation in yield each year (alternate years for optimum fruiting) and climatic conditions affecting crop yield or quality. Hence it was agreed at the Mid Term Review that FEM would only be used for estimation of profit margins, ROI, IRR and NPV for single crops in single years.

5.2.6 Field demonstrations and training

Farmer Field School Manual (www.fao.org/farmer-field-schools/en/) is an FAO tool used by extension agencies around the world to train the farmer's, commune technicians, extension staff during the field days and was an important activity of the project throughout the project life (2015-19).

Field days and training for integrated irrigation and nutrient management

The Project set up 17 large scale demonstrations of peanut and 4 demonstrations of mango. These were used for economic assessments (FEM) and for field days and training sessions (Table 5.10).

Table 5.10 List of peanut field demonstrations using Integrated Irrigation and Nutrient Management approach

Treatments	**Location**	**Year**	**No. of sites**
D1:Farrmer's practice D 2 (MP) Fertilizers according to FP + Manure + Irrigation according to minipan D 3 (MP + BF + M) Best Fertilizers[A] + Manure + Irrigation according to minipan D 4 (MP BF + B) Best Fertilizers + Biochar + Irrigation according to minipan	Cat Hiep commune, Phu Cat district, Binh Dinh province	2015, 2016	2
D1 (FP) Fertilizers according to FP + Manure + (4 tonnes of FYM + 30 N + 29 P + 33 kg K + 300 kg lime/ha) Irrigation according to FP (surface irrigation) D2 (MP+ BF + M) Best Fertilizers + Manure + Sprinkler Irrigation according to mini pan	Cat Trinh, Cat Hanh and Cat Hiep commune, Phu Cat district, Binh Dinh province	2018	3
	Cat Trinh, Cat Hanh, Cat Hiep and Cat Lam commune, Phu Cat district, Binh Dinh province	2019	10
	Binh Trung and Binh Sa commune, Thang Binh district, Quang Nam	2019	2
Total			17

[A]Best fertilizer (BF) in Binh Dinh: ASISOV recommended rates of fertilizer (D1 (FP) Fertilizers according to FP + Manure (8.0 tonne of FYM +45 kg N + 90 kg P_2O_5+ + 9.38 kg $CuSO_4.5H_2O$ + 1 kg $(NH_4)_6Mo_7O_{24}.4H_2O$ + 17.8 kg $ZnSO_4.5H_2O$ + 1.43 kg H_3BO_3 + 500 kg lime) andirrigation according to FP (irrigation by perforated hose).

Best fertilizer (BF) in Quang Nam: 4 tonnes of FYM + 30 N + 29 P + 33 kg K + 300 kg lime/ha and irrigation according to FP (hose irrigation).

Table 5.11 List of field demonstrations carried out for mango production

Name of Experiments	Treatments	Location	Year	No. of sites
Mango demonstration on Integrated irrigation management (IIM)	D5:Farmer Practice (FP) Fertilizers 30 kg Manure + 3 kg NPKS + 0,5 kg KCl /tree + irrigation (800 L water/tree by hose) D6: Drip Irrigated +mini pan+ 3kg NPK + 0.5kg urea + 0.75 kg KCl + 30kg manure/tree applied to soil	Cat Hanh commune, Phu Cat district, Binh Dinh province	2016	1
			2017	1
Mango demonstration on Integrated irrigation and nutrient management (IINM)	D5: Irrigated by farmer's practice D6: Drip irrigation + mini pan + Fertigation (NPKS 0.48: 0.48: 0.94: 0.39 kg /tree)	Cat Hanh commune, Phu Cat district, Binh Dinh province	2018	1
			2019	1
Total				4

Training for use of irrigation technologies under different cropping systems

Irrigation scheduling, design and selection of irrigation ware and installation of irrigation systems were covered in training conducted in all the three provinces (BD, NT, QN). Participants included scientists and researchers from ASISOV and HUAF, technical staff from DARD Extension Centres, staff of Co-operatives and Communes, farmers, and students from HUAF. The training materials were developed for topics as follows:

Table 5.12 Irrigation training topics

Topic	Description
Irrigation scheduling	Participant took part in exercises on drip and sprinkler scheduling
Irrigation scheduling	Covered calculations of crop watering schedules for the complete crop cycle for crops
Dripline selection	a) Dripline flow rate selection – why low flow? Negative impacts of high flow rate dripline b) Relationships of wall thicknesses, maximum operating pressures, pressure gauges & flushing valves – and impacts on operating time/costs c) Irrigation system selection: Flood, Sprinkler or Dripline
Irrigation design	Parameters for design – laterals, sub-main & mainlines
Irrigation exercises	Parameters for design – laterals, sub-main & mainlines. Includes participant exercises re typical designs
Pumps	Types of Pumps and pump selection.

5.2.7 Communication and Engagement activities

Several forms of engagement with Government (DARD, MARD, VAAS, SFRI, MONRE) and private sectors (Irrigation supply ware, fertilizer manufacturers etc)were carried out to influence policy, regulation, and scale out of technologies to sustainably manage soils and groundwater. Some of the major activitiescarried were:

i) Regular meetings with DARD in BD, NT and QN

ii) Meeting in Hanoi at VAAS in 2017: On 20 July 2017, Vietnamese and Australian members of the Project team travelled to Hanoi for a meeting with the Ministry of Agriculture and Rural Development (MARD) and the Vietnam Academy of Agricultural Sciences (VAAS) to present project findings on water saving technologies and to discuss further steps in promoting and extending the same to larger farming audience. The meetings suggested widespread testing and demonstration of the technologies with farmers in other provinces of SCC VN and on other crops.

iii) Three researchers from Nong Lam University (Loi, Liem and Nhat) participated in the International Water Week Conference (VACI) in March 2018 to present the work that our project carried out to emphasise the need for water conservation by adopting water saving irrigation technologies.

iv) The project team organised a study tour in BD province in March 2019 and invited guests from BD, NT and QN provincial governments, VAAS, MARD, IPSARD, SFRI etc to participate in the event to show them the use of irrigation technologies to sustainably manage ground water resource and nutrient management practices developed to improve productivity of crops in infertile sands of SCC VN.

v) The project also sponsored a one-day seminar at the VACI conference March 2019, Hanoi where the project team presented the findings of 5 years of research to promote and create awareness about the use of technologies that are sustainable and beneficial.

vi) Dr Khoi and Dr Son of IPSARD were invited to present their views at the BD and VACI seminars on developing and presenting policies for the profitable and sustainable use ofthe groundwater for the agricultural sector in SCC VN.

vii) The project team is preparing fact sheets, brochures anda monograph to highlight the work done over the last 5 years and promote adoption of technologies that are well suited to SCC VN and will help alleviate poverty of small landholders.

6 Achievements against activities and outputs/milestones

Objective 1: To assess groundwater utilisation and quality in targeted areas within SCC VN.

no.	activity	outputs/ milestones	completion date	Comments
1.1	Interrogate up-to-Date geospatial Information and relevantdata sources (D7, Flinders Uni, NLU)	Report that compiles and describes available information, and identifies knowledge gaps	2015	Div 7, NLU and FU have collected maps and data and created a GIS database and used this for geospatial analysis and data pre-processing for model development. Identified data gaps guided data collection, which has been setup with the goal to support further water balance modeling.
		Project meeting to communicate outputs and directions for water balance modelling	2016	Modeling meeting to communicate outputs and directions on water balance occurred in Aug. 2016
1.2	Groundwater assessment and monitoring (IAS SV, DONRE, ASISOV, D7)	Benchmark study: Report specifying sampling, handling, analytical and quality control protocols for groundwater and surface water samples collected.	2015	Water quality sampling and monitoring completed in BD. Data for groundwater and surface water quality has been regularly collected in NT targeted areas (An Hai and Ninh Phuoc).
		Groundwater assessment protocol implemented in Binh Dinh and Ninh Thuan.	Aug 2015; then at wet and dry season intervals	Groundwater assessment protocol was implemented in 2015 in BD and NT.
		Annual summary reports of water quality.	9th month in each year	Reports of water qualitycompleted inBD.
		Final water quality report synthesising information from present project and previous projects.	2018	Reports of water quality completed by IAS for NT.
1.3 (a)	Groundwater balance modelling (D7, NLU, Flinders Uni, DONRE)	PhD student selected; study programme approved.	2015	PhD student (Hai) selected in 2015.
		Parameters for groundwater balance model determined, data to validate model compiled and plan to fill data gaps developed.	2015	SWAT model calibrated and validated for Cai River in 2016. SWAT model for La Vi catchment completed with improved soil texture and land use data collected by NLU.

no.	activity	outputs/ milestones	completion date	Comments
		Report for groundwater balance for the lower Kone river catchment in BD completed.	2017	Updated soil mapping: Finished. Development of land use maps that capture temporal changes in land use since 2005: finished. A paperon this was published Development of a groundwater model: Finished. Characterization of surface water – groundwater interaction between aquifer and river at the farm level: Finished. Geophysical examination of the aquifer characteristics: Finished Handover of qualitative groundwater level sampling data: Finished Improved watershed delineation for SWAT model: Finished All data apart from high flow discharge estimates is available: Pumping test data: collected and analysed; river discharge data; collected. A SWAT model; a MODFLOW model; a coupled WetSpass-M/SWAT-MODFLOW model; dynamic water balance results; a report describing the models and results as well as containing a Manual how the measurement-modelling procedure can be transferred or used in other areas in Vietnam. Water balance and scenario modelling for La Vi catchment was completed.
		Report forgroundwater balancemodelling applied to coastal catchments in NT.	2019	Since the water balance modelling in La Vi catchment took longer than planned, no workwas done on applying the modelling to NT
1.3 (b)	Model the economic value of groundwater in SCC VN (HU/NLU)	Masters student selected and study program approved.	2015	After unsuccessful attempts to recruit first a Masters student at HCE and then Bachelor's students, this workwas re-assigned to ASISOV.
		Training in FEM and upgrading to model economic value of groundwater	2016	Training on FEM conducted (July 2015), upgrading of the model discussed in April 2016 and during MTR (July 2016). It was concluded that FEM could only be used to estimate single crop profitability, but wasn't suitable to estimate the economic value of groundwater.
		Theses submitted: assessment reported for agro-economic value of groundwater to SCC VN	2017	Not completed. ASISOV reported on the profitability of irrigation options.

no.	activity	outputs/ milestones	completion date	Comments
1.4 ext.	Hydrological and hydrogeological data for La Vi (Div 7 and NLU)	The additional time allows Div 7 and NLU to collect the additional data for modelling.	2019	Successful delivery of data for modelling
1.5 ext.	Update land use and soil maps, landuse Scenarios (NLU, ASISOV)	It is assumed that the additional soil sampling by NLU will be sufficient to prepare a suitable soil map for water balance modelling. Cooperation between NLU and ASSISOV enables creation scenarios of agricultural development	2019	Updated soil, landuse maps and agricultural developments scenarios: Finished
1.6 ext.	Strengthen the calibration and validation of the SWAT and MODFLOW coupled models, its application and analysis of results FU, NLU	Flinders expertise enables building of coupled surface and groundwater models, close cooperation and staff exchange with NLU allows analyses of water resources and future scenarios.	2019	Coupled surface (SWAT) and groundwater (MODFLOW) models developed, calibrated, validated and used to test effects of land use scenarios on water balance.

PC = partner country, A = Australia

Objective 2: To evaluate methods to improve on-farm water use efficiency and evaluate soil amendments to overcome soil constraints and reduce nutrient leaching.

no.	activity	outputs/ milestones	completion date	Comments
2.1	On-farm nutrient balance assessment (HUAF)	Potassium and sulfur loss determined for nutrient balance under different nutrient management practices, soil types, crops and irrigation methods	2018	Ph.D student from ASISOV (Do Thanh Nhan) supervised by Dr Hoa from HUAF assessed and quantified on-farm nutrient balances for peanut and mango in Binh Dinh under different management practices
2.2	Evaluate irrigation management systems to maximise water use efficiency, improve crop productivity and reduce nutrient losses.	Feasible on-farm irrigation scheduling methods and technologies tested, assessed, verified and recommended to DARD for approval based on demonstration and field experiments on farmer's fields.	2018	DARD BD approved the irrigation technologies for peanut and mango in BD for adoption by farmers. Provincial Govt is already promoting drip technology for pumelo and citrus. Published refereed articles on irrigation technologies for peanut in Vietnamese journals. Effect of sprinkler irrigation and mini-pan on K and S leaching reported in international journal papers (Hoang et al. 2019, 2020).
2.3	Evaluate nutrient management to	Deficiencies of nutrients	2018	Fertiliser manufacturers in Binh Dinh and Hue provinces briefedon nutrient

no.	activity	outputs/ milestones	completion date	Comments
	overcome soil potassium, sulphur and micronutrient constraints and strategies to reduce nutrient losses.	(potassium, sulphur and Cu) rates and forms tested, verified and recommended as management guidelines for crops (peanut, mango, onion) grown in sands of SCC VN.		deficiencies and are able to supply balanced fertilisers with micronutrients included. A range of products containing micronutrients are now being used by farmers and that made it difficult to implement a systematic study of micronutrient responses in peanut and mango. Refereed publication on K and S published in International journals and one more paper under preparation for submission.
2.4	Determine residual value of K, S, and Cu fertilisers	Determined residual value of K, S and Cu and options for correcting K, S and Cu deficiencies recommended in sands of SCC VN	2018	Ph.D thesis on role and translocation of Cu for peanut in progress The negative balances of K and S mean that there is effectively no residual value to K and S fertilisers at present unless much higher (uneconomic) rates of fertiliser are applied. A range of products containing micronutrients that are applied by farmers made it difficult to complete a study of micronutrient (B, Cu) residual effects in peanut and mango.
2.5	Select packages of irrigation and nutrient management to test for water use efficiency, profitable crop production and minimal nutrient loss	Profitable packages for water and nutrient use efficiency for peanut and mango crops grown on sands in Binh Dinh developed for farmer's use and updated each year by ASISOV	2017, 2018, 2019	ASISOV has obtained approval of the peanut and mango production technologies for BD use. ASISOV is revising its peanut production technology guidelines for farmers to incorporate the fertiliser and irrigation technologies recommended by the present project. ASISOV will develop and publish its mango production technology guidelines for farmers including the fertiliser and irrigation technologies recommended by the present project.
2.6	Determine effect of clay amendment of sands on soil organic carbon levels in south-west Australia (MU)	Final report outlining effects of climate, clay rates, types and time on soil carbon accumulation after claying in progress	2019	The soil samples were collected from the Dalyup field site and soils analysed for carbon content. The Report has not been finalised yet.

PC = partner country, A = Australia

Objective 3: To determine promising soil and water management technologies for adoption by farmers and develop scale out and communication programmes for SCC VN.

no.	activity	outputs/ milestones	completion date	Comments
3.1	Field demonstrations and training in integrated water, soil and nutrient management	Since 2015, sites were selected for demonstrations of irrigation and fertiliser use technologies on farmer's fields for peanut and mango crops Field demonstrations established each year on different farmer's fields Vietnam Women's Union, commune technicians and farmer groups involved to take part in field days on demonstration sites Trainings provided to commune technicians and farmer's at commune centres each year Survey, training and interaction by women extension specialist with women farmer's	2015-2019	Capacity of ASISOV and DARD personnel developed through training provided by Australian specialists and by experiential learning Extension workers and leading farmers learnt, and applied skills to facilitate famer to farmer learning Farmers trained to improve on-farm integrated water use, soil and nutrient management Engagement with co-opertaives in BD Trainings, field days and media release through TV, newspapers etc to scale out activities and deliver planned project impacts Involvement and interaction with women farmer's improved over time. Overall, 40 % of attendees at field days and training programmes were women.
3.2	Modify and re-evaluate technologies based on cost-effectiveness	Technologies evaluated each year for cost-effectiveness and use FEM evaluations of technology adoption impacts on cash flows and labour requirements Results of cost-effectiveness used in formulation of case for approval by DARD	2017-2018	Technologies tested, verified and evaluated with cost effectiveness in BD, then tested in other provinces (QN and NT), for use on different crops and for adoption by farmers.
3.3	Develop case for approval and support from DARD and central government to extend scale out	Case for use of irrigation and nutrient management technologies developed and	2017-2018	DARD approvals given in BD for peanut irrigation and mango irrigation technologies Yet to be approved by Central government

no.	activity	outputs/ milestones	completion date	Comments
	programs introduced under project	approved by DARD and provincial govt		
3.4	Arrange communication to influence policy; regulation; self-regulation aimed at managing groundwater sustainability	Successfully carried out study tour in BD, presented project findings at VACI conference in Hanoi More than 40 people representing heads and staff from agriculture, water and policy related institutes participated in the study tour and VACI conference organised by the project team in March 2019	2019 March 2019	Dr Khoi, former director IPSARD and now an academic at Hanoi University in the Department of Policy agreed to write a paper on policy for sustainable use of water resources in the agriculture in SCC VN. Draft not yet submitted.
3.5	Develop quality assurance systems in ASISOV laboratories	Project team from Murdoch assisted in the preparation for QUATEST 3 to establish quality control systems and for ASISOV to gain accreditation under the Vietnam Laboratory Accreditation Scheme (VLAS)	2016-2019	ASISOV scientists now have the knowledge of QA/QC protocols and have been analysing samples for government agencies and the labs are adequately equipped to analyse water, soils and plant samples. ASISOV did not maintain the registration because there were insufficient commercial samples analysed to justify the cost
3.6	Engagement with the fertiliser and irrigation technology supply chains	Met with 4 fertiliser manufacturers and wholesalers in 2015-2016. Monitored new irrigation hardware products, tested and recommended those that were efficient and cheaper for farmers to adopt in BD, QN and NT. An adoption study on sprinkler and drip irrigation use and supply chains was completed by ASISOV in Binh Dinh and Ninh Thuan. ASISOV itself has started the supply chain from its	2016-2019	Fertiliser wholesalers in BD and Hue were strongly focused on sales of existing products and showed little interest in innovation with new products. They were interested to receive Project reports and findings on K, S and micronutrient deficiencies. We engaged with a manufacturer of new irrigation ware and facilitated the evaluation of this in Phu Cat. However, the equipment was more expensive and more difficult to use than the existing irrigation ware used by ASISOV and hence this opportunity was not pursued. The Adoption study results from survey of BD and NT provinces shows that there is 50 % adoption of big sprinklers in Phu Cat district, BD with less adoption of small sprinklers that were used by the project. In NT, the adoption of sprinkler systems that the project used has increased to more than 80% and farmer's are now exploring the use of fertigation system for production of asparagus. ASISOV has itself opted to retail irrigation systems in Phu Cat district,

no.	activity	outputs/ milestones	completion date	Comments
		station to supply, train and install irrigation systems. They also supply fertilizers and seeds to farmers		BD and also train farmers to design the layout and use appropriate technology that will be suitable to grow crops like peanut, mango, cashew, vegetables etc.

PC = partner country, A = Australia

7 Key results and discussion

Introduction

Sandy soils occupy >500,000 ha in Vietnam (Hoang et al. 2010). Significant areas of coastal sandy soils occur in the North-central and South-central regions of Vietnam and collectively supports 14 % of Vietnam's population (10 million people) with only 5 % of its total agricultural land.

A diverse range of crops are grown in coastal provinces of Vietnam, however, peanut, vegetables and mango are the dominant cash crops and are mainly dependent on groundwater for irrigation (Fig. 3.4). Among the major dry season crops in SCC VN, peanut is the most significant crop in terms of poverty alleviation and sustainable farming system formulation. Hence, the focus was mainly on developing sustainable systems for the cash crops (peanut and mango) grown by small landholders on large areas in BD: less emphasis was placed on vegetables in NT as many private investors and NGO's are already involved in establishing vegetable production businesses. Given that management of groundwater for irrigation of crops and adequate supply of nutrients are the key constraints limiting productivity in sandy soils, the main emphasis was on sustainable management of water and nutrients by addressing the following questions:

1. How can groundwater abstraction for irrigation be managed to fit the available supply?
2. What are the most practical and cost effective solutions to overcome soil constraints and alleviate soil nutrient deficiencies in SCC VN and WA?
3. What technologies and practices can be utilized by groundwater-dependent farmers in SCC VN to improve on-farm water use efficiency and reduce nutrient losses?

7.1 Results of objective and research question 1

7.1.1 Introduction

The La Vi catchment is located in the central coastal province of BD, Vietnam (Fig. 7.1). It covers an area of almost 100 km^2 and has an elevation ranging from 4 to 395 m. The main river in the catchment is the La Vi, with an approximate length of 12 km. The upstream part of the La Vi River and its tributaries have intermittent flow, typically from September to April (Vu et al., 2017). A weir at the end of the downstream section of the La Vi River generally prevents this lower section from drying out seasonally. Only the downstream reach of the river is used for surface water irrigation of rice crops in riparian fields.

There are five administrative communities within the catchment: the town of Ngo May, large parts of the two communes Cat Hiep and Cat Trinh and small parts of the Cat Hanh and Binh Thuan communes (Vu et al., 2017). The population in the catchment is approximately 37,500 to 51,000 people (Vu, 2019).

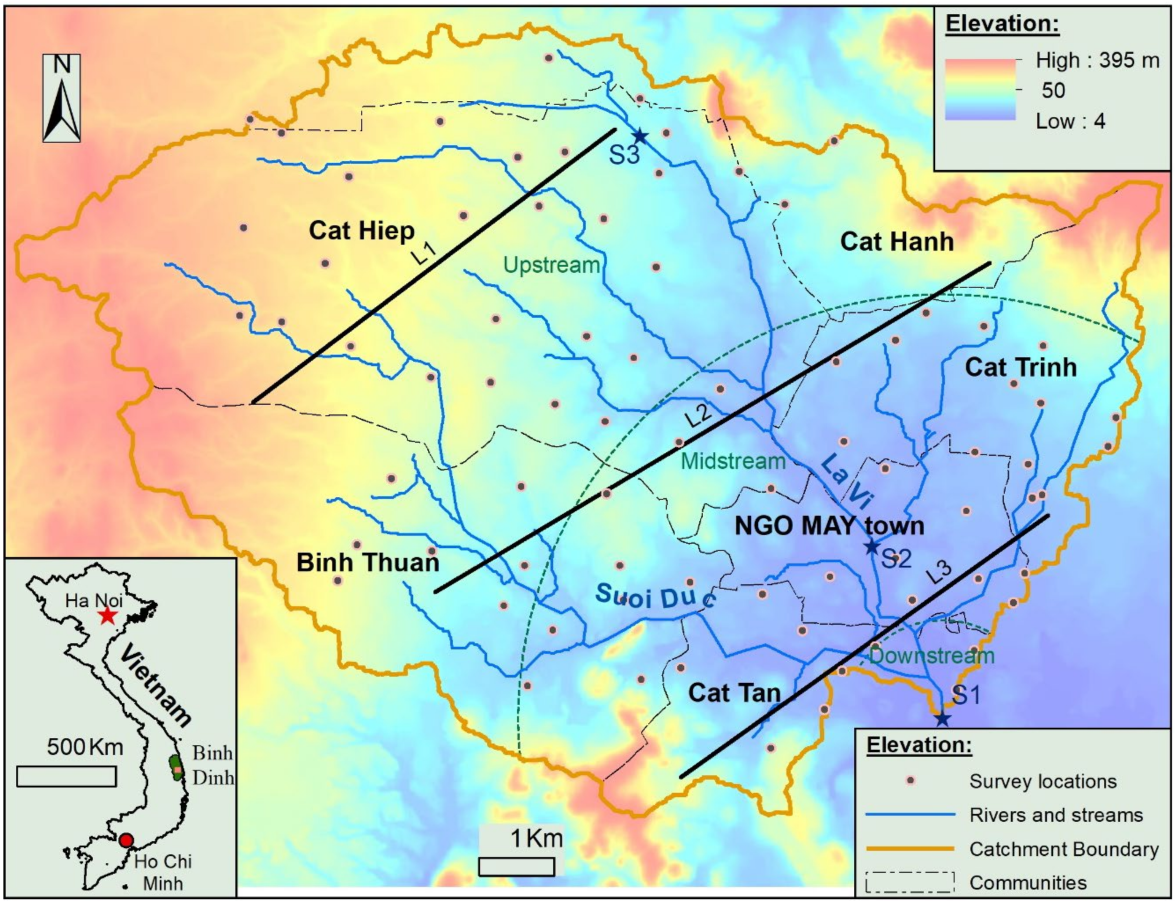


Fig. 7.1 La Vi catchment showing elevation and administrative communities. The digital elevation model (DEM) is based on the 10-m DEM for Binh Dinh province by Binh Dinh DONRE (2015). The town of Ngo May is the only semi-urban area; other communities are rural. The dots show the locations where farmers were surveyed for local knowledge on groundwater table fluctuations and pumping routines. The inset shows the location of the study area within Vietnam (Source: Vietnam Publishing House of Natural Resources, Environment and Cartography) with indication of Binh Dinh province (green region) and La Vi catchment (orange dot). The black lines L1–L3 indicate the location of the hydrogeological cross-sections of Fig. 7.7. S1, S2 and S3, indicated by stars, are respectively the downstream, midstream and upstream locations where baseflow has been estimated. Green dashed lines indicate the boundaries between downstream, midstream and upstream regions.

7.1.2 Climate data

Climate in the La Vi River catchment belongs to the Wet-Dry Tropical climatic subtype (Chang & Lau, 1993) with the wet seasons lasting for approximately 4 months from September to December and during which precipitation is higher than evapotranspiration. January to August is considered the dry season, with higher temperatures and inconsistent, low rainfall.

Five sets of precipitation data were obtained as part of this study (Table 5.1); from Phu Cat, Quy Nhon, Xom Tay, Tan Hoa and An Nhon stations. The daily precipitation data from Phu Cat was used in the SWAT model as the data covers the proposed modelling period of 2008 – 2017 and was more representative of the catchment hydrology than the daily Quy Nhon station data, while the Xom Tay and Tan Hoa station data only cover the 2016-2017 period. Figure 7.2 shows the time series of the precipitation of four of the five datasets.

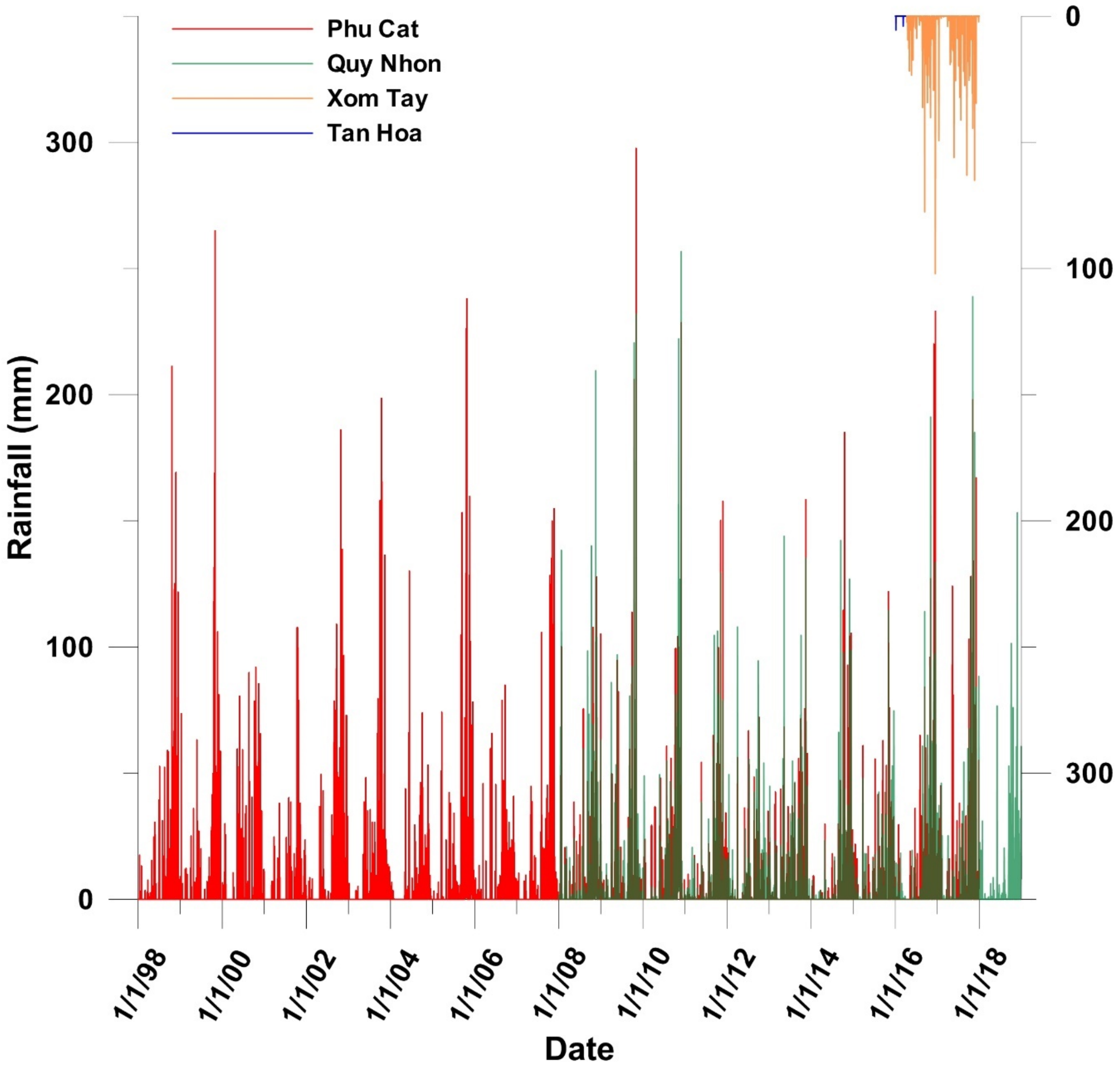


Fig. 7.2 Daily precipitation data from Phu Cat, Quy Nhon, Xom Tay and Tan Hoa stations

The An Nhon station had monthly data for the period 1987-2018. Data from An Nhon was used in the WetSpass-M model. 1990-2018 yearly average temperature for this station is 26.3 ^{o}C, while wet and dry season average temperaturesare respectively, 25.6 and 26.6 ^{o}C.

The data of precipitation at An Nhon station for the 30-year period (1978–2017) showed that annual rainfall varied from 1,099 mm to 2,674 mm, with an average of 1,838 mm and a median precipitation of 1,726 mm. The years, 1988, 2006 and 2012 were categorised as dry years, with annual precipitation of less than 1,239 mm; the years 1991, 1993 and 2016 were considered normal years, with annual precipitation ranging from 1,678 mm to 1,738 mm; and the years 1996, 2008 and 2012 were wet, with annual rainfall above 2,572 mm. Even though annual rainfall was clearly different with increasing order of magnitude from dry to average towet years, these differences were not unique for every month, particularly for the dry period (Fig. 7.3). Also, potential evapotranspiration, another significant factor for the groundwater budget, did not show clear trends between the different conditions of dry, average and wet.

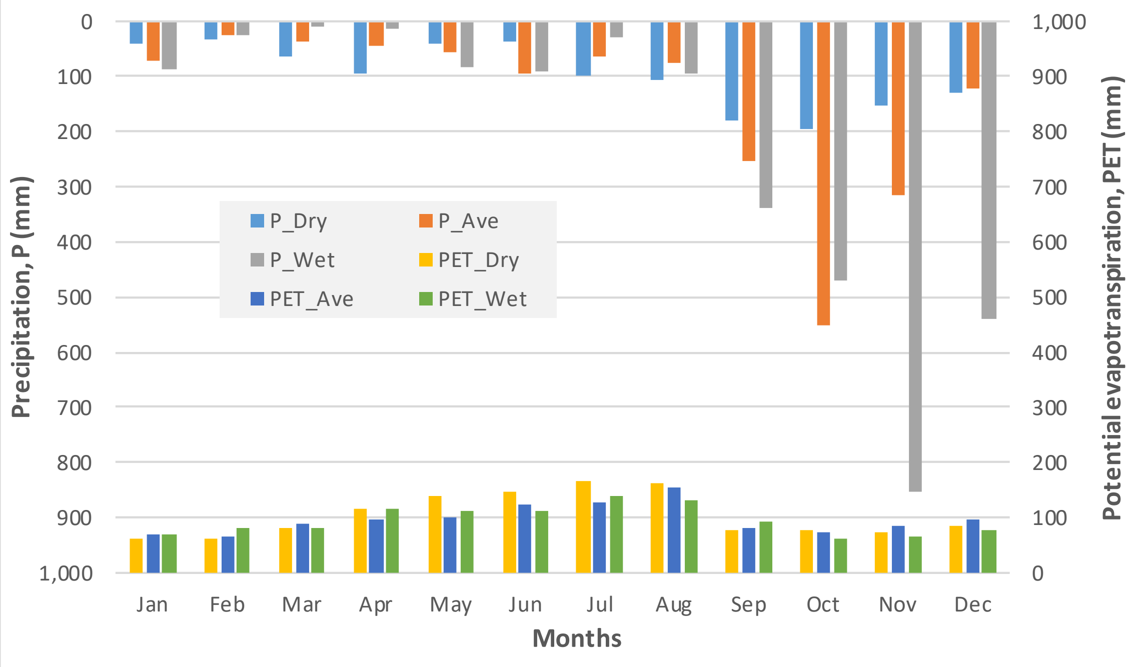


Fig. 7.3 Monthly temporal variation of precipitation (P) and potential evapotranspiration (PET) of years classed as dry, average (Ave) and wet for An Nhon 1987-2017.

Mann-Kendall trend test for the precipitation and temperature time series of An Nhon did not show significant trends over the 20 year period, 1987-2017.

Drought index

McKee et al. (1993) and Edwards (1997) have developed and defined the Standardized Precipitation Index (SPI). SPI is based on the standardized precipitation, defined as:

"Standardizedprecipitation is simply the difference of precipitationfrom the mean for a specified time period divided bythe standard deviation where the mean and standarddeviation are determined from past records."

EDO (2019) relates: "SPI values are in units of standard deviation from the long-term mean, the indicator can be used to compare precipitation anomalies for any geographic location and for any number of time-scales. Note that the name of the indicator is usually modified to include the accumulation period."

"Since SPI can be calculated over different precipitation accumulation periods(typically ranging from 1 to 48 months), the resulting different SPI indicators allow for estimatingdifferent potential impacts of a meteorological drought:

- SPI-1 to SPI-3: When SPI is computed for shorter accumulation periods (e.g., 1 to 3 months), it can be used as an indicator for immediate impacts such as reduced soil moisture, andflow in smaller creeks.
- SPI-3 to SPI-12 When SPI is computed for medium accumulation periods (e.g., 3 to 12 months), itcan be used as an indicator for reduced stream flow and reservoir storage.
- SPI-12 to SPI-48: When SPI is computed for longer accumulation periods (e.g., 12 to 48 months),it can be used as an indicator for reduced reservoir and groundwater recharge."

SPI anomalies are classified according to Fig. 7.2.

ANOMALY	RANGE OF SPI VALUES	PRECIPITATION REGIME	CUMULATIVE PROBABILITY	PROBABILITY OF EVENT (%)	COLOUR
Positive	2.0 < SPI <= MAX	Extremely wet	0.977 - 1.000	2.3	Purple
	1.5 < SPI <= 2.0	Very wet	0.933 - 0.977	4.4	Plum
	1.0 < SPI <= 1.5	Moderately wet	0.841 - 0.933	9.2	Lilac
None	-1.0 < SPI <= 1.0	Normal precipitation	0.159 - 0.841	68.2	White
Negative	-1.5 < SPI <= -1.0	Moderately dry	0.067 - 0.159	9.2	Yellow
	-2.0 < SPI <= -1.5	Very dry	0.023 - 0.067	4.4	Orange
	MIN <= SPI <= -2.0	Extremely dry	0.000 - 0.023	2.3	Red

Fig. 7.4 SPI classification scheme (EDO, 2019)

Applying a 6-month aggregation SPI analysis on the 1987-2017 monthly precipitation time series for An Nhon shows moderate, very and extremely dry periods (Fig. 7.3). Especially in the recent years some extremely dry periods are observed.

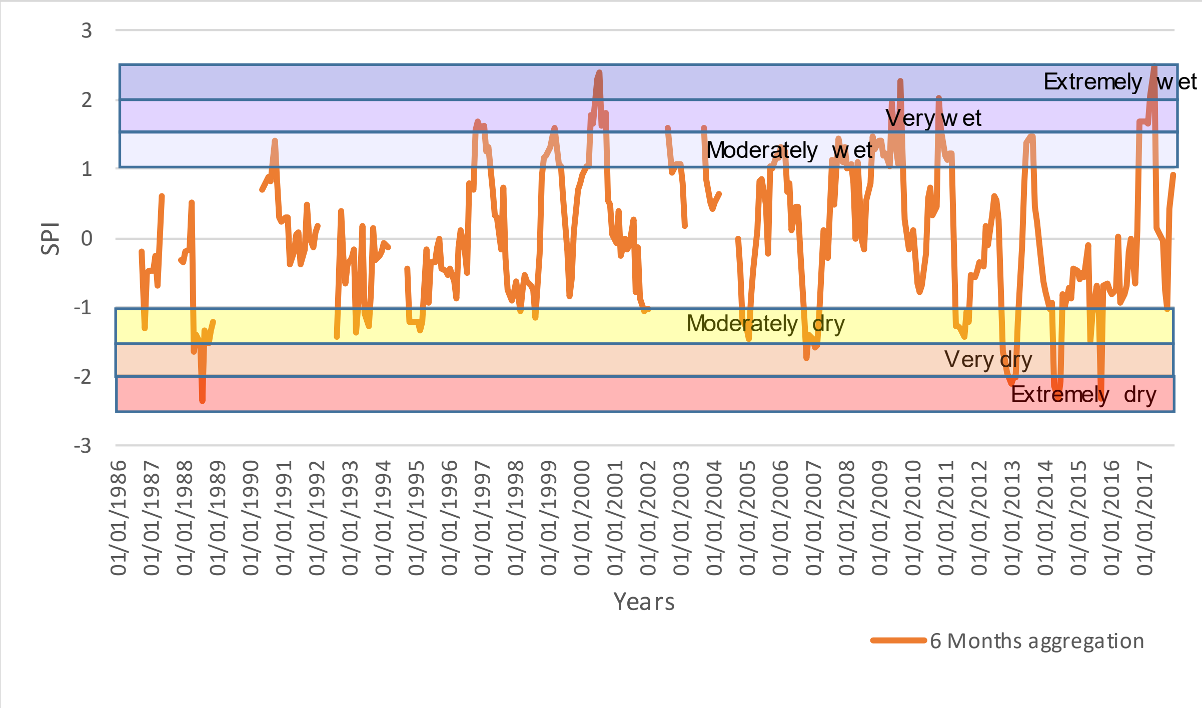


Fig. 7.5 Standardized Precipitation Index 6 month's aggregation for An Nhon time series

Extreme wet years can be defined as those with a total annual precipitation >90th percentile of the historical distribution, and dry years were defined as those with total annual precipitation <10th percentile (Knapp et al. 2015). For An Nhon the extreme rainfall years were as follows; 10 % percentile is 1,239 mm, 90 % percentile is 2,572 mm.

7.1.3 Hydrological data

A digital elevation model (DEM) of the LaVi catchment (Fig. 7.1) at 10 m spatial resolution was extracted from the national grid. The DEM generally represents the topography of the catchment well, however the elevations along the main river channels were incorrect. To improve the hydrological modelling of the catchment, longitudinal and cross-sectional profiling of the river channel upstream of the Tan Hoa Bridge were carried out (Fig. 7.6) and elevations along the river channel were determined. The river channel elevation grids were incorporated into the original DEM to produce an accurate LaVi catchment DEM.

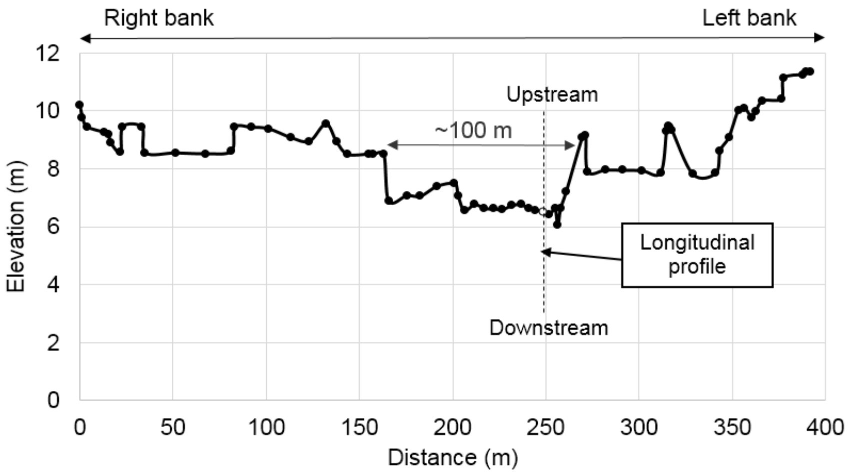


Fig. 7.6 Cross section of main river upstream of the Tan Hoa Bridge

River discharge data is crucial to the understanding of the hydrology of the La Vi catchment and especially required for the SWAT model calibration and validation. However, as there were no stream flow gauges or water level measurements, the La Vi catchment was ungauged and hence collection of river water depth was initiatedIn November 2015.

A limited set of river discharge gaugings was collected (Table 5.1). Based on these gaugings river discharge time series was estimated at the upstream side of Tan Hoa bridge with a 20 minutes resolution using the slope-area method (Manning equation) with an optimized Manning n parameter of 0.136. Fig. 7.7 shows the resulting low flow in the dry season with discharge ranging from 1.7 to 20.5 m³/s, equivalent to a 0.76- 1.79 m water depth. At the beginning of the wet season, the flow in the river channel was still relatively low with discharge values of about 2.8 m³/s (approximately 1 m water depth). However, in the middle and end of the wet season when large rainfall events occur, the flow increased rapidly. Discharge exceeded 200 m³/s (equivalent to water depth above 3.8 m) in the two extreme events that occurred in November and December 2017.

Besides seasonal variation due to the impact of rainfall, the flow regime in the catchment is also affected through human interference. A weir was constructed about 2.5 km downstream of Tan Hoa bridge with the aim of preventing seawater intrusion and maintaining water levels in the river during the dry season. The weir affects the estimated discharge time series of the river by increasing the water level while impeding the water flow and therefore the estimated river discharges are too high.

The periods when the weir affected river stage were determined, including the dry seasons of 2016 (21 January- 28 May), 2017 (25 February- 18 May, 9 June- 21 August), 2018 (31 January- 9 February). The estimated discharges by the slope-area method in the above periods were discarded and not used in the calibration and validation of the SWAT model.

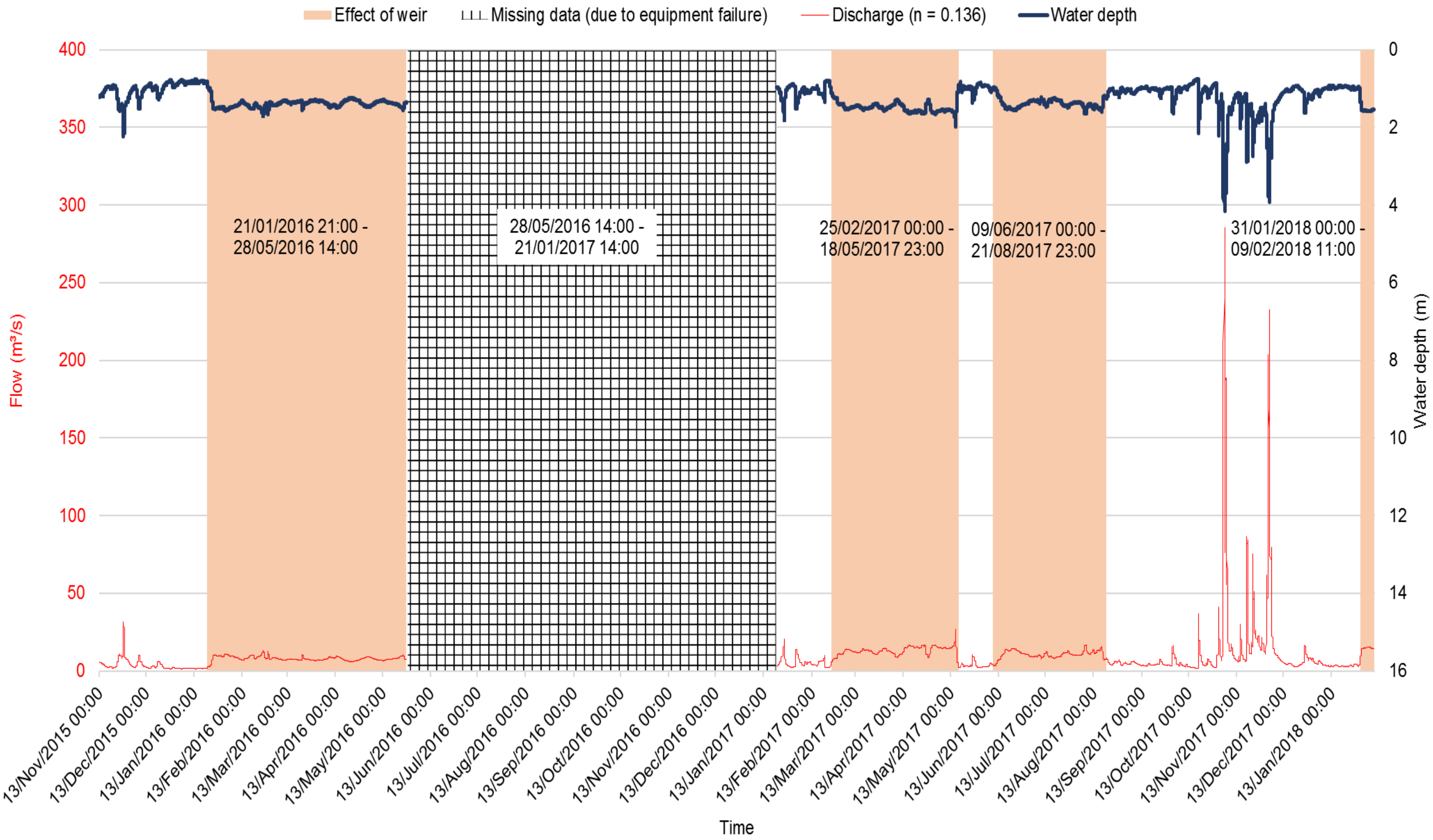


Fig. 7.7 Estimated discharges (n = 0.136) every 20 minutes at the upstream side of Tan Hoa bridge from November 2015 to February 2018

7.1.4 Hydrogeological and soil data

Hydrogeology and groundwater levels

A shallow sandy Quaternary aquifer, which covers a granitic basement rock, extends throughout the catchment (Fig. 7.8 and Fig. 7.9).

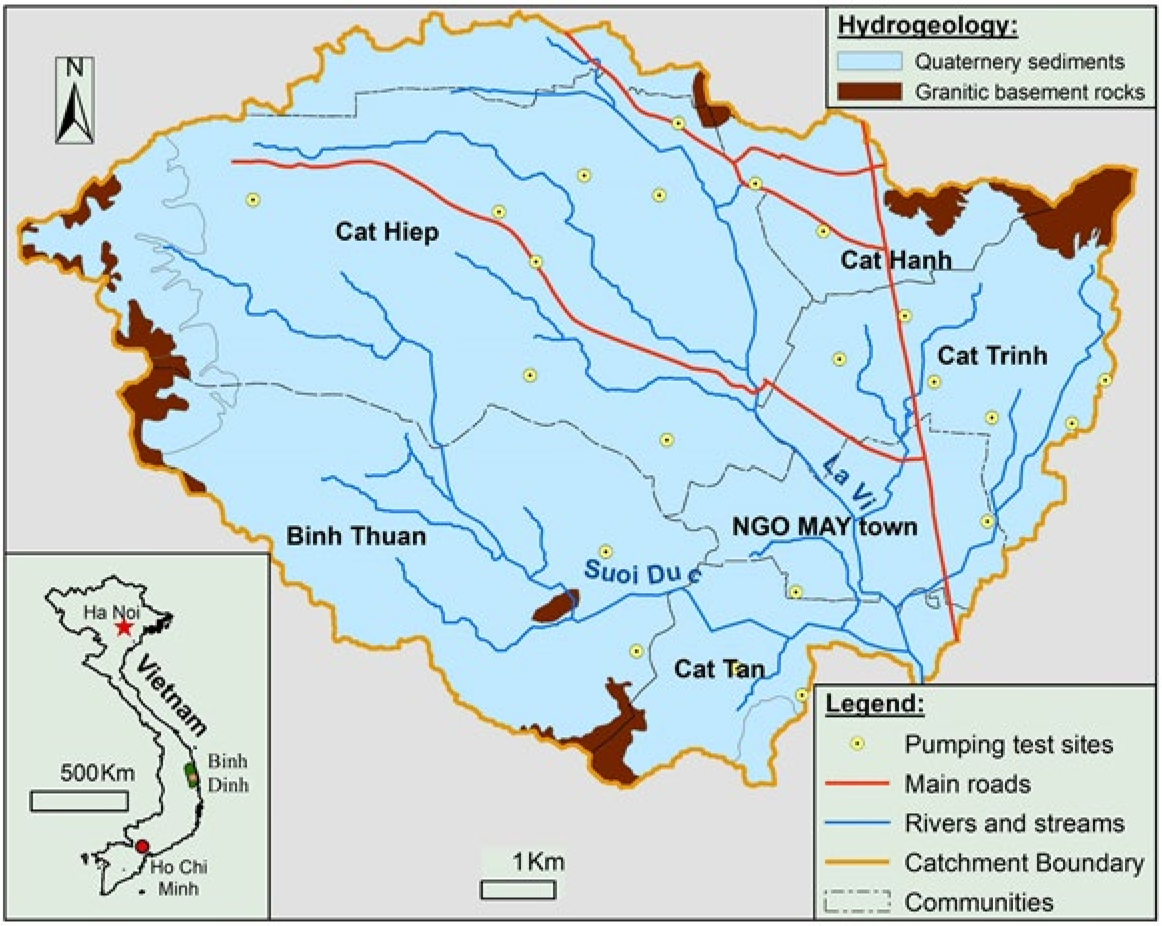


Fig. 7.8 Hydrogeological map of La Vi River catchment, showing the extent of Quaternary sandy sediments and granitic basement rocks.

The aquifer serves as the main source of water for irrigation of cropped land, as well as water for domestic consumption for local residents and family-based livestock farming (as surveyed by the Central Division of Water Resources Planning and Investigation in Vietnam between 21 to 25 October 2015). The sandy soils of the area allow high infiltration, making diffuse recharge from precipitation the main process of aquifer replenishment (Do, 1987). The sinks for the groundwater system are base-flow to the stream network, evapotranspiration from shallow groundwater tables and anthropogenic abstractions for irrigation and domestic use. Due to the strong seasonal precipitation, the La Vi River and its tributaries flow intermittently; they only provide irrigation water for rice crops during the beginning of the dry season. Hence, during the long (eight-month) dry season from January to August, farming is strongly dependent on irrigation from groundwater.

The survey at 77 farmers' wells (most of them were multi-purpose wells located near the home compound) showed that the highest groundwater table typically occurred at the end of the rainy season in December, with the groundwater depths spatially varying up to a maximum 1.4 m below ground surface. The groundwater level dropped to its lowest level at the end of dry season in August, with a 1.6–9.8 m drop observed. Larger variations were typically observed in upland areas close to the water divide, rather than in the valleys.

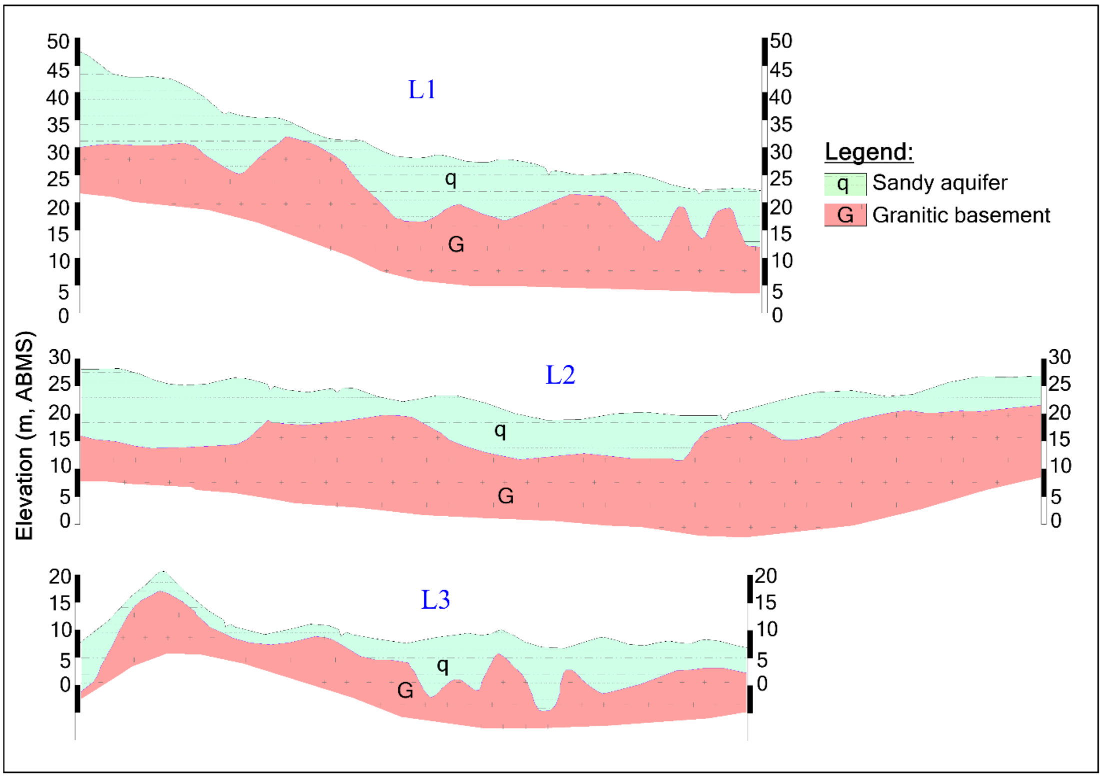


Fig. 7.9 Hydrogeological cross-sections L1–L3 as indicated in Fig. 7.1, showing the variation in the thickness of the unconfined aquifer (q), which is underlain by the granitic basement rock (G) (based on Do, 1987).

Both interpolated minimum and maximum groundwater levels were correlated with ground elevation, as groundwater gradients are from the high elevation at the watershed divide to the low elevations along the river, and from upstream to downstream. At the end of the rainy season (in December), the groundwater level was maximum with its absolute elevation spatially varying between almost 6 m (near the outlet of the catchment) up to about 49 m (north-west corner of the catchment) above mean sea level (Fig. 7.10a). At the end of the dry season in August, the groundwater table dropped to its lowest level, spatially ranging from about 4 m to 42 m above mean sea level (Fig. 7.10b). In mountainous areas, there were no observations of groundwater depths from the survey. This resulted in poor interpolation of the groundwater table in some areas with elevations lower than the aquifer bottom. Hence, for about 20 % of the area (mostly remote hilly terrain), the elevation of the groundwater table could not be determined and was treated as no data.

Groundwater extractions

Owners of 77 wells reported their pumping routines regarding the amount, time and purposes of extracted groundwater. The information was not specific for a particular year but rather indicative of typical average year conditions. Generally, intensive groundwater abstraction was reported during the dry season (from January to August), particularly for the main cropping period from the end of December to the beginning of April, accounting for up to 70 % of total annual abstraction. Surveyed farms showed much lower irrigation during the wet season, and some of the domestic water demand was covered by rainwater. The amount of water extracted varied from well to well and from month to month. Smaller abstractions were observed at wells used for domestic demand only, with 5–10 m^3 of water pumped per month, while larger abstractions were reported for wells for irrigation and multiple purposes. Monthly average abstractions slowly increased from about 65 m^3 up to 175 m^3 during the wet season (September to December) and increased significantly at the beginning of the dry season (January to March) for crop irrigation up to about 330 m^3 per month (Fig. 7.11). In the second half of the dry season (May to August), the surveyed abstractions dropped significantly. Even though total water use for domestic purposes and livestock farming was constant with time, the amount of groundwater used for these purposes dropped at the end of the dry season (June to August) (Fig. 7.11), as some wells dried out and water use was satisfied by other sources (e.g., surface water and bottled water).

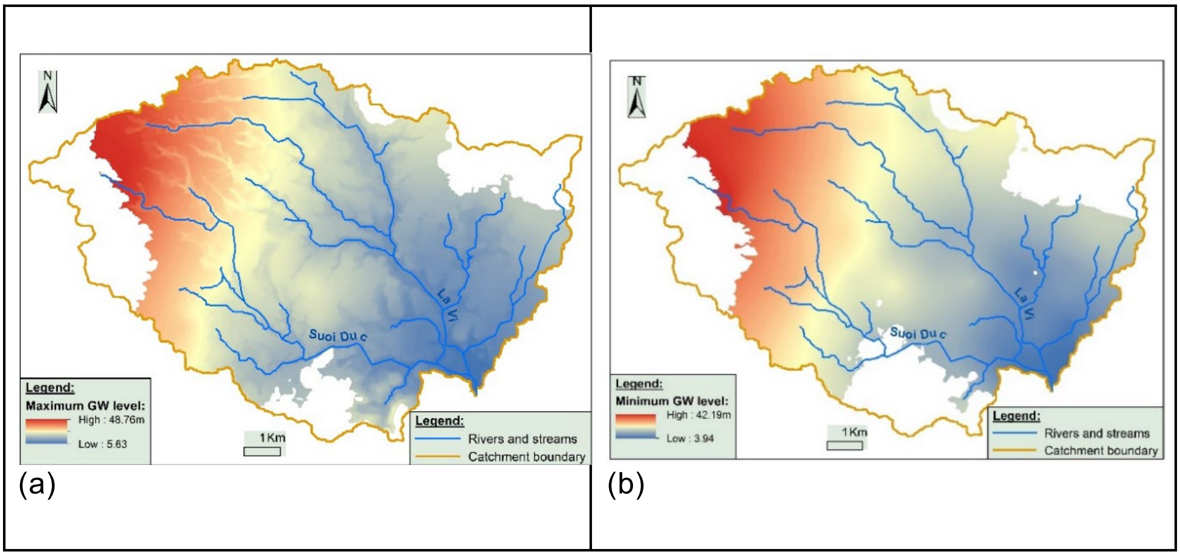


Fig. 7.10 (a) Interpolated maximum groundwater level occurring in December (results from the farmer surveys), and (b) minimum groundwater level in August.

Summation of the results of the 77 surveyed farmer wells showed a total groundwater abstraction of 137,775 m^3/yr or 1,800 m^3/yr per well for satisfying the water demands for domestic use, livestock farming and irrigation. Irrigation was the dominant water user with 84% of the total annual abstraction, while domestic use and livestock farming (e.g., cows and pigs) consumed 11 % and 5 % of the total, respectively (Fig. 7.12).

Table 7.1 summarizes the groundwater consumption rates for each land use class for the La Vi catchment, calculated based on irrigation rates resulting from the survey and FAO guidelines. Vu et al. (2020) provides more detail: “The surveyed results showed that the maximum consumption rate was for vegetables (e.g., cucumber and chilli), with rates of 11,625 m^3/ha annually, as they are seasonally planted in rotation and normally require irrigation the whole year. 75 % (8,732 m^3/ha) of this amount was consumed during the dry season (January to August). Conversely, mango required the least water for irrigation, needing only 3,303 m^3/ha annually, as it requires water for only five months (typically from January to May). Intensive irrigation occurs during the dry season, contributing to at least 75 % of annual groundwater extraction. The irrigation estimates based on the FAO guidelines were smaller than the estimates from the farm surveyed results (Table 7.1). The exception was cassava, which the survey showed is a low-income crop planted in remote, hilly areas or in rotation with other crops, and not irrigated.”

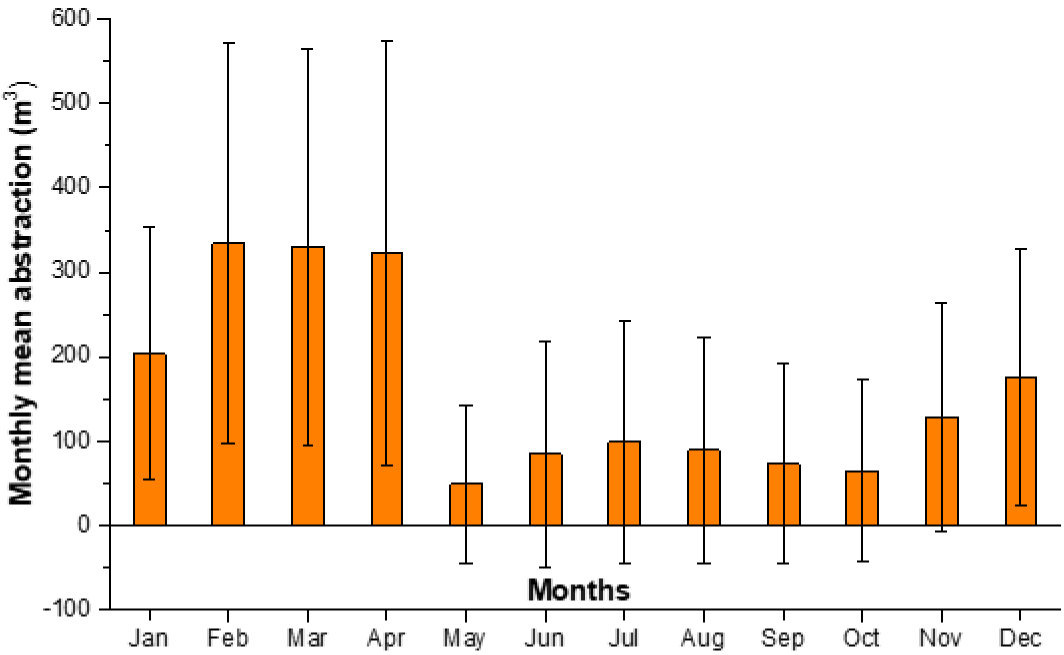


Fig. 7.11 Monthly mean abstraction of the 77 surveyed wells. The error bars indicate the standard deviation.

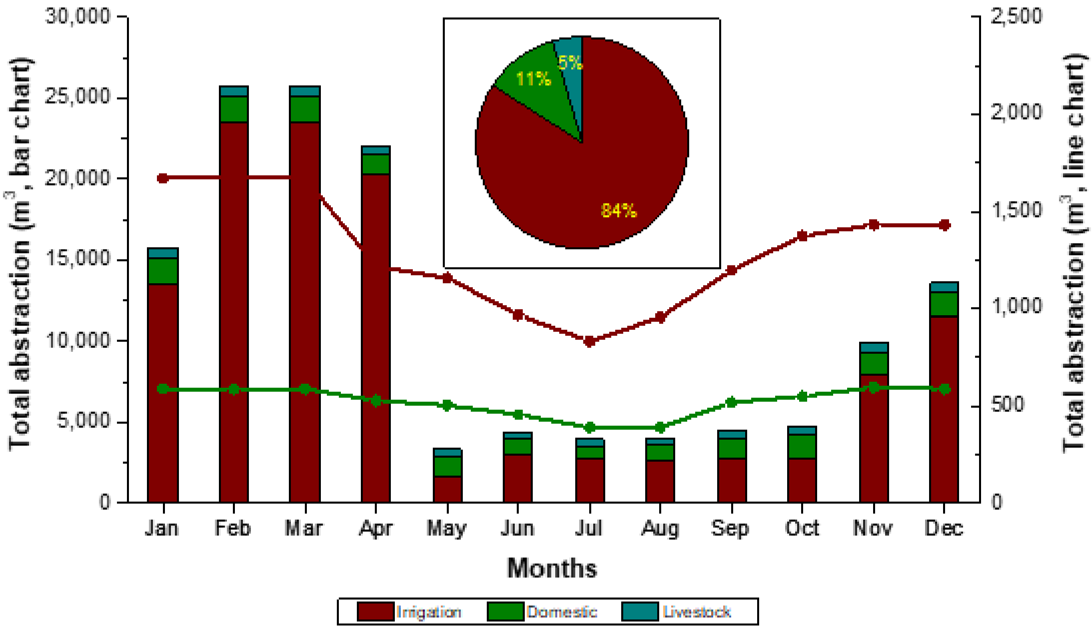


Fig. 7.12 Monthly groundwater abstracted for irrigation, domestic and livestock use from 77 surveyed wells. The bar chart shows the abstraction of the three uses, the line chart shows the usages for domestic and livestock separately. The inset pie chart exhibits the contribution of the three different uses to the total yearly abstraction.

Table 7.1 Groundwater consumption rates for each land use class for the La Vi catchment, calculated based on irrigation rates resulting from the farm survey and FAO guidelines.

Land use class	**Dry season (m³/ha)**		**Wet season (m³/ha)**		**Annual (m³/ha)**	
	Survey	**FAO**	**Survey**	**FAO**	**Survey**	**FAO**
Paddy rice (single)	0	0	0	0	0	0
Paddy rice (double)	0	1,499	0	0	0	1,499
Paddy rice (triple)	3,614	3,866	0	0	3,614	3,866
Cassava	0	4,665	0	0	0	4,665
Paddy rice, cassava	0	4,665	0	0	0	4,665
Peanut, cassava	6,553	4,661	902	0	7,455	4,661
Paddy rice, peanut, cassava	7,510	5,076	0	0	7,510	5,076
Peanut	6,553	1,359	902	0	7,455	1,359
Paddy rice, peanut	7,510	1,010	0	0	7,510	1,010
Other annual plants	8,732	3,591	2,920	0	11,652	3,591
Perennial plants*	4,672		0		4,672	

Soil data

The soil types for the whole of Binh Dinh province, including the La Vi catchment, has been mapped in 2005 by the National Institute of Agricultural Planning and Projection (NIAPP) (NIAPP, 2006). For this study, an update of the soil classification was performed. Seven soil types were recognised within the catchment (Fig. 7.13). Among these, the greyed (Xa) and the greyed degraded (Ba) soils, derived from weathered acid igneous rocks and sandstones, are dominant in the catchment, covering 50% and 37%, respectively. The reddish-yellow soil (Fa), a product of acid igneous rocks, covers 8% of the catchment area. The deluvial deposited soil (D) and the yellowish-brown soil derived from old alluvium (Fp) cover approximately 2 % each, while the eroded skeletal soil (E) and the red and yellow patched alluvial soil (Pf) account each for around 0.2%.

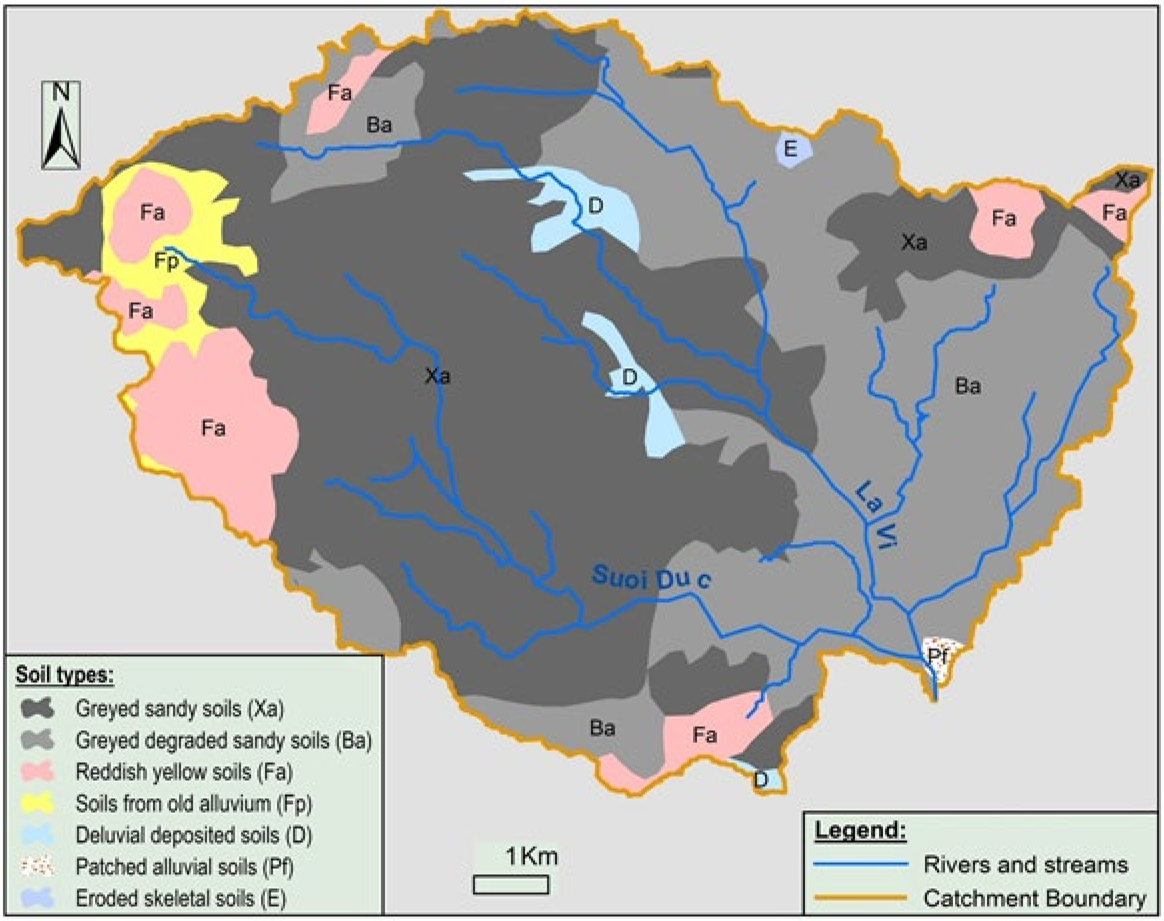


Fig. 7.13 The soil map of the La Vi catchment with seven soil types mapped (NIAPP, 2006). The dominant soils are the greyed (Xa) and greyed degraded (Ba) sandy soils, covering 50 % and 37 % of the catchment, respectively, followed by reddish-yellow soils contributing to 8 % of the catchment. The other four soil types each cover small areas (0.25–2.5 %) of the catchment.

7.1.5 Landuse

Current and past land use

Land cover maps were developed for 2005, 2010 and 2016, with seven land cover types classified (Fig. 7.14). Land cover change analysis between these years showed the significant conversion of bare land to agricultural lands and to built-up land (urban) to a lesser extent. Specifically, bare land decreased significantly from 4,315 ha (41.8 % of the catchment area) in 2005 to 2,605 ha (25.2 %) in 2010 and 333 ha (3.2 %) in 2016. In response, other annual plants with a coverage of 916 ha (8.9 %) in 2005 increased more than five times to 3,388 ha (32.8 %) in 2010 and 4,801 ha (46.5 %) in 2016. Built-up land slightly expanded from 264 ha (2.6 %) in 2005 to 353 ha (3.4 %) and 436 ha (4.2 %) in 2010 and 2016, respectively. Forest and water body cover remained stable, contributing 13–15 % and approximately 1% of the total catchment area, respectively. Rice and perennial crops fluctuated. Paddy rice decreased from 3,234 ha (31.3 %) in 2005 to 1,351 ha (13.1 %) in 2010, before increasing to 2,357 ha (22.8 %) in 2016. Conversely, perennial plants increased substantially from 123 ha (1.2 %) to 1,112 ha (10.8 %) between 2005 and 2010, then slightly decreased to 816 ha (7.9 %) in 2016. The details of the land use changes from 2005 to 2010 and from 2010 to 2016 are presented in the land cover conversion matrices (Table 7.2 and Table 7.3).

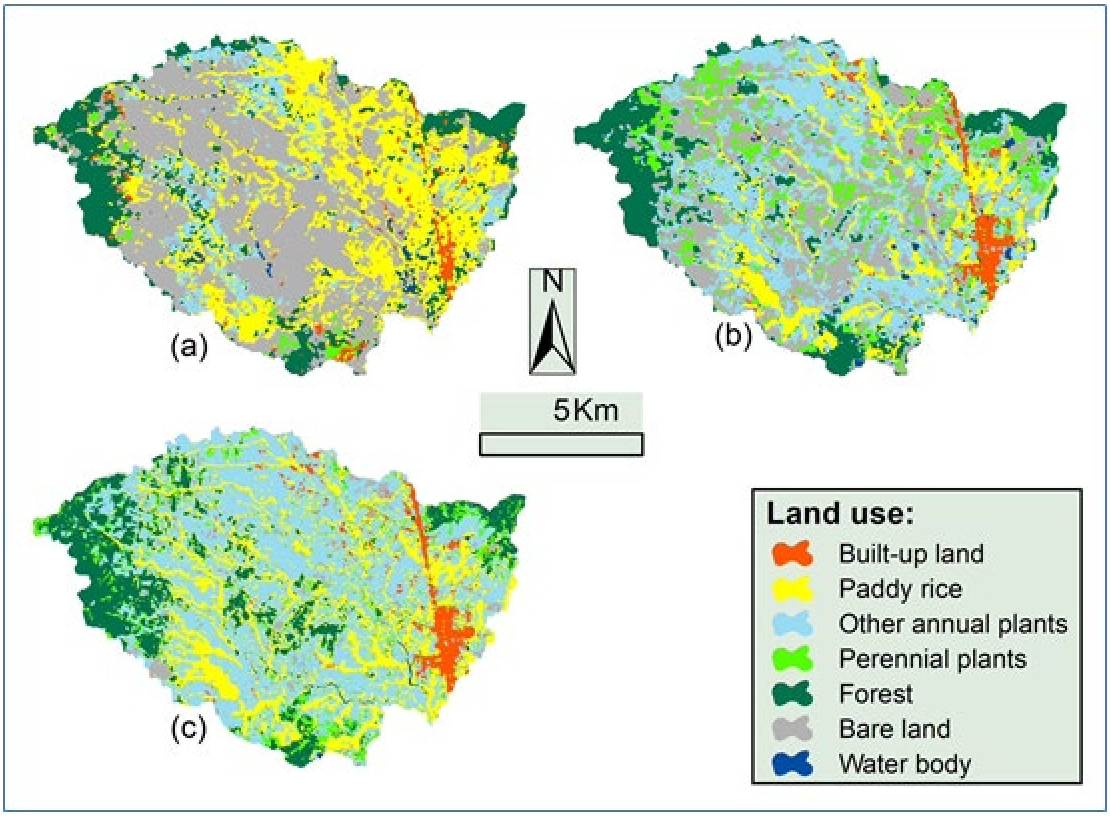


Fig. 7.14 Land cover data for the years 2005 (a), 2010 (b) and 2016 (c), based on Tran et al. (2018).

Table 7.2 The probability matrix of land cover changes for 2005 to 2010

		Land cover 2005															
	Land cover classes	**Bare land**		**Built up**		**Forest**		**Other annual plants**		**Paddy rice**		**Perennial plants**		**Water body**		**Total**	
		(ha)	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**ha**	**(%)**
Land cover 2010	**Bare land**	1,981	21.9	15	0.2	324	3.6	1,073	11.9	292	3.2	585	6.5	44	0.5	**4,314**	**47.7**
	Built up	27	0.3	104	1.1	35	0.4	18	0.2	45	0.5	29	0.3	6	0.1	**264**	**2.9**
	Forest	89	1.0	7	0.1	843	9.3	261	2.9	55	0.6	87	1.0	5	0.1	**1,347**	**14.9**
	Other annual plants	114	1.3	2	0.0	5	0.1	713	7.9	58	0.6	22	0.2	2	0.0	**916**	**10.1**
	Paddy rice	376	4.2	221	2.4	138	1.5	1.3	0.0	801	8.9	377	4.2	43	0.5	**1,957**	**21.6**
	Perennial plants	10	0.1	2	0.0	44	0.5	15	0.2	41	0.5	11	0.1	1	0.0	**124**	**1.4**
	Water body	8	0.1	2	0.0	6	0.1	30	0.3	60	0.7	0	0.0	17	0.2	**123**	**1.4**
	Total	**2,605**	**29.0**	**353**	**4.0**	**1,395**	**15.0**	**2,111**	**23.0**	**1,352**	**15.0**	**1,111**	**12.0**	**118**	**1.0**	**9,045**	**100.0**

Table 7.3 The probability matrix of land cover changes for 2010 to 2016

		Land cover 2010															
	Land cover classes	Bare land		Built up		Forest		Other annual plants		Paddy rice		Perennial plants		Water body		Total	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	ha	(%)
Land cover 2016	**Bare land**	228	2.5	34	0.4	306	3.4	1,468	16.2	346	3.8	216	2.4	7	0.1	**2,605**	**28.8**
	Built up	0	0.0	332	3.7	0	0.0	20	0.2	0	0.0	0	0.0	1	0.0	**353**	**3.9**
	Forest	8	0.1	4	0.0	812	9.0	182	2.0	162	1.8	227	2.5	0	0.0	**1,395**	**15.4**
	Other annual plants	40	0.4	32	0.4	220	2.4	2256	24.9	654	7.2	180	2.0	6	0.1	**3,388**	**37.5**
	Paddy rice	14	0.2	10	0.1	18	0.2	314	3.5	965	10.7	28	0.3	2	0.0	**1,351**	**14.9**
	Perennial plants	38	0.4	22	0.2	189	2.1	524	5.8	181	2.0	158	1.7	0	0.0	**1,112**	**12.3**
	Water body	5	0.1	2	0.0	4	0.0	37	0.4	49	0.5	7	0.1	14	0.2	**118**	**1.3**
	Total	**333**	**4.0**	**436**	**5.0**	**1,549**	**17.0**	**4,801**	**53.0**	**2,357**	**26.0**	**816**	**9.0**	**30**	**0.0**	**10,322**	**114**

Land use scenarios

With the validated water balance model, the aim is to model the impact of various land use change scenarios on catchment scale water balance. The outputs of this work will form the basis for advice to water resource and agriculture planners.

The scenarios developed and their rationale are explained below. The actual land cover data for the year 2016 was considered as the base scenario (S0). In total, 12 land cover scenarios were developed from this base scenario (Table 7.4). In the base scenario (S0), there were 15 land use classes (Table 7.4). The land use pattern was quite complicated, as there was a strong mixture of cropped land and residential areas. In general, the area was dominated by agricultural lands, which accounted for 64.7% of the total catchment area, and were mostly located in the lowland area in the centre of the catchment. The town of Ngo May in the southeast corner of the catchment is dominated by built-up land. The forest cover occurs mostly in the mountainous area at the edges of the catchment.

The first eight developed land use scenarios (all S1 and S2 scenarios) involve the development of water-saving irrigation techniques and the consequent replacement of water-efficient crops with water-intensive ones. In the first two scenarios, S1a and S2a, the cropping patterns were not changed compared to the base scenario (S0), but the amount of water consumed for irrigating peanut and cassava was reduced by 25% and 50%, respectively. In addition to the changes made to S1a and S2a, in the scenarios of S1b and S2b, cassava was replaced by peanut as a consequence of saving water on irrigation. An increase of 500 ha of perennial plants (mango and coconut) at the expense of forest cover at the centre of the catchment was part of the S1c and S2c scenarios. Finally, the conversion of barren land (334 ha) to peanut was implemented as a further change in the S1d and S2d scenarios, compared to the scenarios of S1c and S2c.

The next three scenarios (S3, S4, S4b) looked at the conversion of water-intensive crops, paddy rice and peanut, to the water-efficient maize and cassava crops, respectively, as well as the filling in of barren land by non-irrigated cassava. In S3, paddy rice (in the base scenario S0) was replaced by maize in the second half of the dry season (May to August), resulting in the conversion of 364 ha of paddy rice (double) and 143 ha paddy rice (triple) land to become a newly added class of paddy rice and maize (planted in a rotation). In scenario S4, cassava replaced peanut, resulting in a change of 3,053 ha of peanut lands to become cassava lands, compared to the base scenario (S0). In addition to the changes in S4, in the scenario S4b, 334 ha of barren land became cassava.

The final scenario, S5, is based on the prediction of a growing market for vegetables. As such, 714 ha of perennial plants of mango and coconut was converted to vegetables, classified as ‘other annual plant’, resulting in an increase of this land cover from 1,169 ha to 1,883 ha, compared to the base scenario (S0).

Table 7.4 Land use scenarios. Blue text indicates irrigated crop, brown indicates rain fed crops.

	Landuse class	**Area**	**Scenarios**							
No.	**Base S0;** LU Class in 2016	Area (ha) (2016)	**S1a& S2a:** Unchanged LU, respectively saving 25% and 50% of water for irrigation on Peanut @ Mango	**S1b & S2b:** Respectively saving 25% and 50% of water for irrigation on Peanut @ Mango, consequence to the replacing cassava by peanut	**S1c & S2c:** Respectively saving 25% and 50% of water for irrigation on Peanut @ Mango, consequence to the replacing cassava by peanut and acacia (forest) by mango (perennial plant)	**S1d & S2d:** Respectively saving 25% and 50% of water for irrigation on Peanut @ Mango, consequence to the replacing cassava by peanut and acacia (forest) by mango (perennial plant); all bare land becomes peanut+cassava (in a rotation)	**S3:** Maize replaces Rice (in dry season) in wetland	**S4:** Cassava replaces Peanut (in dry season)in upland	**S4b:** Cassava replaces Peanut (in dry season)in upland; all bare land becomes cassava	**S5:** Vegetables replace Mango/Coconut
1	**Water body:** Surface water body	23.6	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
2	**Bare land:** The bare land	333.6	Unchanged	Unchanged	Unchanged	**Peanut, Cassava:** Peanut (Jan to Apr) and cassava (Mar to Oct) are planted together	Unchanged	Unchanged	**Cassava:** Cassava planted from Mar to Nov	Unchanged
3	**Built-up land:** The residential areas	368.1	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged

	Landuse class	Area	Scenarios							
4.1	**Forest-center:** brush forest and acacia	500.0	Unchanged	Unchanged	**Perennial plants:** Mango (mostly) and coconut	**Perennial plants:** Mango (mostly) and coconut	Unchanged	Unchanged	Unchanged	Unchanged
4.2	**Forest-edge:** brush forest and acacia	1,016.6	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
5	**Paddy rice (single):** Rice crop planted and irrigated one per year, from Dec to Apr	1,130.9	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
6	**Paddy rice (double):** Rice crop planted and irrigated twice per year continously, from Dec to Jun	364.2	Unchanged	Unchanged	Unchanged	Unchanged	**Paddy rice, Maize:** Rice crop (Dec to Apr) and Meize (Apr to Aug) are planted together	Unchanged	Unchanged	Unchanged
7	**Paddy rice (triple):** Rice crop planted triple times continuously, from Dec to May, and Jun to Sep	143.4	Unchanged	Unchanged	Unchanged	Unchanged	**Paddy rice, Maize:** Rice crop (Dec to Apr) and Maize (Apr to Aug) are planted	Unchanged	Unchanged	Unchanged

	Landuse class	Area	Scenarios							
							together			
8	**Paddy rice, Cassava:** Rice planted from Dec to Mar, followed by cassava till Nov	332.5	Unchanged	**Paddy rice, Peanut:** Rice (Dec to Mar), and Peanut (Apr to Jul) are planted together.	**Paddy rice, Peanut:** Rice (Dec to Mar), and Peanut (Apr to Jul) are planted together.	**Paddy rice, Peanut:** Rice (Dec to Mar), and Peanut (Apr to Jul) are planted together.	Unchanged	Unchanged	Unchanged	Unchanged
9	**Paddy rice, Peanut:** Rice (Dec to Mar), and Peanut (Apr to Jul) are planted together.	176.2	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged	**Paddy rice, Cassava:** Rice planted from Dec to Mar, followed by cassava till Nov	**Paddy rice, Cassava:** Rice planted from Dec to Mar, followed by cassava till Nov	Unchanged
10	**Paddy rice, Peanut, Cassava:** Paddy rice (Dec to Mar), then followed by Peanut (Mar to Jun) and Cassava (till Nov) are planted together.	122.1	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged	**Paddy rice, Cassava:** Rice planted from Dec to Mar, followed by cassava till Nov	**Paddy rice, Cassava:** Rice planted from Dec to Mar, followed by cassava till Nov	Unchanged

	Landuse class	Area	Scenarios									
11	**Peanut:** Peanut is planted from Jan to Apr	1,147.7	Unchanged (Decrease water use)	**Peanut (double):** Peanut is planted twice continuously from Jan to July	**Peanut (double):** Peanut is planted twice continuously from Jan to July	**Peanut (double):** Peanut is planted twice continuously from Jan to July	Unchanged	**<u>Cassava:</u>** Cassava planted from Jan to Nov	**<u>Cassava:</u>** Cassava planted from Jan to Nov	Unchanged
12	**Peanut, Cassava:** Peanut (Jan to Apr) and cassava (Jan to Oct) are planted together	1,783.5	Unchanged (Decrease water use)	**Peanut (double):** Peanut is planted twice continuously from Jan to Jul	**Peanut (double):** Peanut is planted twice continuously from Jan to Jul	**Peanut (double):** Peanut is planted twice continuously from Jan to Jul	Unchanged	**<u>Cassava:</u>** Cassava planted from Jan to Nov	**<u>Cassava:</u>** Cassava planted from Jan to Nov	Unchanged
13	**<u>Cassava:</u>** Cassava planted from Mar to Nov	594.4	Unchanged	**Peanut, Cassava:** Peanut (Jan to Apr) and cassava (Mar to Oct) are planted together	**Peanut, Cassava:** Peanut (Jan to Apr) and cassava (Mar to Oct) are planted together	**Peanut, Cassava:** Peanut (Jan to Apr) and cassava (Mar to Oct) are planted together	Unchanged	Unchanged	Unchanged	Unchanged
14	**<u>Other annual plants:</u>** Vegetables (cucumber, pepper chili, etc.), planted (in a rotation) and irrigated throuhgout the year	1,169.2	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged

	Landuse class	Area	Scenarios							
15	**Perennial plants:** Mango (mostly) and coconut	714.1	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged (Decrease water use)	Unchanged	Unchanged	Unchanged	**Other annual plants:** Vegetables (cucumber, pepper chili, etc.), planted (in a rotation) and irrgated throuhgout the year
	Total	***9,920***								

7.1.6 Groundwater quality assessments in Binh Dinh and Ninh Thuan

Water quality investigations were conducted in both Binh Dinh and Ninh Thuan provinces to assess water quality changes over time and as they relate to agricultural inputs.

In Binh Dinh, water quality investigations were conducted in the La Vi River Basin to understand spatial and temporal variability in surface and groundwater water quality, including pH, salinity, temperature, and nutrient concentrations. The La Vi River basin is a sub-basin and tributary of the Con (also spelt Kone) River, which is the largest river in BD and discharges into Quy Nhon Bay, 12 km to the north of Quy Nhon city.

In the La Vi catchment, BD,a total of 36 groundwater bores and 16 river samples were analysed for each field campaign: in April 2015, October 2015, and April 2016. These samplings did not identify areas with consistently high nutrient concentrations, but did show a seasonal change. Concentrations of nitrate ranged from 0.01 – 2.62 mg/L (mean of 1.15 in wet season and 0.56-0.68 mg/L in dry season), phosphate was between 0.01 and 1.72 mg/L (mean of 0.38 in wet season and 0.13 - 0.27 mg/L in dry season), pH values ranged from 5-8. Nitrate concentrations were typically higher in groundwater than surface water during dry season samplings, but were similar and 1.5 - 3 times higher overall during the rainy period sampling (October 2015), suggesting mobilisation of nutrients throughout the groundwater and into the river during the rainy season. The relative concentrations of nitrate and phosphate also suggest that presence of algae in surface waters is not limited by phosphorus availability, although this would need to be tested further.

Subsequent sampling focused on a few sites but at a weekly sampling frequency for 8 weeks (with a few pauses) beginning 8 December, 2016. The results did not show further patterns in water quality beyond what could be understood from the initial, basin-wide sampling. It was acknowledged that sampling at the beginning of the rainy season would be necessary to capture initial mobilisation of nutrients. Therefore, during the 2016 rainy season, groundwater samples were collected at four locations forming a transect between a farm and the river, approximately 200 m downgradient of the farm. Nutrient concentrations across this transect collected during several rain events showed both a gradual decrease of overall nutrients at all locations, and a drastic decrease in nutrient concentrations between the point sources directly at the farm and the narrow riparian area. Analysis of this data indicated that heavy dilution (up to 80 %) of the groundwater along the flowpath (mixing with fresh groundwater recharge) could largely explain the low nutrient concentrations found near and in the river. This indicates that despite the intense use of surface and groundwater supplies and point-source contribution of nutrients at each household, intense rain events currently serve to dilute water sources below acceptable limits of the Vietnamese water guidelines for drinking and irrigation purposes. However, close to point sources of nitrate pollution from households and animal holding pens high concentrations occur and possibly these contaminated groundwaters are used by some households.

In An Chan commune of Phu Yen province, 32 sites from agricultural (vegetable and rice) area were selected to collect surface (streams, irrigation channels) and groundwater (tube and open wells) to investigate the level of contamination (NO_3^- andPO_4^{3-}) from fertilizer or animal sources (Do et al. 2015). The results show that the source of nitrate and phosphate contamination in wells (tube and open wells) used for household purposes was partly from agricultural practices (e.g. fertilizers or chemicals), but the majority of these nutrients were from cattle housing or septic tanks located next to the houses. Levels of phosphate (32 mg/L) and nitrate (80 mg/L) exceeded values that are suitable for human consumption. The levels of NO_3^- andPO_4^{3-} in the water samples collected from tube and open wells from An Hai and Nhon Hai communes of NT showed even higher concentrations of NO_3^- (198 mg/L) and PO_4^{3-} (76 mg/L) andexceeded the Vietnamese maximum permissible limits (MPL) of NO_3^- (10 mg/L) and PO_4^{3-} (3 mg/L) (Do 2019).

In another study conducted in NT during 2015, sample collection was conducted at 27 sites in An Hai and Nhon Hai communes from areas around intensive vegetable production. Results of groundwater samples collected in 2014 and 2015 from An Hai and Nhon Hai communes of Ninh Thuan showed that more than 75 % of the samples in Nhon Hai exceeded the MPL for nitrates and EC. In An Hai, around 30-50 % of the samples exceeded MPL for nitrates and 30 % for EC. Open wells generally had higher values of nitrate than in tube wells. These high values were likely due to salt intrusion from the sea (for EC) and high fertilizer and manure rates (for NO_3^-). Phosphate values were generally lower throughout.

In 2017, samples were collected every two months along two transects in Ninh Hai and in the Cai River to investigate interannual variability (Fig. 7.15). The results showed that, on average, groundwater EC increased over the dry season, and dropped sharply at the onset of the wet season. Patterns in nutrients were different between the two transects; while a sinusoidal pattern in nitrate was observed in transect 1 (increasing March to May, then decreasing through September before increasing through January 2018), transect 2 showed a steady decrease through the dry season, then a sharp increase into the wet season. A strong correlation (R^2= 0.67) was found between local fertiliser application and groundwater nitrate levels in both transects. In the Cai River, EC, nitrate and phosphate levels were all highest in March, with EC and nitrate abruptly lower in May and all samples thereafter. Phosphate levels declined steadily throughout the year, with a spike in September.

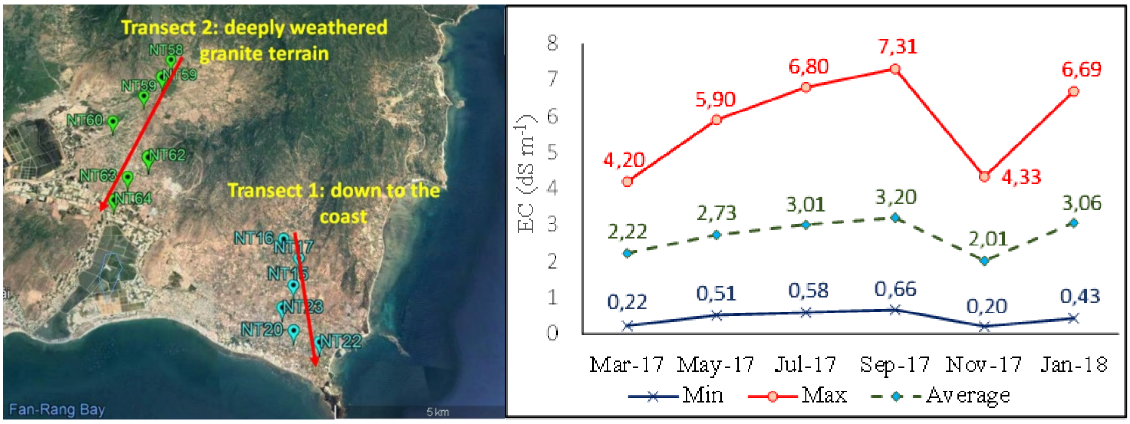


Fig. 7.15 Locations of two bi-monthly groundwater sampling transects in the Ninh Thuan province (left) and the EC results during 2017 (right).

7.1.7 WetSpass-M water balance model

For the current situation as represented by the year 2016, called the base scenario S0, the total net recharge for the dry season from January to August (2016) was mostly negative (i.e., actual evapotranspiration from groundwater), as the 365 mm precipitation for the dry season is only 14 % of the annual rainfall. The spatial recharge pattern (Fig. 7.16) showed relatively high evapotranspiration in the central part of the catchment between the two main tributaries, particularly for the lowland areas along these streams, as here groundwater tables are shallow, and evapotranspiration is high. In contrast, actual recharge (positive values) were observed in the upland areas in the west and north-east where groundwater is deepand evapotranspiration was lower than in the lowlands.

Comparing between different combinations of climatic conditions (i.e., wet, average and dry) and land use scenarios, net recharge was influenced most by climate, but seasonal variation was obvious (Fig. 7.17). In all combinations of land use and climatic conditions, simulated net recharge was low in the dry season from January to August, and it reached the lowest values in March and April when precipitation was extremely low, with no or even negative net recharge observed. High net recharge was simulated for the rainy season, from September to December, with an average net recharge for the whole catchment of about 100–160 mm monthly. Total net recharge for the four months of the wet period was 497 mm, accounting for 81 % of the annual recharge in the base scenario (S0).

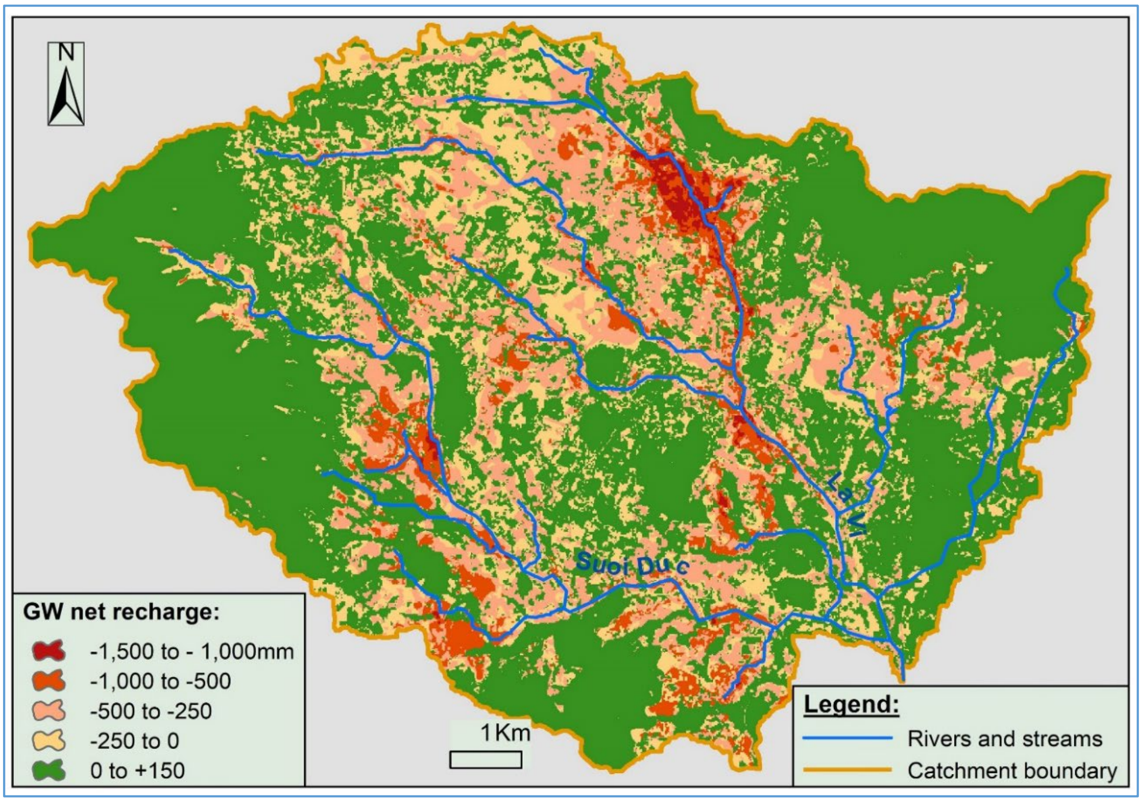


Fig. 7.16 Net recharge to groundwater as simulated by WetSpass-M for the dry season from January to August 2016 of the base scenario S0.

In the first half of the dry period (January to April), when precipitation was low and return flow from irrigation was a main source for recharge to groundwater, the simulated recharge for the different scenarios varied slightly (Fig. 7.18). The lowest recharge was obtained for the S4b scenario, followed by S2a. S5 exhibited the highest recharge, slightly above that for the S0 scenario. For the rest of the year, when precipitation started increasing and irrigation reduced, the differences in the simulated recharge among scenarios were negligible (Fig. 7.18). Comparing to the base (current) land use scenario, all other scenarios had a lower annual net recharge, with a 0.2–7.0 % reduction from the 633 mm of net recharge for the base scenario (equivalent to 1.2–41.6 mm reduction). Comparing between the climatic conditions, the average condition had an estimated net recharge of 568 mm/year, while the values for the dry (10th percentile rainfall) and wet (90th percentile rainfall) conditions were 345 mm/year and 933 mm/year, respectively, equating to 61 % and 164 % of the net recharge for the average condition. In the rainy season (September to December), the discrepancies between the recharge in the different climatic scenarios were obvious and their magnitude corresponded to that of rainfall. However, for the dry months (January to August), these differences were not consistent.

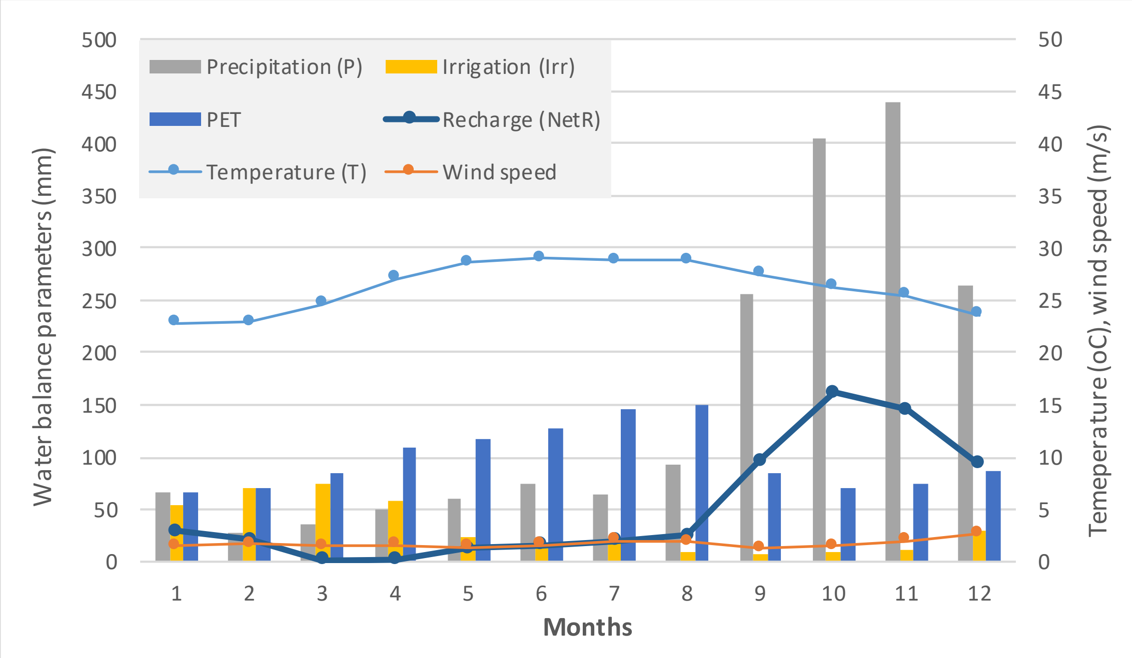


Fig. 7.17 Temporal variation of the monthly simulated net recharge by WetSpass-M and other climatic and water balance component data as inputs, averaging for all combinations of land use scenarios and climatic conditions.

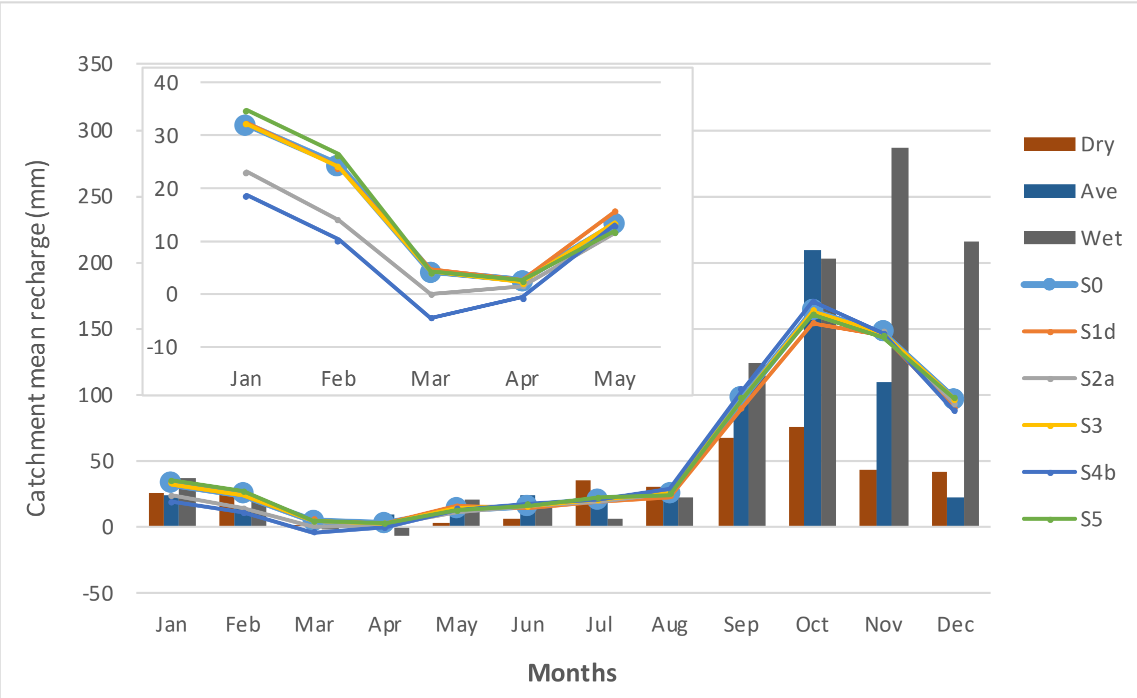


Fig. 7.18 Temporal variation of the monthly simulated net recharge for different land use scenarios, averaging over dry(<1,239 mm, i.e. 10th percentile of rainfall), average (1,838 mm)and wet (>2,572 mm, i.e. 90th percentile of rainfall) climatic conditions (line chart) and for dry, average and wet climatic conditions, averaging over all land use scenarios (bar chart). The inset shows the temporal variation of the net recharge for the dry period for different land use scenarios.

7.1.8 Modelling surface water – groundwater interaction

The total flux of groundwater discharge to the river estimated for three calibrated cross-sectional models (S1, S2, S3, Fig. 7.1) increased from upstream to downstream (Fig. 7.19). The flux at S1 was three and six times higher than at S2 and S3, respectively. Also, the amplitude of the flux downstream is up to two and five times higher than at midstream and upstream. The average exchange velocity at S1 (0.005 m h^{-1}) was nearly two times higher than that at S3 and the wetted cross-section downstream (98.5 m) was approximately three times the cross-section upstream (37.0 m). Temporally, the flux reduced from the wet to the dry season. Fluxes at all three sites decreased suddenly from the onset of the precipitation, when the river stage started to increase; reached a minimum before the river stage peaked; and increased again when the river stage began to drop. In general, the total fluxes at all three sites showed highly variable fluxes during the rainy season, then steadily decreased to low fluxes into the beginning of the dry season before flow ceased. Expressed as the total amount of water exchanged at the GW-SW interface along the full wet cross-section per meter of river length, fluxes of up to 1.6 m^2 h^{-1} and 0.2 m^2 h^{-1} were estimated for the wet season in the upstream and downstream sections, respectively, while during the dry season the fluxes were only 1.0 m^2 h^{-1} upstream and 0.15 m^2 h^{-1} downstream (Fig. 7.19). S1 was an exception and showed a higher rate of decrease at the end of the study period; however, this was due to anthropogenic causes (downstream dam operation) and impeded river flow.

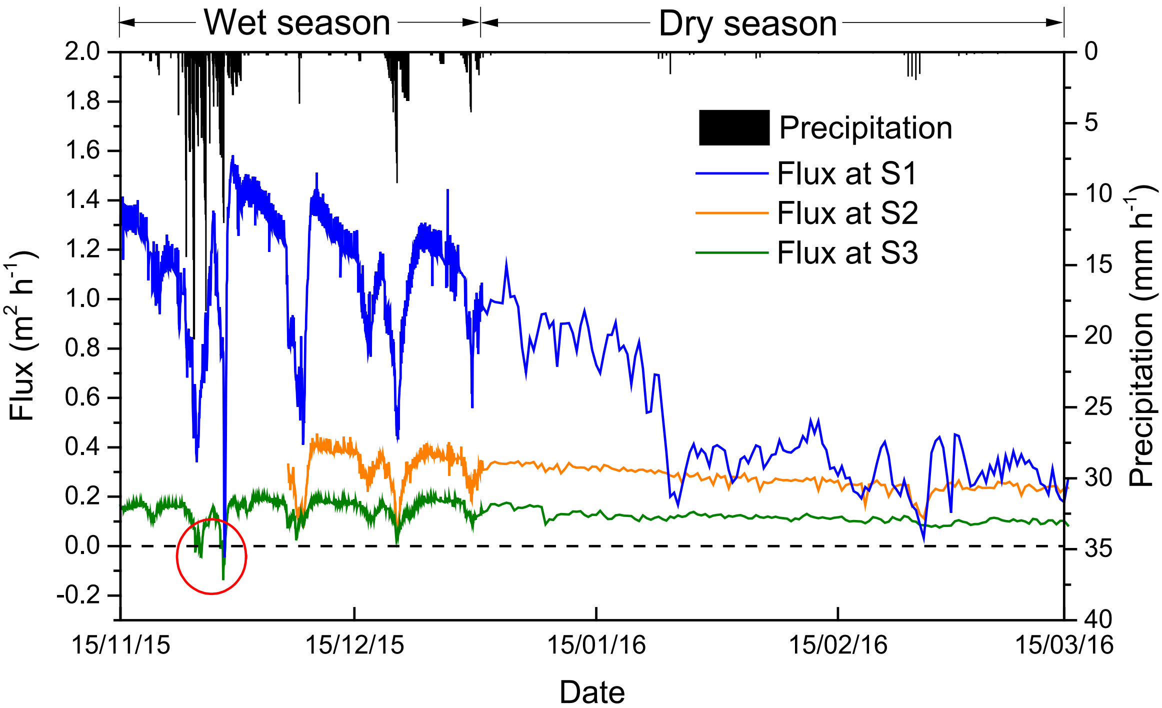


Fig. 7.19 Modelled flux of groundwater discharge to the river at the three sites using groundwater level long-term trends (pumping effects removed). Modelled flux reversed from discharge to the river to infiltration into the banks (marked in the red circle) at the upstream and downstream sites (S3 and S1) during a large storm event on 28 November, 2015. The flux is given in m^2 h^{-1}, i.e., as the total amount of water exchanged at the GW-SW interface along the full wet cross-section per metre of river length.

With pumping effects removed, modelled flux at all three study sites was generally gaining, i.e., discharge from groundwater to the river. The only exception to the gaining conditions is at the moment of peak flow during the first (biggest) storm event, a flux from surface water to groundwater was observed before the peak in river stage. This flux reversal was maintained for approximately 2-4 hours, after which the interaction returned to normal condition of groundwater flux to the river. Upstream, three reversals were observed compared to only one downstream.

Fig. 7.20 shows the simulated GW-SW interaction fluxes using the observed data and the 12-hour moving average filtered data. The fluxes closely parallel one another, with the biggest differences observed during sudden jumps in water levels. The changes induced by groundwater extraction caused small changes in groundwater discharge to the river in terms of magnitude, and a brief (observed for one time step) reversal in the direction of modelled GW-SW interaction at the river on February 25 in S1 (Fig. 7.20c; not seen in Fig. 7.19 when pumping effects are removed from the data). Comparing the results of the two model scenarios, which did not include the groundwater levels affected by pumping, showed that the groundwater pumping reduced the cumulative flux on average by 0.6 %. This translates to 0.45 % at the end of wet season and up to approximately 3.0 % halfway through the dry season (15 March).

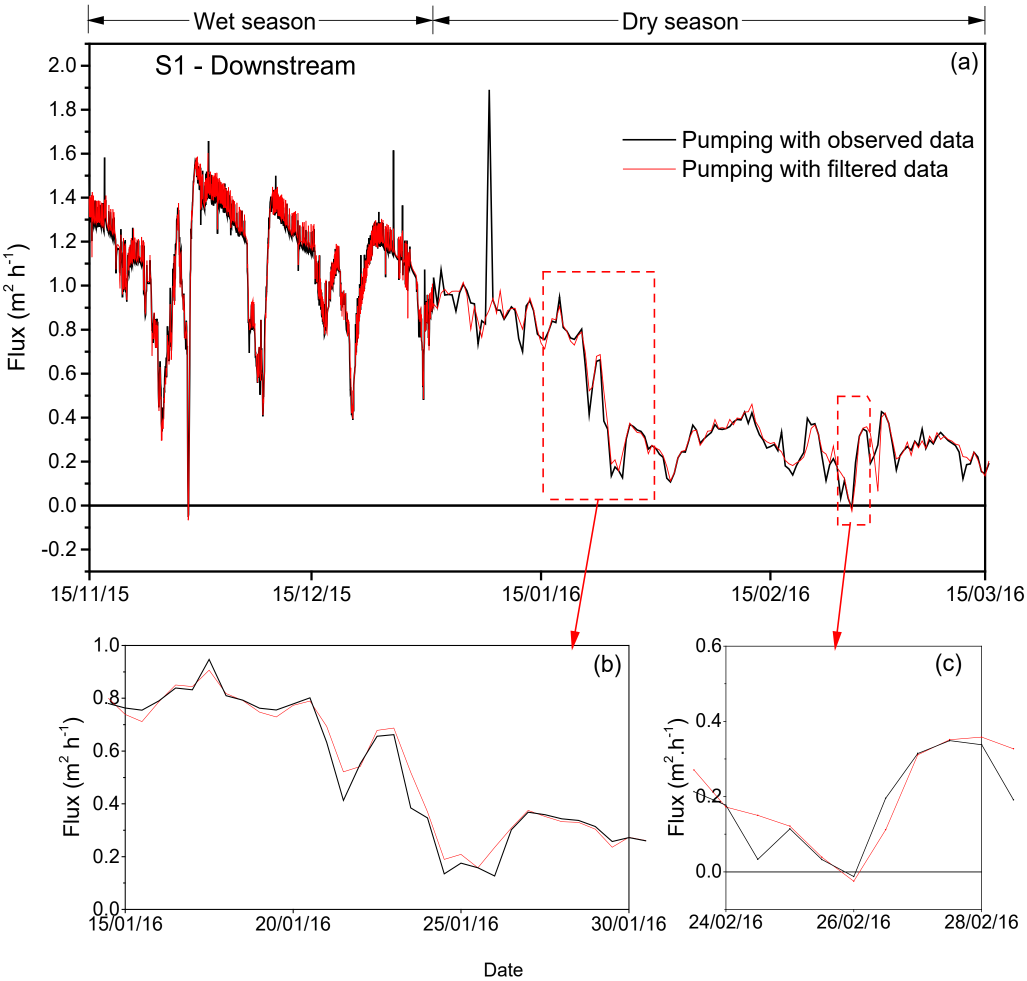


Fig. 7.20 Simulated fluxes from groundwater to the river with pumping included, using observed data and data filtered with 12-hour moving average for the whole period of simulation (a); focused in to show the period at the beginning of the dry season when pumping is intensive (b), and the flow reversal on 26 February (c).

7.1.9 SWAT modelling of surface water

The SWAT model for the La Vi catchment was developed using the ArcSWAT extension of the ArcGIS software. The adapted 10 m DEM was used to delineate the stream network and catchment extent. The soil, land use and slope data over the catchment was used to create 68 unique HRU's. The obtained daily climate data was used to run the model between 2008 and 2017. A warm up period of two years (2008 and 2009),for which the results were not printed, was included in the model.

The model was calibrated to river discharge data in the sequential uncertainty fitting algorithm (SUFI-2) using 69 days of data between November 2015 and January 2016 during which the weir was down (Fig. 7.21). After a successful calibration exercise, the model was validated using 132 days of discharge data in 2017 (Fig. 7.22).

The performance of the SWAT model in simulating discharge was evaluated by using three statistics quantitative indices including Nash–Sutcliffe Efficiency (NSE), percent bias (PBIAS), Kling Gupta Efficiency and coefficient of determination (R^2). The performance ratings for NSE, PBIAS and R^2 in SWAT modelling according to a guideline for successful calibration (Moriasi et al., 2007) (Table 7.5). The model was able to represent the hydrological system using the above statistical metrics in the validation exercise and

Table 7.6 summarizes the result of the calibration and validation exercise of the model.

Table 7.5 Performance ratings for statistics quantitative indices

Index^A	**Performance rating**		
	Satisfactory	**Good**	**Very good**
NSI	0.50 < NSI ≤ 0.65	0.65 < NSI ≤ 0.75	NSI > 0.75
PBIAS (%)	± 15 ≤ PBIAS < ± 25	± 10 ≤ PBIAS < ± 15	PBIAS < ± 10
R^2	0.50 ≤ R^2 ≤ 0.65	0.65 < R^2 ≤ 0.81	R^2 > 0.81

^{A}Nash–Sutcliffe Efficiency (NSE), percent bias (PBIAS), Kling Gupta Efficiency (K_{GE})and coefficient of determination (R^2)

Table 7.6 Performance statistics calibrated and validated SWAT model

Model		N_{SE}	R^2	K_{GE}	P_{BIAS}
LaVi SWAT model	Calibration	0.88	0.89	0.92	4.2
	Validation	0.92	0.93	0.79	20.2

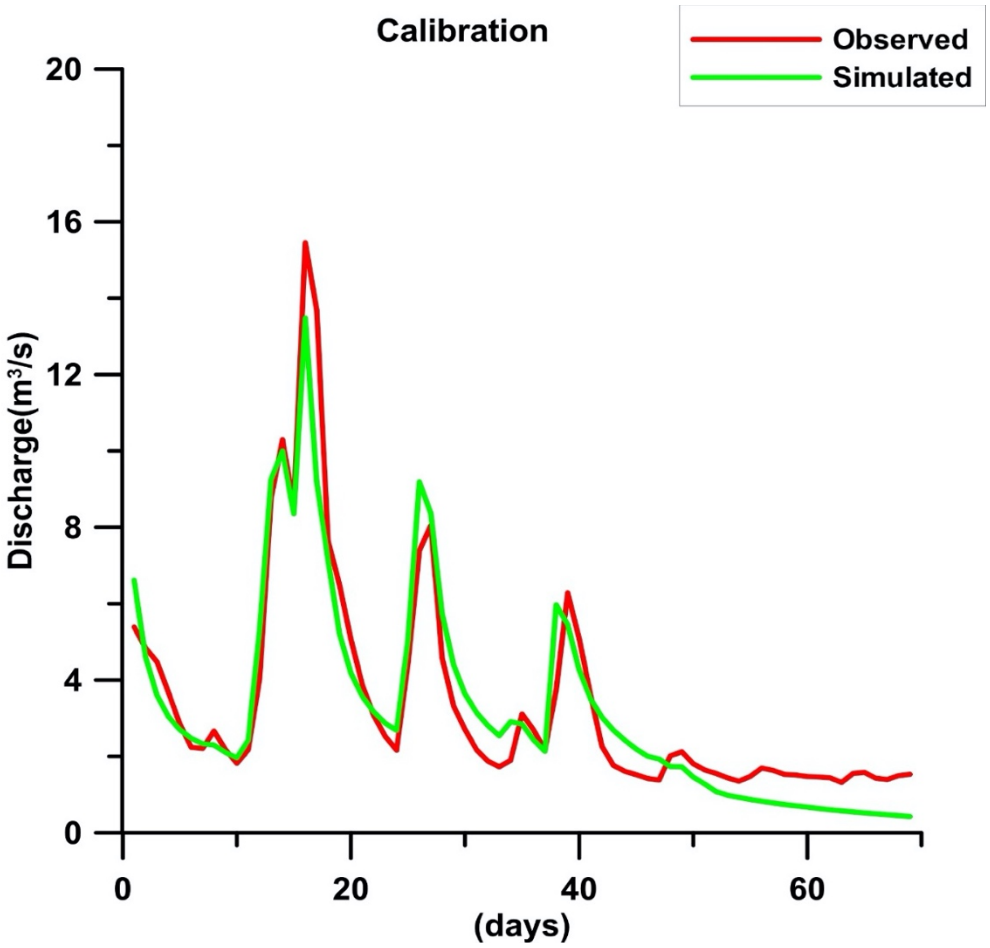


Fig. 7.21 SWAT model simulated river discharge for 69 calibration days (non-consecutive) between November 2015 and January 2016.

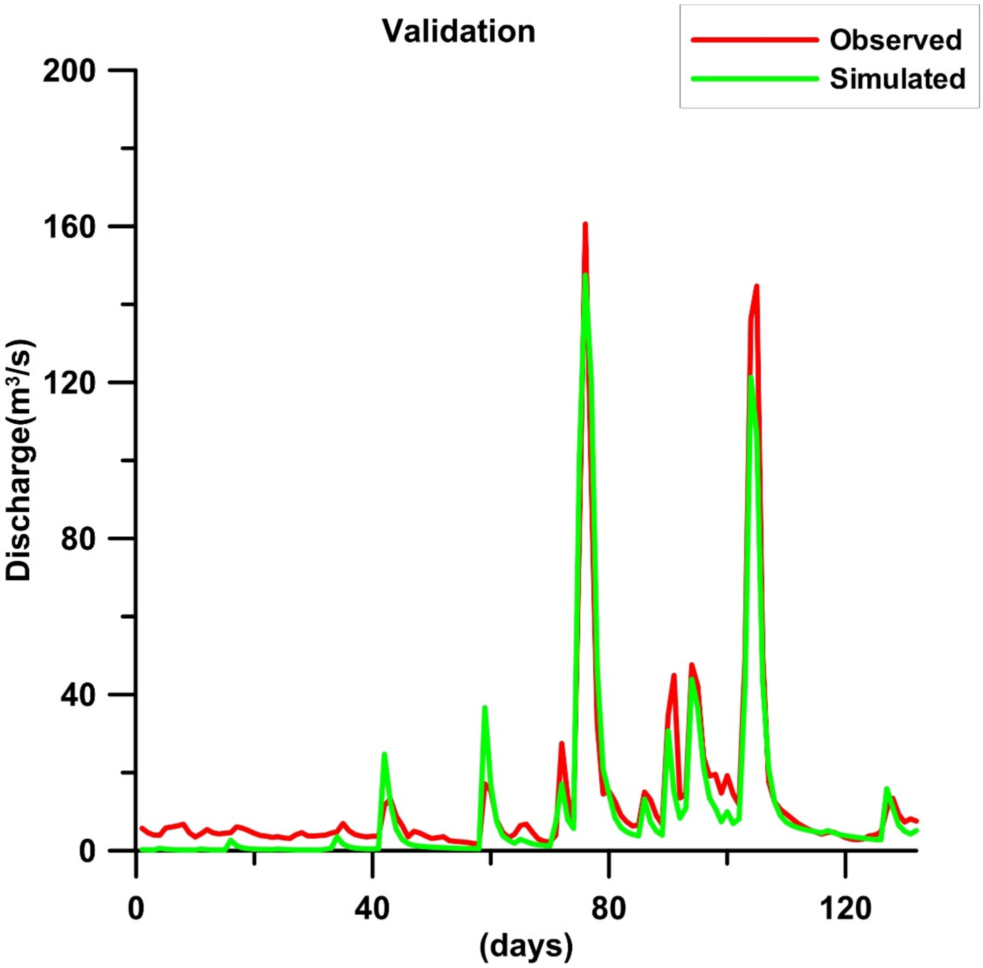


Fig. 7.22 SWAT model simulated river discharge for 132 validation days (non-consecutive) in 2017.

7.1.10 Coupled WetSpass-M - MODFLOW modelling of groundwater

The 3D finite-difference groundwater model code MODFLOW-NWT (Harbaugh, 2005) was selected for simulating groundwater flow and assessment of the groundwater balance. Running and post-processing of model outputs was carried out with the Python package Flopy in Python 2.7. The model extent was defined by the catchment boundary and set as a no flow boundary. A one-layer flow model was set up, representing an unconfined aquifer on top of the bedrock, which is considered an aquiclude. The model top was defined by the 10 by 10 m resolution of the local DEM, and the aquifer thickness was interpolated from a set of electrical resistivity tomographies together with locations of bedrock outcrops. The horizontal discretisation of the model was 100 by 100 m. The hydraulic conductivity and specific yield parameters of the aquifer were obtained from the set of 22 pumping tests, located throughout the catchment (Fig. 7.8).

The main La Vi River running along the centre of the catchment was treated in MODFLOW as a river boundary condition (RIV), with its bottom elevation 0.5 m below the surface of the river cells. Surface water levels monitored at three stations from upstream to downstream locations were interpolated and extrapolated to all river cells. The tributaries of the La Vi River were conceptualised with the drain package (DRN) with its level assigned equal to the ground surface, which acts as a sink and prevents heads from building up above the land surface.

The actual recharge to groundwater was estimated by the WetSpass-M model, including recharge from natural precipitation and return flow from irrigation. To do that, a map of irrigated water (for each month) was converted from the land use map for each scenario, based on the cropping pattern and rates of irrigation for different crops. Then, rainfall precipitation was added to the irrigated water map as a ‘precipitation’ input for the WetSpass-M simulation. The MODFLOW recharge package (RCH) was activated with the WetSpass-M calculated recharge. As the input recharge could be negative (i.e., dominated by evapotranspiration), care was taken to ensure that negative recharge was not applied to cells where there was not enough water to match the forcing.

For calibration purposes, a monthly transient model was established for the year 2017, which represented the most data-rich period. Time series data were collected for the year 2017, monitored by pressure transducer loggers at 14 wells located throughout the catchment area. These were then converted to the groundwater levels by subtracting them from the DEM values of the wells. The model calibration was carried out using the parameter-estimation software PEST (http://www.pesthomepage.org/). PEST was used in estimation mode, adjusting parameters for hydraulic conductivity and specific yield spread out across 152 pilot points across the catchment. This produced 304 adjustable parameters. The initial values for hydraulic conductivity at the pilot points were obtained through radial basis function interpolation from measured K values across the catchment. Values of K at each of the pilot points was allowed to vary between 90 % of the minimum measured K and 110 % of the maximum measured K, thus constraining the K values to measured values only, with a small margin of error allowed.

The calibration of hydraulic groundwater head from the 14 observation wells yielded a fit with model efficiency of 0.98, a percentage bias of -2.53 %, and a root mean squared error of 1.41 m. Given the uncertainty associated with the groundwater level data, the fit was deemed sufficient. The fit is shown below in Fig. 7.23. The calibrated values of K ranged from 0.1 to 30.0 m/d and closely followed the pattern of K measured in the field. The final specific yield ranged from 0.232 to 0.296.

Fig. 7.24 presents for the base case S0, the simulated groundwater fluxes for the dry, average and wet year recharge conditions for the La Vi catchment. Important conclusions can be drawn from this graph and connected values with respect to the sustainability of the groundwater resources. It is clear that in wet years groundwater pumping is less than 46 % of the recharge. Hence, the recharge still can maintain baseflow to the river, which is generally important for maintaining minimum ecological conditions in river valleys. In a year with average precipitation the groundwater pumping increases to 75 % of recharge. As a result, the baseflow to the river is decreased significantly, i.e. baseflow is captured by the groundwater extractions in this case. This likely significantly decreases the ecological stability of groundwater dependent vegetation in valley areas and ecological aquatic conditions in the streams. In dry years with low precipitation, the groundwater pumping exceeds the natural recharge, i.e. 116 %, thereby reducing the baseflow to practically zero. Groundwater storage has to contribute now for 17 % to the groundwater pumping, which effectively reduces groundwater storage by about 7 M m^3/yr.

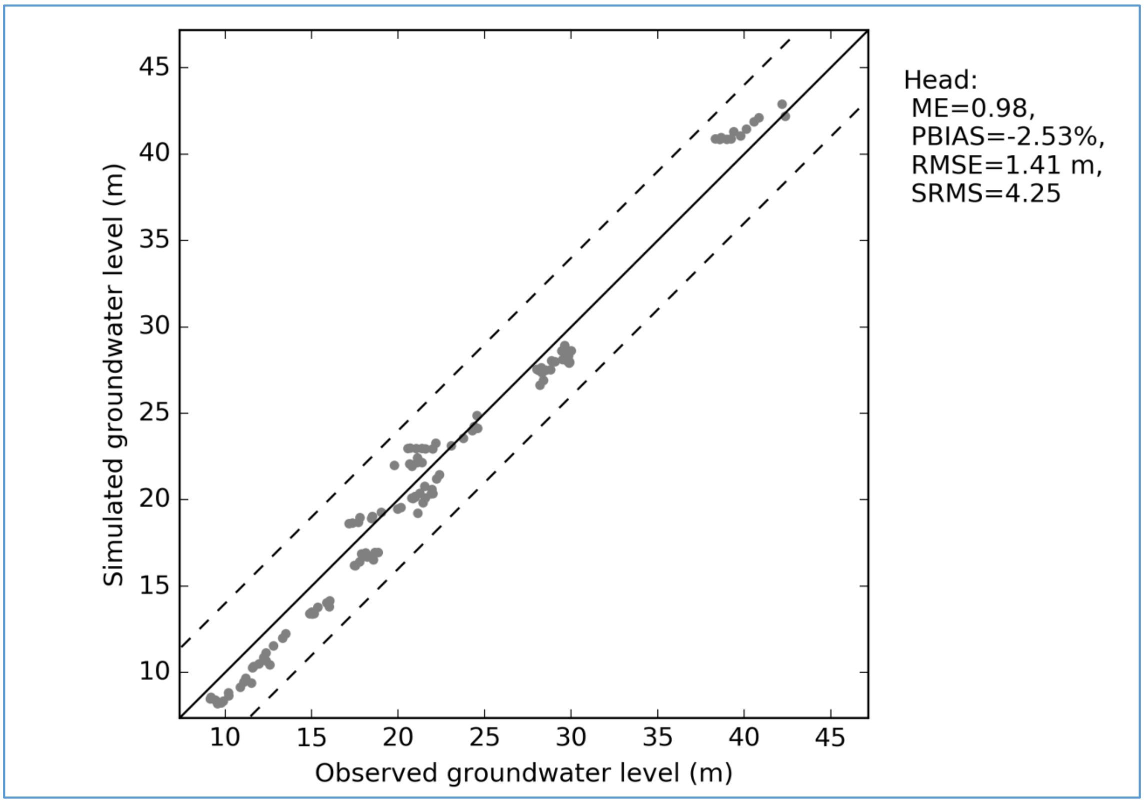


Fig. 7.23 Observed versus simulated groundwater levels at 14 monitored wells for all time steps of the calibrated model (for the year 2017).Dashed lines represent a standard error of 2 m assuming the errors are normally distributed.

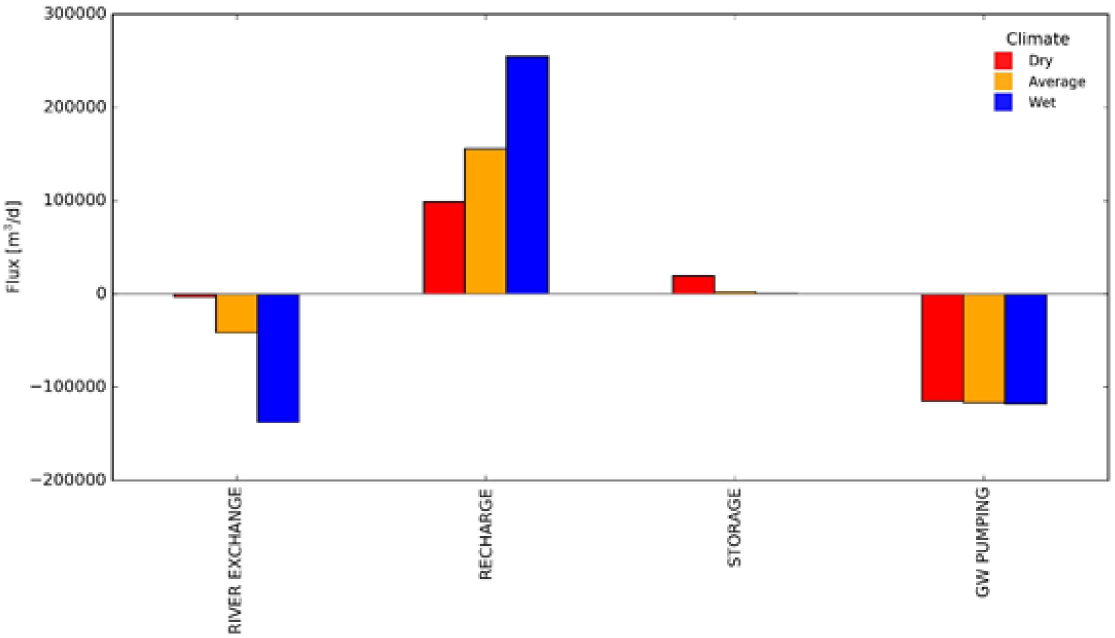


Fig. 7.24 Base case scenario S0 simulated groundwater fluxes for dry, average and wet year recharge conditions.

7.1.11 Coupled SWAT-MODFLOW model

The SWAT model was coupled to the MODFLOW model after calibration and validation using the SWAT-MODFLOW model. The coupled model produced daily recharge to the aquifer, groundwater-surface water interaction in the river channel and groundwater hydraulic head across the catchment. Fig. 7.25 shows the groundwater balance across the catchment for the period 2015 -2017.

The results show that recharge into the aquifer, charging the groundwater resource, occurs principally between November and February. Groundwater contributions to river flow is mainly occurring during the wet season. Moreover, the results show that the effect of groundwater pumping on the groundwater resources cause significant reductions in the groundwater storage between February and June. This transient flux pattern confirms the presented average water balance results of the base case S0 scenario of Fig. 7.24.

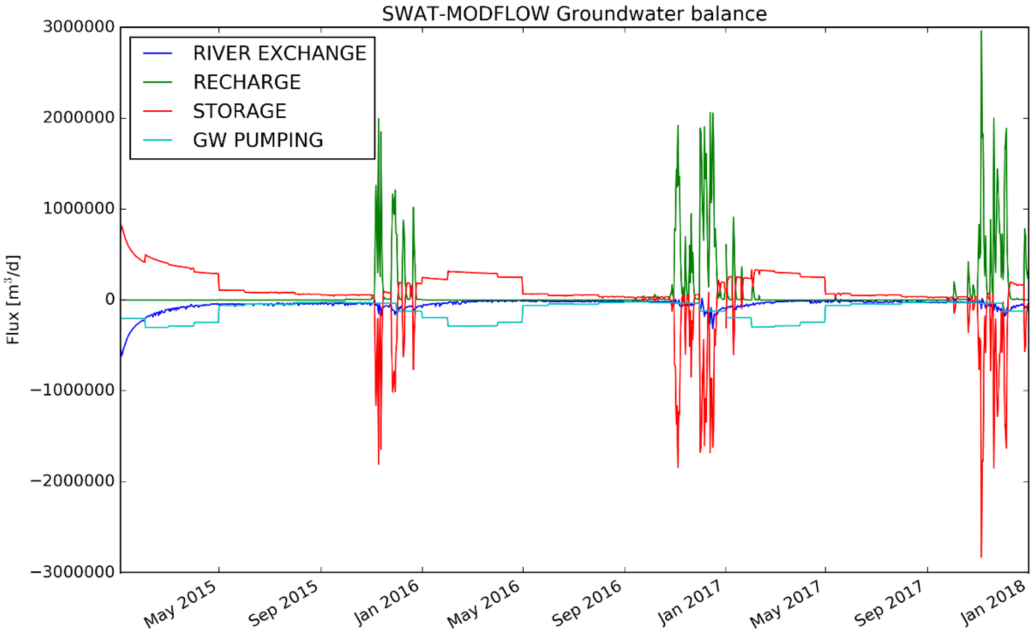


Fig. 7.25 Simulated catchment average fluxes for coupled SWAT-MODFLOW model for 2015-2017

7.1.12 Impact of various land use and water use scenarios on the water balance of La Vi, Binh Dinh (WetSpass-M – MODFLOW simulation)

Variation in water demand for different scenarios

The variation of cropping patterns and irrigation requirements between different land use scenarios resulted in changes in groundwater demands for irrigation for different scenarios and times (Fig. 7.26). Total annual catchment groundwater consumption for irrigation between scenarios ranged from 17.45 x 10^6 m^3 (S4 and S4b) to 57.14 x 10^6 m^3 (S1d), with the total annual catchment consumption of the base scenario (S0) estimated to be 40.53 x 10^6 m^3. Regarding the temporal changes, intensive consumption is observed for the first half of the dry season (from January to April), or the entire dry season (until August) for some scenarios, as this was the intensive cropping (and irrigating) season.

Total groundwater consumption for the dry period (January to August) accounted for 80–92 % of the total annual consumption for irrigation in every land use scenario. Irrigation was dominant in groundwater consumption and contributed 97.5 % of the total groundwater abstraction (for all purposes), while the amount of groundwater abstraction for domestic use and livestock was the same amongscenarios. The groundwater abstraction ratio (proportion of annual groundwater abstraction to annual recharge) of all scenarios ranged from 0.20-1.58 with a mean value of 0.72. Averaging all land use scenarios for each climatic condition resulted in abstraction ratios of 1.07, 0.68 and 0.42 for dry, average and wet conditions, respectively.

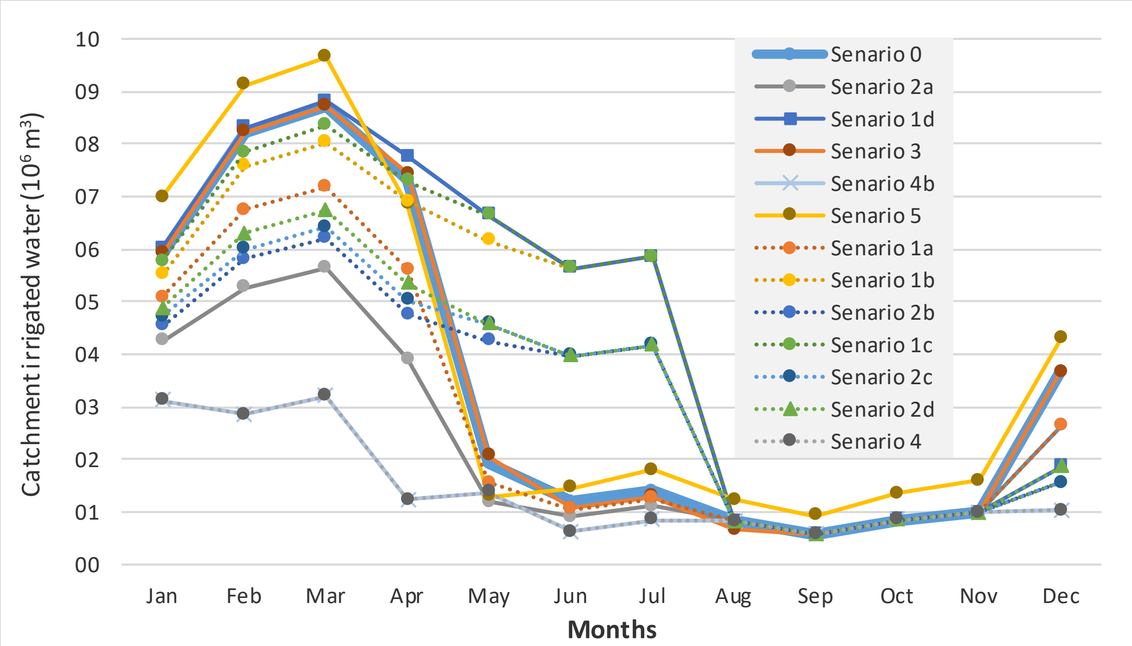


Fig. 7.26 Temporal and scenario variation in calculated catchment groundwater abstraction for irrigation. Scenarios presented in solid lines are used in the groundwater modelling for evaluating their impact on the groundwater resources.

WetSpass-M – MODFLOW simulated water balance fluxes for different scenarios

Analyses were performedon each of the modified land use scenarios' (S0, S1d, S2a, S3, S4b and S5) demanded groundwater abstractions versus the groundwater systems' ability to meet these demands into the future under continued average climatic conditions as well as extreme persistent dry and wet conditions. Fig. 7.27 (top) shows clear differences over the scenarios in total actual pumping able to be delivered by the groundwater system,with S1d the highest and S4b the lowest pumping. Also it is observed that the impact of dry to wet climatic conditions on the individual scenarios is smaller than the difference between the scenarios. Still, relatively higher climatic impact is shown for the higher demand scenarios. Further,it is noticible that only after a few years for most scenarios the amount of pumping has reduced to a level that can be supplied by the groundwater system. This indicates that the unconfined groundwater system rapidly approaches a new equilibrium. The small increase in total actual pumping in the first 2 years is an effect on a model initial condition (starting from an average steady-state condition). Fig. 7.27 (bottom) presents for the different scenarios the actual pumping in the future as a ratio of the demanded abstraction, i.e. the percentage of pumping that can be met by the groundwater system. Most scenarios start between 90 and 95 % demand met. This is due to the fact that model forced groundwater extraction, which is based on the land use scenario, is not always congruent with the hydrogeological conditions of being able to even initially supply groundwater at the requested demand. Overall, as a summed total demand over the catchment, the demand is met reasonably well for the average and wet scenarios, while there is a significant reduction for the dry scenarios.

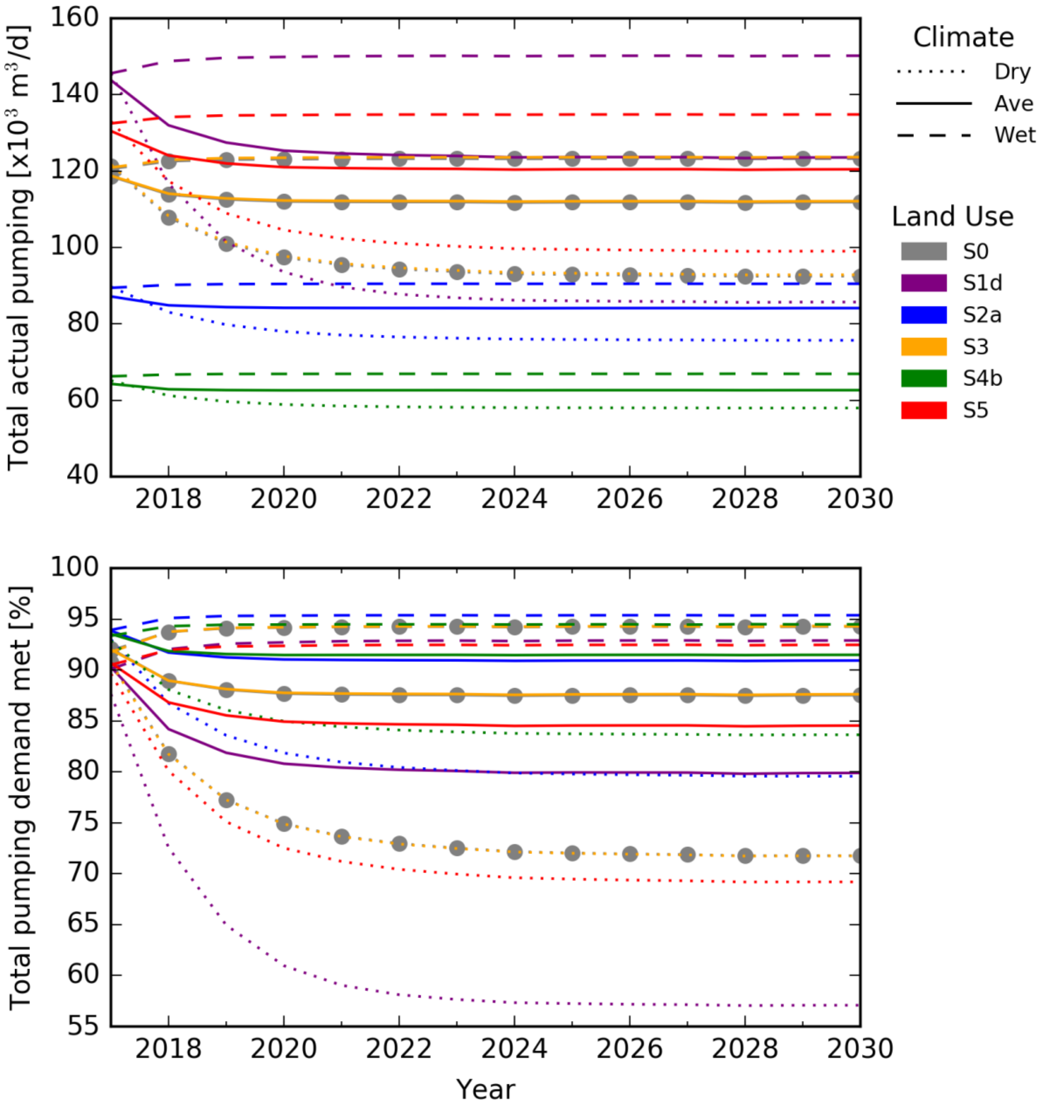


Fig. 7.27 Total volume of pumping applied (top), and the total percentage of pumping demand met (bottom) in each scenario.

Negative change in groundwater storage (withdrawal) was observed in the dry period (January to August) and positive change (recharge) was observed in the rainy season (September to December) (Fig. 7.27). Changes in groundwater storage reflected the variation in groundwater demand for irrigation over the range of land use scenarios (i.e., an increase in groundwater demand caused a decrease in groundwater storage), particularly during the dry period. Compared to the base scenario, scenarios S1d and S5 showed an increase in groundwater storage of 44 % and 3 % (for the dry period) and 26 % and 2 % (for the wet period), respectively. Conversely, S4b and S2a showed a decrease in groundwater storage by 39 % and 24 % (for the dry period) and 33 % and 19 % (for the wet period), respectively. The groundwater storage of S3 was similar to that of the base scenario S0. When averaged for all land use scenarios, changes in groundwater storage amongclimatic conditions were smaller in the dry season than in the rainy season, as the magnitude of precipitation, and hence recharge, in the dry season is much smaller than in the rainy season.

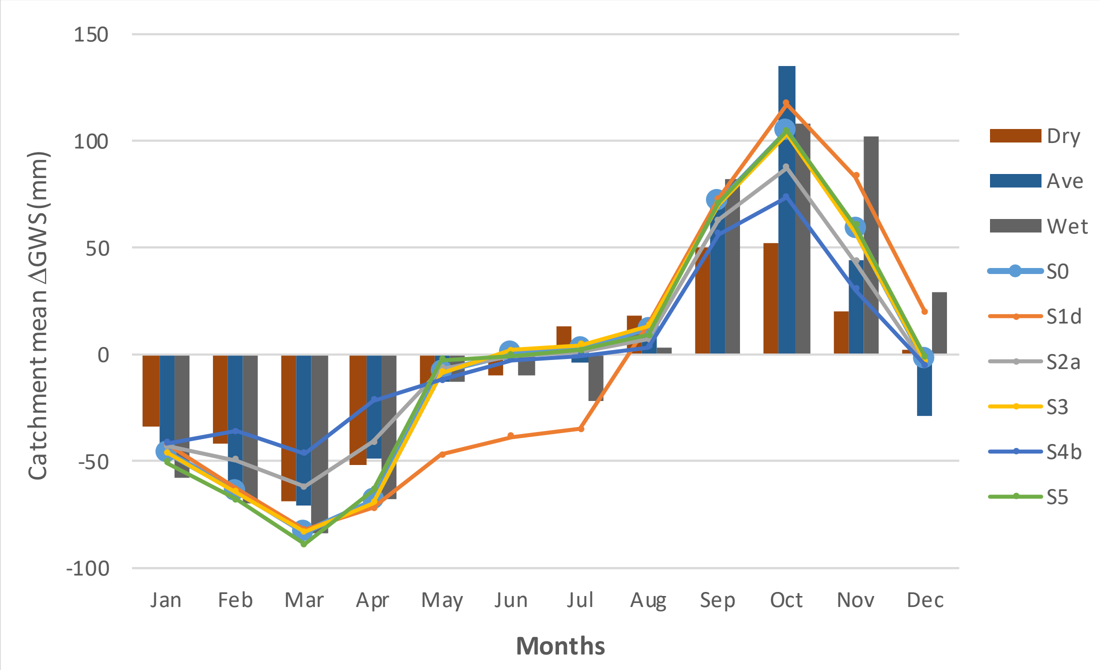


Fig. 7.28 Temporal variation of the monthly simulated change in groundwater storage for different land use scenarios, averaged over dry, average and wet climatic conditions (line chart) and for dry, average and wet climatic conditions, averaged over all land use scenarios (bar chart).

Base-flow was relatively small, varying between 10% and 40% of groundwater abstraction or change in groundwater storage, during the dry period, particularly for the first four months (January to April) (Fig. 7.28). However, during the rainy season, base-flow was the most significant sink of the aquifer, with the total base-flow for the four-month rainy season being four times higher than that of the abstraction, and five times higher than that of the change in groundwater storage. The different scenarios all show that the base-flow was small during the dry period (January to August), about 30 % of the total yearly base-flow. However, in the wet season (September to December), total base-flow was much higher, approximately 70 % of the total yearly base-flow. The beginning of the year (which is also the beginning of the dry season) until April showed a decreasing base-flow, while it starts rising from May until the end of the year. Base-flow varied amongeach land use; respectively, S4b and S2a had a base-flow that was 70 % and 30 % (annually) and 124 % and 47 % (for the dry period) higher than in the base scenario (S0). S1d and S5 had lower base-flow compared to the base scenario, by 33 % and 15 % (annually) and 30 % and 15 % (for the dry period), respectively. S3 had the same base-flow as S0. Considering that recovery of groundwater levels in response to pumping in different scenarios is a slow process, the differences in the wet season base-flow across the different land use scenarios were still significant, varying from -34 % to 56 % compared to the base scenario.

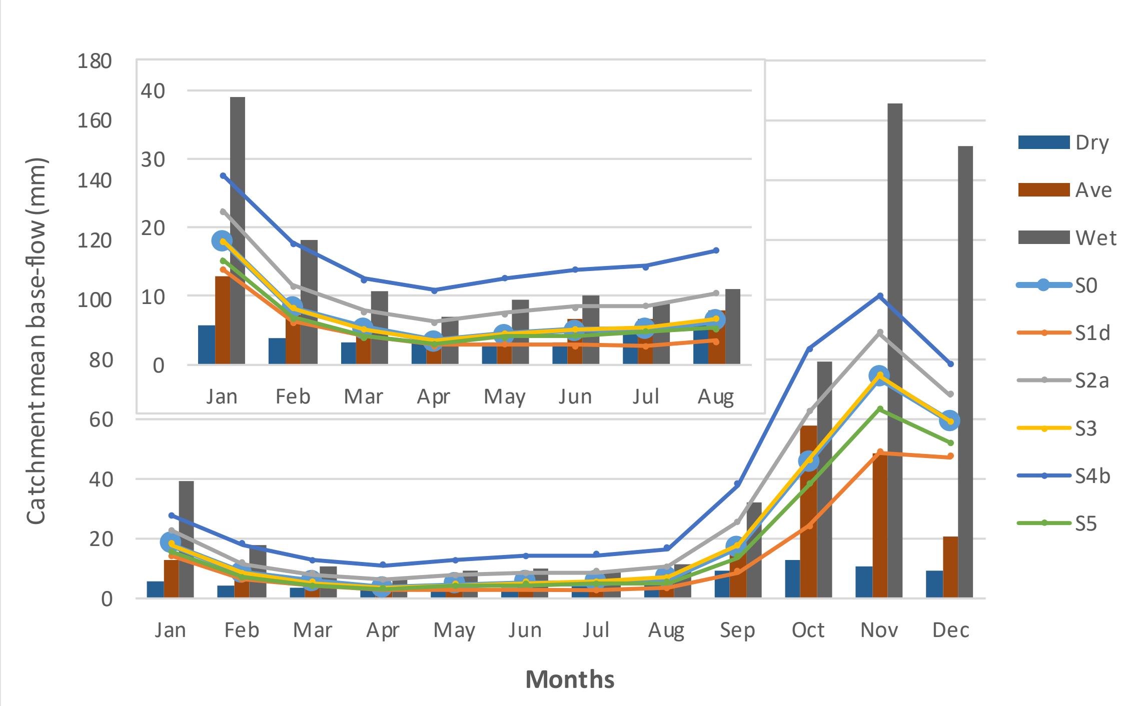


Fig. 7.29 Temporal variation of simulated base-flow to streams for different land use scenarios, averaged over dry, average and wet climatic conditions (line chart) and for dry, average and wet climatic conditions, averaged over different land use scenarios (bar chart). The inset shows data for the dry period (January to August).

Evaluation of the research question of Objective 1

Finally, in order to evaluate the research question of objective 1:

1. How can groundwater abstraction for irrigation be managed to fit the available supply?

a comparison is made of the base case S0 and five simulated agricultural development scenarios. Fig. 7.29 presents as bar charts the yearly average difference in groundwater balance fluxes for dry, average and wet year conditions. Comparing the graphs, it is obvious that the recharge to the groundwater does not vary a lot among the scenarios, but much more among the climate conditions. Groundwater pumping varies significantly over the scenarios with most to least pumping (for average climate) occurring in the range of scenarios S1, S5, S0, S3, S2 and S4. To further evaluate the groundwater abstractions versus the recharge, Fig. 7.30 presents the ratio of these as a percentage. Scenarios having an abstraction higher than the recharge to the system, hence depleting the groundwater system are the dry scenarios of S1, S5, S0, S3 as well as S1d_Ave. Scenarios having an abstraction between 100 and 50% of the recharge are: S2a_Dry, the average scenarios S5, S0, S3, S1d_wet, S2a_Ave, S4b_Dry, S5_Wet. The least impactful scenarios are S0_Wet, S3_Wet, S4b_Ave, S2a_Wet and S4b_Wet.

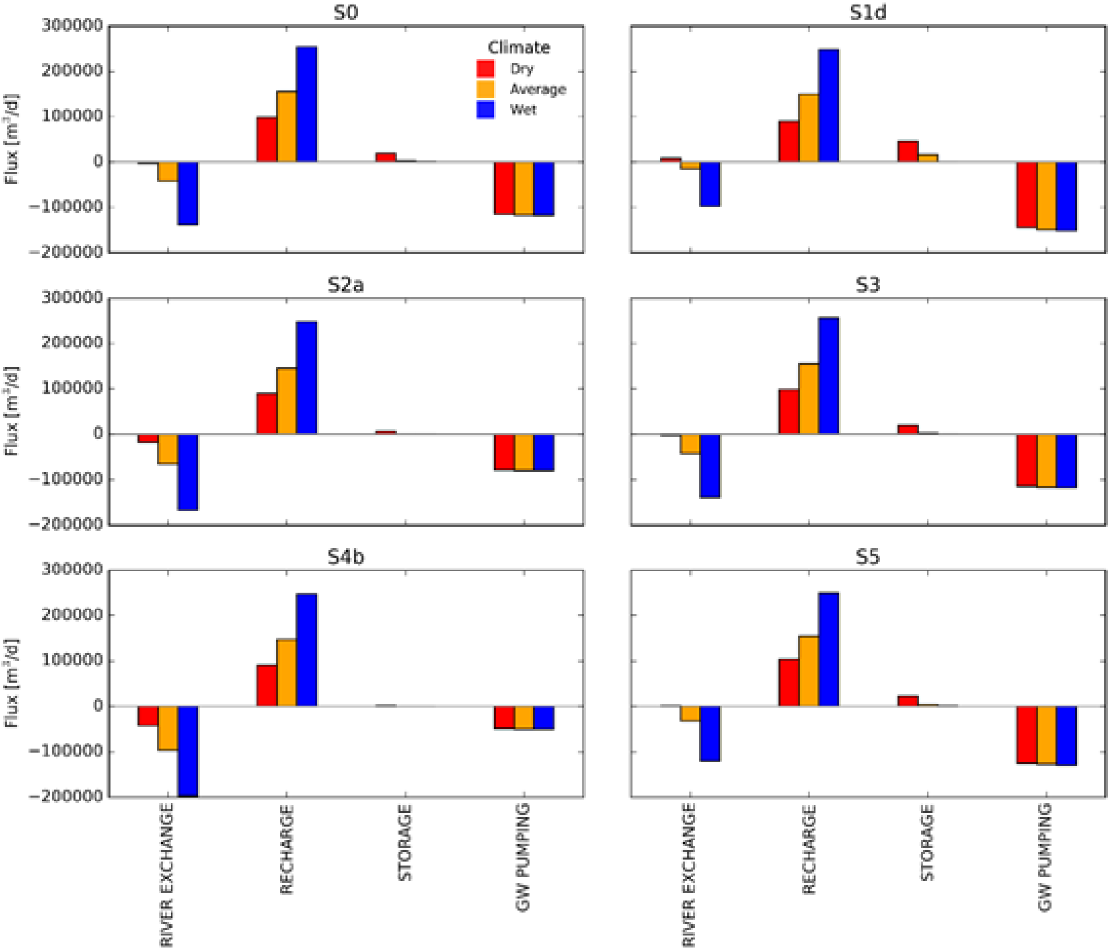


Fig. 7.30 Groundwater balance fluxes as simulated by the coupled transient WetSpass-M – MODFLOW model for the base case S0 and 5 agricultural development scenarios.

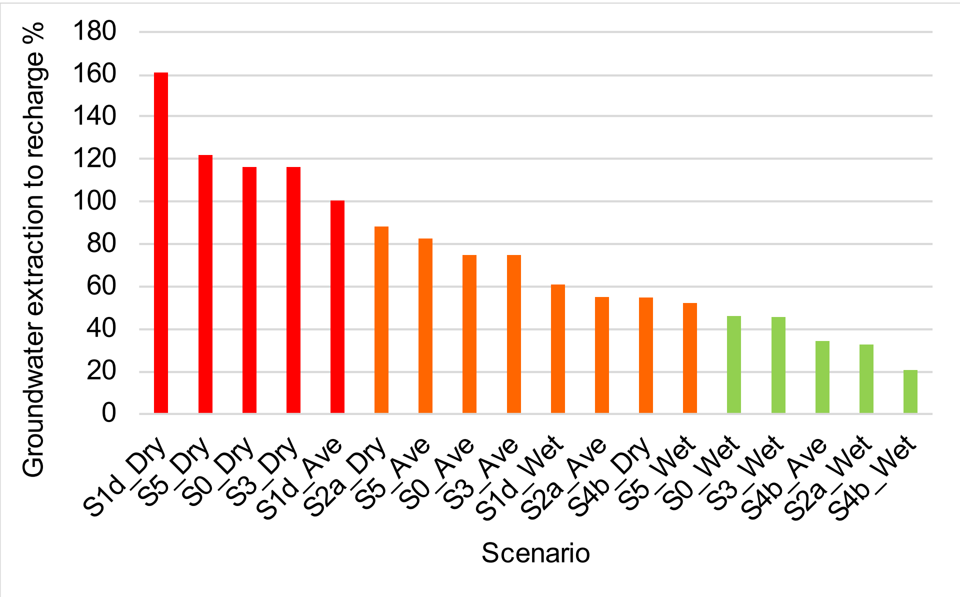


Fig. 7.31 Ratio (as a percentage) of groundwater extraction versus groundwater recharge for the different simulated scenarios.

Weiskel et al. (2007) introduce the concept of the water use regime represented as a two-dimensional, x-y plot of normalized human withdrawals (h_{out}) versus normalized human (irrigation) return flows (h_{in}). The four end-member regimesare (Weiskel et al., 2007):

(1) natural-flow-dominated (or undeveloped, where $h_{out} = h_{in} = 0$),

(2) withdrawal-dominated (depleted; $h_{out} = 1$; $h_{in} = 0$),

(3) return-flow-dominated (surcharged; $h_{out} = 0$; $h_{in} = 1$), and

(4) human-flow-dominated (churned; $h_{out} = h_{in} = 1$).

In order to come to this plot, the groundwater extractions (H_{out}) and the irrigation return flows (H_{in}) for every scenario was calculated. The last as the difference in WetSpass-M simulated recharge for only precipitation and scenarios of simulated recharge from precipitation loaded with additional irrigation water. To get normalised withdrawals (h_{out}) and return flows (h_{in}), H_{out} and H_{in} are divided by the $NetFlux_{aquifer}$, which is calculated as the sum of H_{out} and D_{sw}, being the aquifer discharge to adjacent surface water systems.

The resulting figure for the 18 scenarios (base case S0 and five agricultural development scenarios, each for dry, average and wet climatic conditions) is presented in Fig. 7.31. It shows that 10 scenarios fall in the quarter indicating conditions towards depleting the groundwater resource. Clearly, the most sustainable development scenario is S4b. It is the only scenario, which is under wet and average climatic conditions in a ‘safe’ groundwater management space, while being close to this under dry climatic conditions. To recall, in scenario S4b, cassava replaces peanut (alslo in combinations with rice) (in dry season) and all bare land becomes cassava.

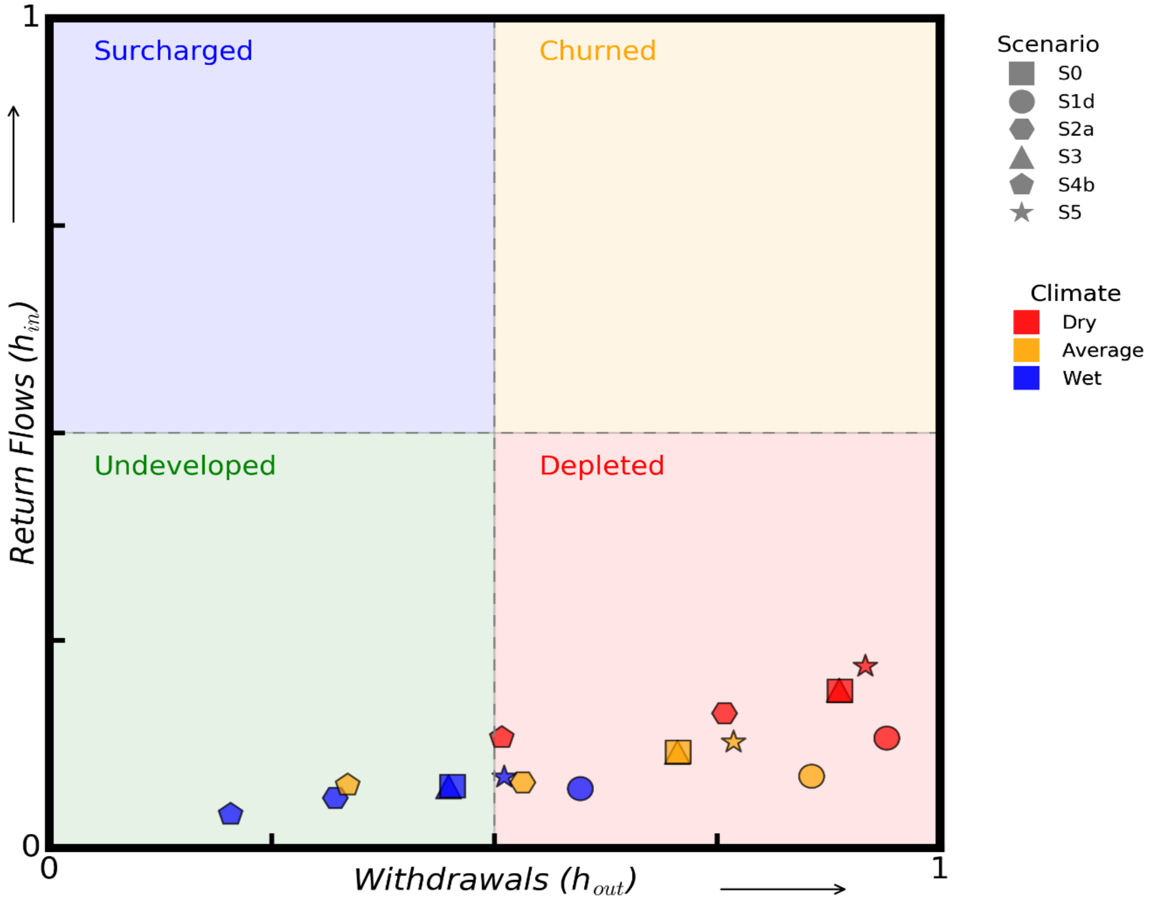


Fig. 7.32 Groundwater resources sustainability evaluation of simulated base condition S0 and fourdifferent agricultural development scenarios for dry, average and wet climatic conditions.

Groundwater vulnerability maps were generated by comparing the change in pumping demand (at each 100 m x 100 m pixel [*i*] being met in year 1 from scenario *A* vs demand being met after100 yearsof pumping under demanded groundwater extractions as defined by scenario *A:*

$$Vulnerability[i] = \frac{pump_{actual}{}_A^{yr=1}}{pump_{forced}{}_A} \times 100\% - \frac{pump_{actual}{}_A^{yr=100}}{pump_{forced}{}_A} \times 100\%$$

With $pump_{actual\_A}$ the actual pumping amount that the groundwater system is able to supply, while $pump_{forced\_A}$ is the amount of groundwater requested to be extracted based on the demand for the irrigation and other groundwater usuage as defined by the spatial land use scenario *A*. A high vulnerability of the groundwater system would indicate that groundwater storage or baseflow is strongly reducing over time and that the demanded groundwater extractions are not sustainable. Note that each land use scenario is simulated for 100 years under persistent average climatic conditions as well as under the extreme cases of persistent dry and wet conditions.

The vulnerability can be categorised to ease interpretation with the guide shown in Table 7.7.

Table 7.7 Categories of groundwater vulnerability as used to classify the spatial vulnerability analyses.

Vulnerability category	**Demand met**	**Interpretation**
Extreme	0 – 25%	Mostly unable to meet pumping demand
Very High	25 – 50%	Only a small amount of pumping demand met
High	50-75%	Pumping demand is not securely met
Medium	75-100%	Pumping demand is mostly met
Low	100%	Aquifer supply to pumping demand easily met
Pumping not present	-	Not applicable

Fig. 7.33 shows that in all scenarios there are areas in the catchment that are categorised as being highly to extremely vulnerable. In particular, the land use change to peanut and cassava from the bare land (S1d) shows widespread high to extreme vulnerability in the average and dry conditions. In the persistent dry scenaros, large areas of the catchment show high to extreme groundwater vulnerability. The climatic average scenarios still have large areas in the La Vi River valley which are high to very highly vulnerable., In all scenarios under the persistent wet conditions, there is a noticeable band along the main river in the south east that shows local areas of high vulnerability. Consistent with previously presented results scenario S4b shows lowest vulnerability.

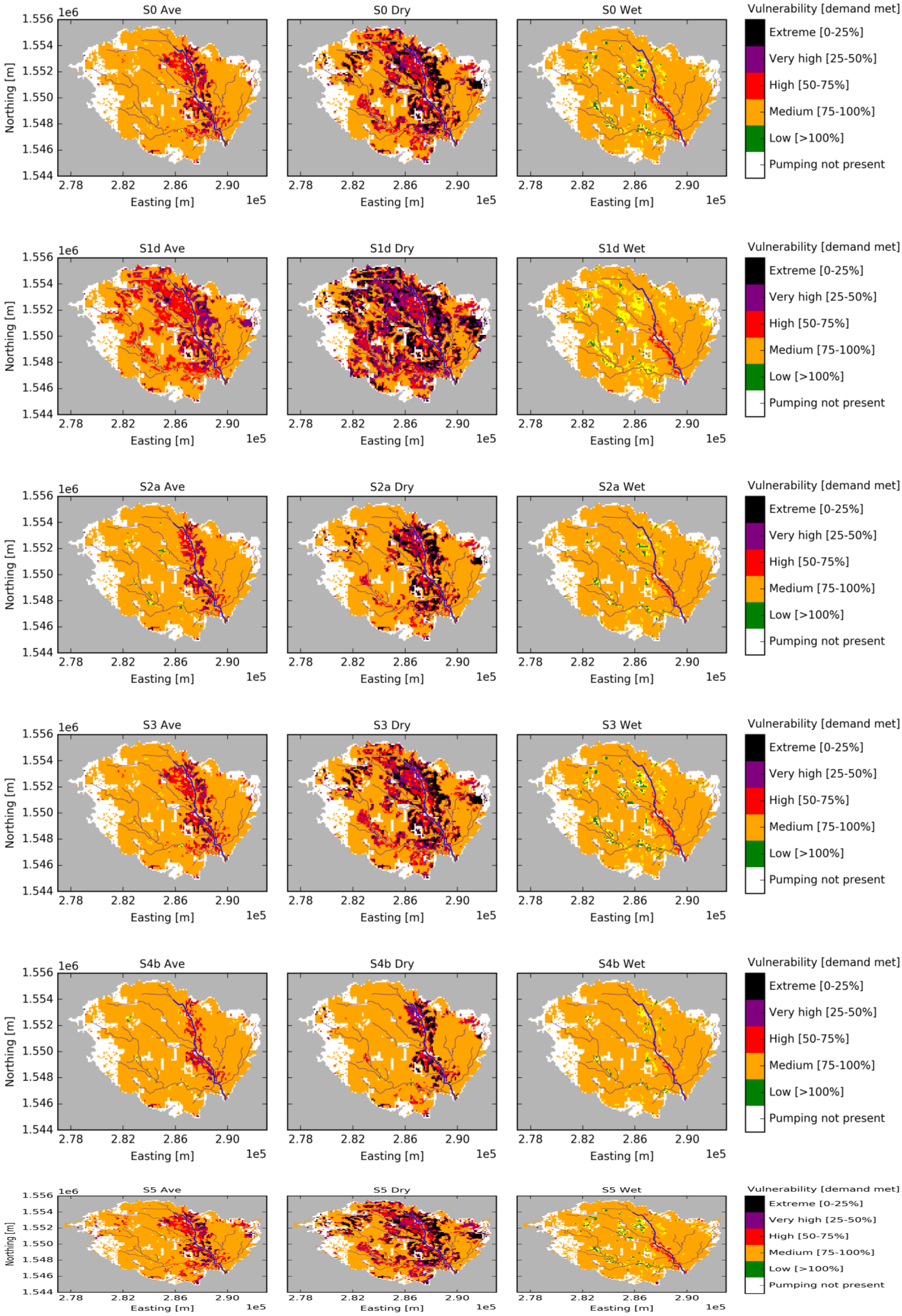


Fig. 7.33 Vulnerability during persistent average, dry and wet conditions for land use change scenarios S0 (the 2016 land use), S1d (saving 25 % and 50 % irrigation for peanut and mango after changing cassva to peanut and acacia to mango), S2a saving 25 % and 50 % irrigation for peanut and mango with 2016 land use), S3 (maize replaces irrigated dry season rice), S4b (cassava replaces peanut and expands onto bare land) and S5 (irrigated vegetables replace mango/ coconut).

7.2 What are the most practical and cost-effective solutions to overcome soil constraints to alleviate soil nutrient deficiencies in SCC VN and WA

7.2.1 Crops grown on sandy soils inprovinces of SCC VN

The project targeted infertile sandy soils which cover > 330,000 ha in SCC VN and are characterized by low water and nutrient holding capacities but are suitable for irrigated crops like peanut, mango, and vegetables (Table 7.6).

Table 7.8 Planted area of crops dependent on groundwater for irrigation in coastal provinces of central Vietnam in 2017

Province	Crops (ha)		
	Beans/veg	Mango	Peanut
Da Nang	980	57	-
Quang Nam	18,276	191	9,935
Quang Ngai	14,184	191	6,021
Binh Dinh	16,517	1,297	9,851
Phu Yen	10,689	365	3,758
Khanh Hoa	6,239	8,052	571
Ninh Thuan	12,746	421	510
Binh Thuan	16,535	2,954	5,244
Total	96,166	13,529	35,889

Source of data: (Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan, Binh Thuan) Provincial Statistical year book, 2018

Most of these crops are irrigated during the dry seasons by withdrawing groundwater from open wells up to 10 m deep or from bores installed to various depths depending on the water table depth. Currently, farmers flood irrigate these crops in NT or hand water them using a hose in BD. Both methods are believed to result in overuse of water, uneven distribution of water, and loss of nutrients due to leaching. In addition, overuse of water by current practices during the dry season (April- September) resulted in water shortages, and at times, farmers had to wait for the groundwater to refill the wells or bores to irrigate their fields. In provinces like Ninh Thuan where rainfall is below 800 mm, the open wells were almost dry during the dry season leaving limited water available for irrigation. Hence, the project focused on

- i) using different techniques to identify nutrient deficiencies (omission, double pot, visual deficiency symptoms);
- ii) testing the use of water saving irrigation technologies (sprinklers, drippers, fertigation, mini pan);
- iii) using different amendment materials to improve water and nutrient retention/efficiencies (manure, compost, clay, bentonite, crop residues);
- iv) testing fertilizer forms and rates for the deficient nutrients (K, S) to overcome nutrient constraints affecting crop growth.

The research was conducted in BD, NT and QN provinces of SCCVN where farmers were facing productivity constraints as a result of poor water and nutrient use efficiencies. More focus was placed on peanut crop especially in BD and QN. Mango research was confined to BD while vegetables research was confined to NT.

Identifying nutrient deficiencies by cost effective soil and plant testing as used in Australia is a challenge due to poor laboratory infrastructure, lack of instruments, contamination of samples during collection, preparation and analysis and limited interpretation criteria for making recommendations. Hence, the project used multiple approaches (double pot technique, omission trials, soil and plant tissue tests, field experiments with different rates of nutrients) to identify, verify, and correct the deficiencies of K and S. Key findings using these techniques are discussed below:

7.2.2 Identifying nutrient deficiencies

Double pot technique

The double pot technique proved to be a valuable diagnostic tool to evaluate the nutrient supplying capacity of soils. Its simplicity and cheapness make it ideal for large scale screening of soils in pot experiments. Most of the soils collected from the experimental sites in BD, NT and QN provinces were tested by this means to identify the nutrient deficiencies.

Most of the sandy soils tested by way of nutrient omission using the double pot technique showed major (N, P, K, S) and micronutrient (Zn, Cu, B) deficiencies. However, the relative severity of the deficiencies varied among sites. For example, limiting nutrients in sandy soils of Binh Trung commune, Thang Binh district, QN province were: potassium > nitrogen > sulfur > zinc > boron > copper > phosphorus, whereas at Binh Sa commune the order of severity was: potassium > sulfur > boron > zinc > phosphorus > copper > nitrogen. Hence more site-specific testing for nutrient status on sands is warranted to achieve the best crop productivity.

The plant availability of both K and S in most sands in BD and NT was low based on soil tests and confirmed by the glasshouse nutrient omission studies (double-pot), as well as field experiments (Hoang et al. 2015). In addition, sandy soils from all experimental sites were tested for their nutrient status and were categorised as low based on studies conducted by Peverill et al.(1999), Target 10 (2005) and Hazelton & Murphy (2007) (Table 7.7). Status of micronutrients was found to fall in the lower category as well (Table 7.8).

Table 7.9 Status of nutrients, organic carbon (OC) and cation exchange capapcity (CEC) in sandy soils from experimental sites in Binh Dinh, Quang Nam and Ninh Thuan provinces

No.	Parameters	Low	Normal	High
1	OC (%) (Peverill et al. 1999)	<1.5	1.5-2.9	>2.9
	Sandy soil in Binh Dinh	<1.5	-	-
	Sandy soil in Quang Nam	<1.5	-	-
	Sandy soil in Ninh Thuan	<1.5		
2	K_{avail} (mg/kg) (Target 10, 2005)	<140	141-170	>170
	Sandy soil in Binh Dinh	<140	-	-
	Sandy soil in Quang Nam	<140	-	-
	Sandy soil in Ninh Thuan	<1.40		
3	S (mg/kg)	<8	9-12	>12
	Sandy soil in Binh Dinh	<8	-	-
	Sandy soil in Quang Nam	<8	-	-
	Sandy soil in Ninh Thuan	<8		
4	CEC (meq/100g) (Hazelton & Murphy, 2007)	<12	12-25	>25
	Sandy soil in Binh Dinh	<12	-	-
	Sandy soil in Quang Nam	<12	-	-
	Sandy soil in Ninh Thuan	<12		

Table 7.10 Status of available micro nutrients in sandy soil of Binh Dinh, Quang Nam and Ninh Thuan.

Trace element	Preferred level in soil (mg/kg)	Sandy soil in Binh Dinh (mg/kg)	Sandy soil in Quang Nam (mg/kg)	Sandy soil in Ninh Thuan
B	0.5-4	4.3	1.4	12.6
Cu	2-50	2.3	1.0	1.4
Zn	1-200	6.8	8.6	6.8

Source: Hazelton and Murphy (2007)

K and S rates for peanut on farmer's fields

After identifying deficiencies of K and S, experiments were conducted to determine rates required for these deficient nutrients (K and S) for optimum yields and crop profit on farmer's fields.

Multiple trials were conducted (Cat Hiep, Cat Hanh, Cat Lam communes) in Phu Cat district, representing types of sandy soils that are prevalent in Binh Dinh province to test K rates (0, 50, 75 and 90 kg Kha) and forms (KCl, K_2SO_4, K 40%) for the main peanut cropping season (winter/spring season). In general, there were no significant differences in peanut yield between 75 and 90 kg K/ha regardless of the forms of K applied (Fig. 7.34).

Similarly, experiments were conducted to determine the optimum rates (0, 15, 30 and 45 kg S/ha) and forms (K_2SO_4, $(NH_4)_2SO_4$, NPK 16-16-8-13S) of S for peanut crops in sandy soils of Phu Cat district, Binh Dinh province (Cat Hiep, Cat Hanh, Cat Lam communes). The peanut pod yield was highest at rate of 30 kg S/ha where K_2SO_4 was applied (3.29 to 3.83 t/ha) (Fig. 7.35).

Combined effects of organic and inorganic fertilisers on farmer's fields

Manure from livestock or compost is generally available for crop production as most farmer's practice mixed farming systems in SCC VN. Hence, for most of the experiments conducted on farmer's fields, the project used a basal application of farmyard manure (FYM) or the compost in combination with inorganic fertilizers. Biochar, a product that was previously tested by the ACIAR project (SMCN 2007/109) and showed promising results, was also tested as a treatment in combination with inorganic fertilizers to determine its effect on crop performance. Hence, experiments were conducted with three types of organic fertilizers (Nil, 8 tonnes of FYM and 10 tonnes of rice husk biochar) with 3 rates (0, 50, 75 kg K) and forms (KCl and K_2SO_4)/ha) of K over the years (2015-17) to determine the effect on peanut yield in Cat Hanh and Cat Hiep communes. The application of 8 tonnes FYM or 10 tonnes of rice husk biochar + 50-75 kg K/ha as K_2SO_4 + 30 kg S and along with basal fertilizer of 500 kg lime + 40 kg N + 40 kg P/ha had highest peanut yield varying between 3 to 4.8 t/ha (Table 7.9). The effects of organic fertilizer addition were additive to the response to inorganic fertilizer Kor S rates. This shows that additional nutrient availability and uptake from organic fertilizers made a contribution to increased nutrient and water use efficiency that led to higher peanut yields.

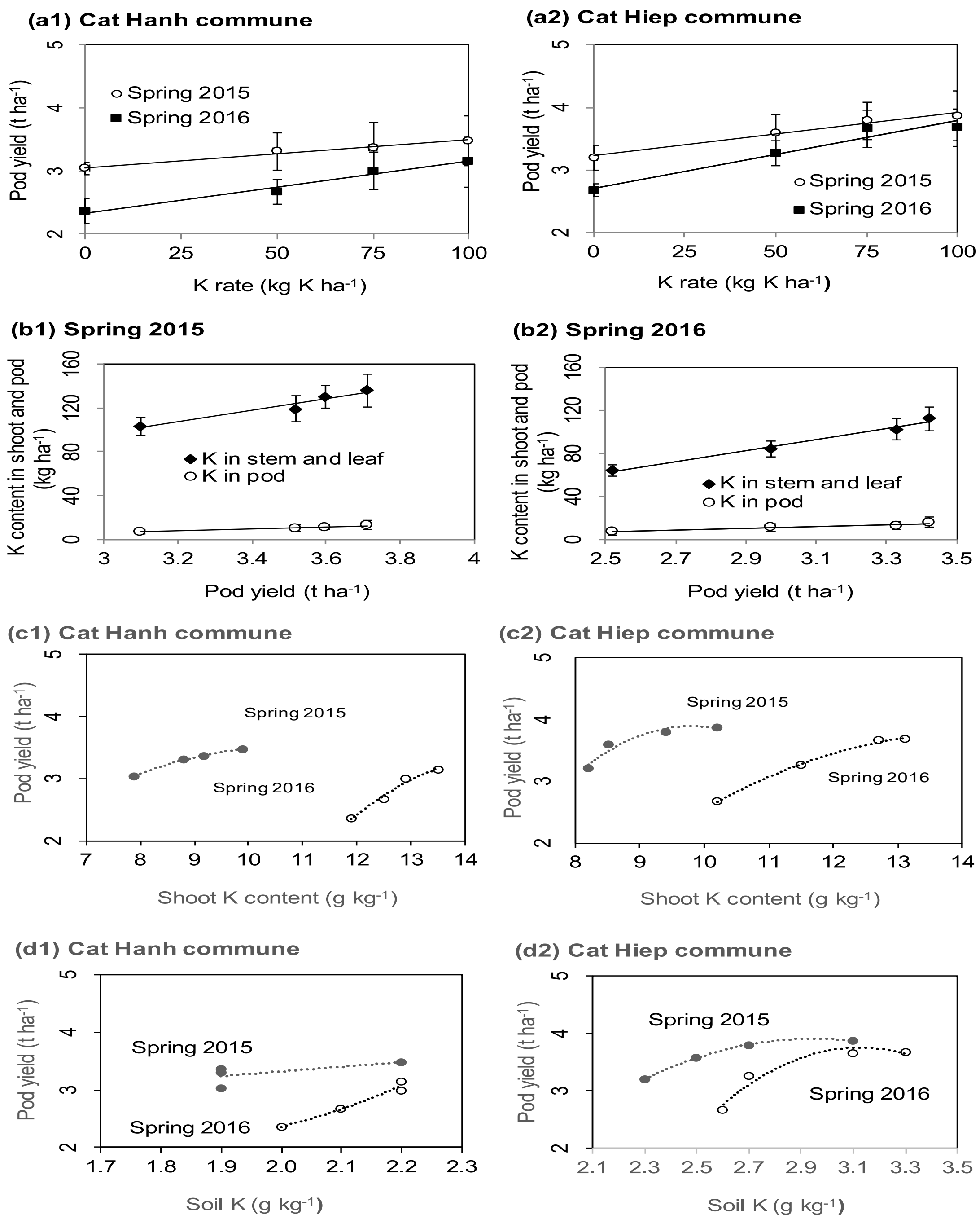


Fig. 7.34(a1, a2) Relationship between K rates (kg ha^{-1}) and pod yield (t ha^{-1}); (b1, b2) between pod yield and K concentration (g kg^{-1}) in stem, leaf and pod; (c1, c2, d1, d2) Pod yield (t ha^{-1}) in relation to shoot K concentration (g kg^{-1}) and soil K (g kg^{-1}).

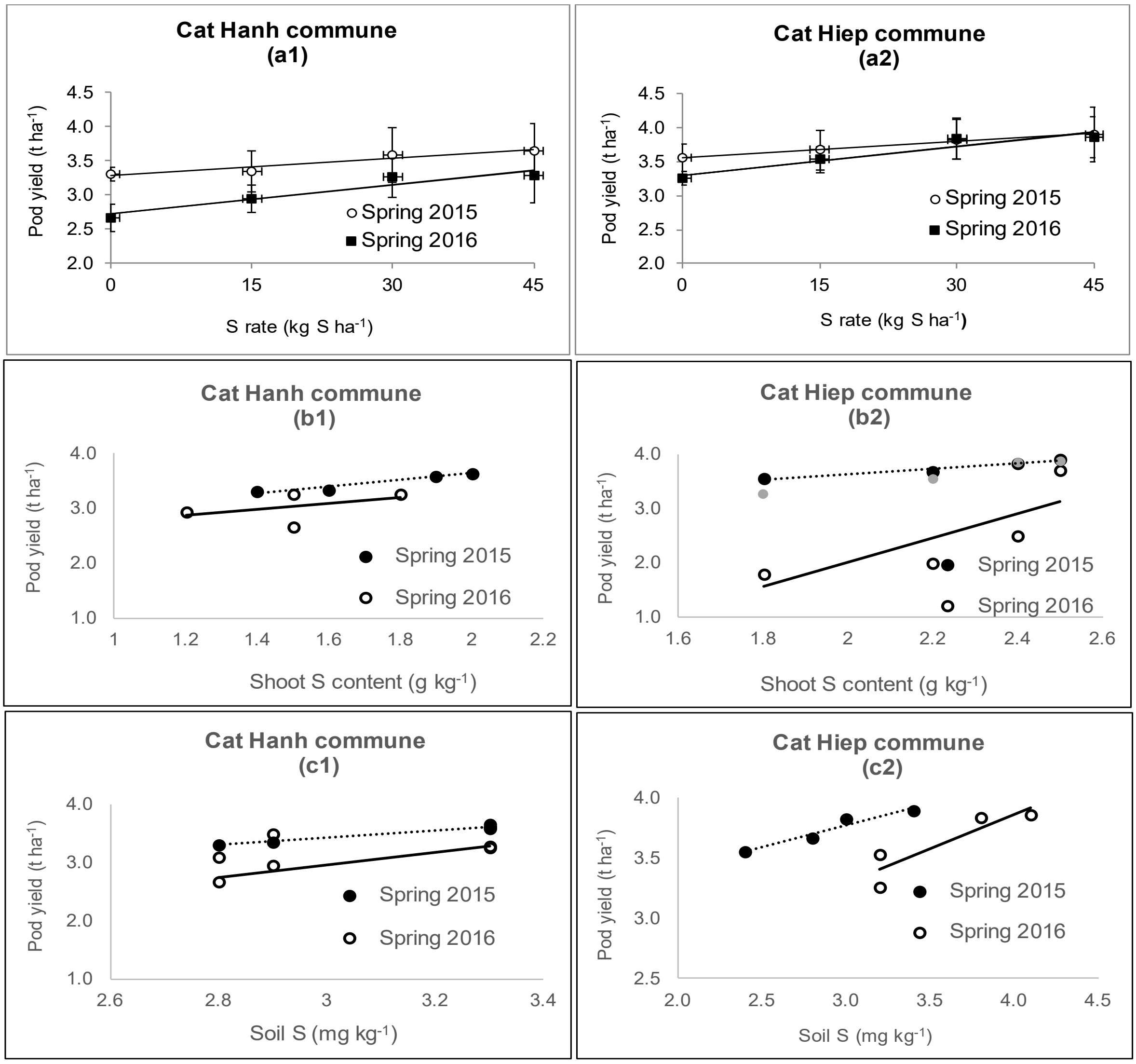


Fig. 7.35(a1, a2) Relationship between S rates (kg ha^{-1}) and pod yield (t ha^{-1}); (b1, b2) Pod yield (t ha^{-1}) in relation to shoot S content (g kg^{-1}); and (c1, c2) Pod yield (t ha^{-1}) in relation to soil S (mg kg^{-1}).

Table 7.11 Peanut yield with organic amendments and optimal K fertilizers in Binh Dinh

Expt	Site location	Year	Max yield range (t/ha)	Optimum rates (kg K/ha) *	Manure/ biochar added (t/ha)
K types and rates	Cat Hanh	2015	3.48 – 3.64	75	8 t manure
	Cat Hiep	2015	3.69 – 3.95	75	8 t manure
Integrated organic fertilizers and K	Cat Hanh	2015	3.80 – 4.09	50	8 t manure
	Cat Hanh	2015	3.57 – 3.92	50	10 t biochar
	Cat Hiep	2015	3.57 – 3.92	50	8 t manure
	Cat Hiep	2015	4.65 – 4.82	50	10 t biochar
K rates	Cat Hanh	2016	3.00 – 3.15	75	8 t manure
	Cat Hiep	2016	3.66 – 3.88	75	8 t manure
K rates (+30 kg S)	Cat Hanh	2017	4.10	75	8 t manure
	Cat Hiep	2017	4.42	75	8 t manure

* based on statistical significance

Even with organic fertilizer at 8 tonnes manure/haand K fertiliser at 90 kg K2O/ha K balances were negative (KCl: -53 kg K/ha; K_2SO_4: -62 kg K/ha). Soil S outputs were close to balanced with inputs when combined organic and inorganic S forms were applied (1.7 kg S/ha at 8 tonnes manure/ha and -8.3 kg S/ha at 10 tonnes of biochar/ha).

Effect of K and S rates on nutrient balances of soils on farmer's fields

Nutrient balance at farm level:

Farm level partial nutrient balance considered the boundary of the farm including all owned or rented and cultivated land by an individual farmer including all livestock production facilities and was estimated on a yearly basis. It does not include land that is rented to others.

Farm partial nutrient balances consider the nutrients that are imported (fertilizer, manure, amendment materials etc) onto farms,those exported out of the farm (manure, crop residue etc), recycled on the farm, and or lost to the environment. These nutrient balances can illustrate environmental and economic imbalances and can be managed to correct them accordingly. Here, the mass nutrient balance considered the difference between the amounts of N, P, and K imported through purchased products and the amounts exported off the farm via milk, meat, crops, manure and/or compost, however, did not consider S or the micronutrients for nutrient balance.

The average balance for N was positive on most of 10 farms but negative on some farms in BD, Phu Yen and NT. Inorganic fertilizer N accounted for above 50 % of the total N inputs for farms, whereas,N inputs as feed varied from 14 to 41 % of total N inputs. The study indicates that roughly 50 % of N was not exported from the farm through managed outputs. The fields with higher inputs (mainly from inorganic fertilizers) than nutrient removal from crop products would obtain positive balance and conversely minimal use of purchased inputs would result in negative balance in other fields. Negative balance is also possible by other ways through volatilization or leaching losses which were not included in this study.

In general, P balance was positive in all farms in BD, Phu Yen and NT. However, 3 farms in BD province the balance was zero or negative. The main inflow of P into fields was in inorganic fertilizer (over 80 %) and the outflow was only in the harvested crops (100 %). The phosphorus input amount exceeded the output amount in the crop fields at studied farms which normally leads to a net P accumulation in soil over years. In NT, shallow unconfined coastal aquifers generally had relatively higher phosphate concentrations, which might be related to positive P balances.

The farm balance showed negative K balanceson most of the farms studied. The largest inflow of K was with inorganic fertilizer (above 60 %), followed by purchased feed. The largest outflow of K was through the crop products.

As discussed above, major inputs and outputs were considered in the field including only mineral fertilizers and manure, and crop removal of nutrients through harvested products. The potential return of N, P, K nutrients to the fields in the manure on these farms is always less than the uptake of nutrients in the crops that were harvested and fed to the livestock. Nutrients from the crops are both retained by the animals and lost in the process of manure handling. If the nutrients from the manure are not efficiently returned to the fields, there are more likely chances of nutrients loss on the fields and the whole farm,hence,management of nutrients is critical for efficient productivity of the farm.

Of all the nutrients, substantial amounts of K were exported from fields, thus making the K balances more negative and have been observed at field level. Many fields are estimated to have negative K balances year after year, but very few instances of obvious K deficiency are reported. Altough, there are several possible explanations from other studies, such as, inputs from accumulated soil reserves originating from earlier periods with more intensive fertilizer application and soil's inherent capacity to release K through weathering of primary mineral sources. However, these explanations are highly unlikely given that farmer's focus is more on N and P fertilizers rather than K and soils being sandy in nature with less than 5% clay, the release of K from weathering of minerals would be limited. However, K deficiency can be hidden where productivity is limited by other nutrients (Oenema *et al.,* 2003).

Looking at the whole farm system, the continuous importation of feed and fertilizer in excess of nutrient exports at farm level results in large positive N and P balances. The farmers in the research area do not regularly and effectively recycle the residues from crops like rice straw, peanut or sweet potato which contain appreciable amounts of K and can upset the balances accordingly. The crop production system, which is the major source of the nutrients leaving the farm, has the highest risk for soil nutrient depletion.

Nutrient balance at field level:

Rates of K and S fertiliser were tested in experiments in Cat Hanh and Cat Hiep communes to determine a suitable rate for optimising peanut yield and to acsertain soil K and S balances on farmer's fields (Hoang et al. 2019; 2020). Without the application of K fertiliser, the partial K balances were negative and ranged between -93.1 and -52.1 kg K/ha at both the sites (Fig. 7.34). The partial K balances were less negative when 100 kg K ha^{-1} was applied and ranged between -42 kg ha^{-1} and -19 kg ha^{-1} in Cat Hanh commune and -34 kg ha^{-1} and -4 kg ha^{-1} in Cat Hiep commune. A close relationship between K rates and partial K balances was observed at both the sites (R^2 from 0.95 to 0.99). Irrigated peanut crops grown on sandy soils showed negative soil K balances at all K fertilizer rates largely due to K removal by peanut biomass and peanut pods. Even with increase of K fertiliser rate to 100 kg K ha^{-1}, only one out of four sites showed neutral to slightly positive partial K balance signifying the importance ofK fertilizer application for sustainable crop production (Table 7.12).

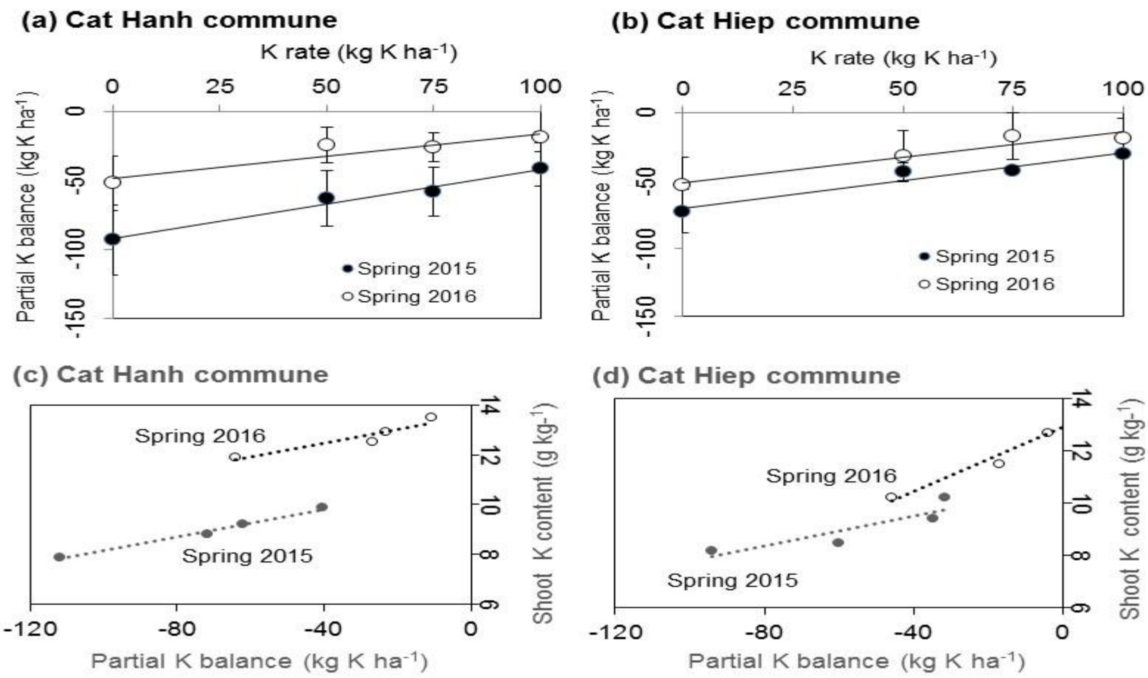


Fig. 7.36(a, b) Relationship between K rates and partial K balance in Cat Hanh and Cat Hiep communes in 2015 and 2016; (c, d) Relationship between shoot K concentration (g kg^{-1}) and partial K balance in Cat Hanh and Cat Hiep communes in 2015 and 2016 growing peanut seasons.

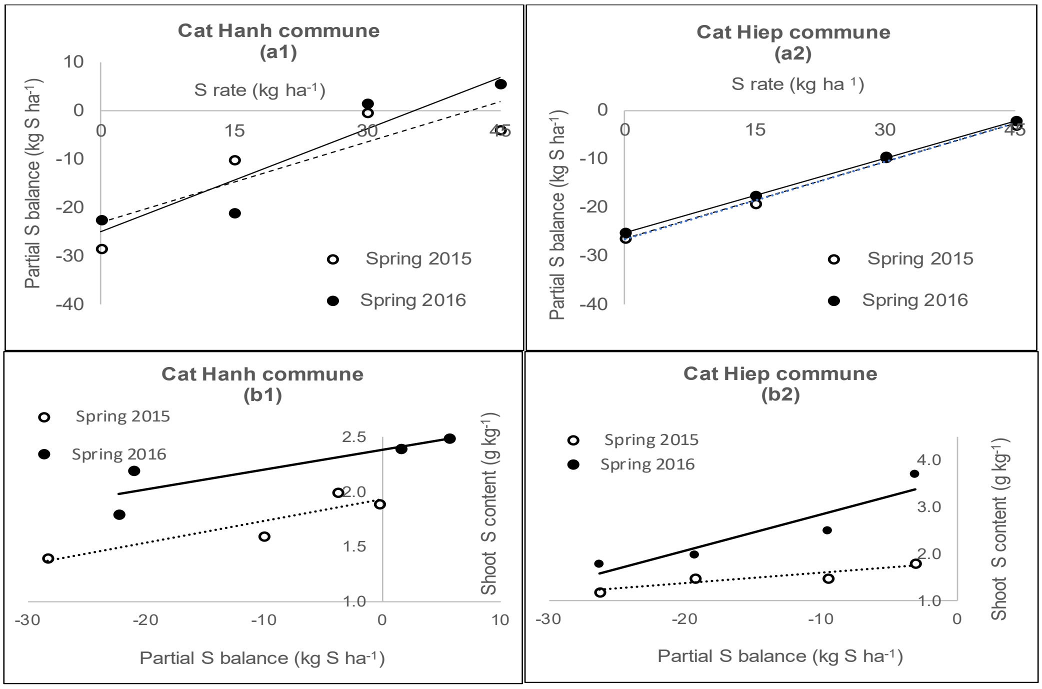


Fig. 7.37(a1, a2) Relationship between S rates and partial S balance in Cat Hanh and Cat Hiep communes in 2015 and 2016; (b1, b2) Relationship between plant S (g kg^{-1}) and partial S balance in Cat Hanh and Cat Hiep communes in 2015 and 2016 growing peanut seasons.

The negative partial S balances found without S application were almost fully reversed at higher rate of S fertilizer application, with values increasing from -26.4 kg S ha^{-1} (control) to -0.7 kg S ha^{-1} (45 kg S ha^{-1}) in spring season 2015 and –19.5 kg S ha^{-1} (control) to 3.2 kg S ha^{-1} (45 kg S ha^{-1}) in spring season 2016 (Hoang et al. 2020). There was positive partial S balance at all rates of S fertilizer application (Table 7.12). There were close positive relationships between partial S balance and S rate application (R^2 from 0.74 – 0.99) as well as with plant S (R^2 from 0.75 to 0.86) in both communes and seasons.

Table 7.12 Summary of peanut yield, profit, soil K and S balances and soil K and S levels under current (farmer's practice) or improved irrigation and K and S fertilizer regimes.

Site/year	Nutrient/ Irrigation method	Best Fertilizer treatment (K/S, in kg/ha))	Pod yield range (t/ha)	Profit (Million VND)	Soil K balance (kg K/ha)	Soil S balance (kg S/ha)	Soil K (%)	Soil S (mg/kg)
Binh Dinh (BD)/ 2015	Farmer's Practice (FP)	50K (KCl)	3.31-3.59	39.65-46.03	-26 to -42		0.19-0.24	
	K rates and forms	75K (K_2SO_4)	3.59-3.88	45.08-49.70	-23 to -37		0.19-0.25	
BD/ 2015	FP	0 S	3.31-3.56	32.45-44.99		-23 to -21		2.80-3.06
	S rates and forms	30 S (K_2SO_4)	3.59-3.83	38.41-50.73		-4 to 6		3.70-3.76
BD/ 2015	FP	50 KCl	3.12-3.65	31.23-42.35	-9 to -22	-16 to -21	0.21-0.22	4.56-4.83
	K rates	50	4.09-	40.45-	-22 to -	-7 to 2	0.22-	4.77-

Site/year	Nutrient/ Irrigation method	Best Fertilizer treatment (K/S, in kg/ha))	Pod yield range (t/ha)	Profit (Million VND)	Soil K balance (kg K/ha)	Soil S balance (kg S/ha)	Soil K (%)	Soil S (mg/kg)
	and FYM	K_2SO_4 + 8 t FYM	4.81	48.78	62		0.32	4.89
BD/ 2016	FP	50K	2.67-3.26	29.25-38.78	-32 to -31	-22.3 to -25.1	0.13-0.16	2.40-3.20
	K, S rates	75K, 30S	3.76-4.24	37.86-43.24	-67 to -83	-20.2 to -32.3	0.17	3.50-4.50
BD/ 2017	FP	50K	2.93-3.88	30.23-45.87	-18 to -18	-14.0 to -14.7		
	K, S rates	75K, 30S	3.62-4.66	35.67-46.89	-22 to -24	1.0 – 1.9		
Quang Nam (QN)/ 2018	FP	30N-26P-33K	1.80-3.48	11.75-47.27				
	Sprinkler +MP	75K, 30S	2.50-4.72	29.63-74.13				
QN/ 2019	FP	30N-26P-33K	1.76-2.13	10.43-19.68				
	Sprinkler +MP	75K, 30S	2.21-2.71	23.40-34.18				

7.2.3 Effect of irrigation technologies on crop performance peanut, mango and onion on farmer’s fields

Most farmers in the BD and NT provinces irrigate their crops by flooding, hand-held hose, perforated hose etc . The groundwater is pumped from open wells normally dug to 10-12 m or from tube wells installed to different depths depending on the depth of water table. Most of these practices led to overuse ground water resulting in substantial lowering of water table during summer season and at times resulted in non-availability of ground water for irrigation. Given the limited amount of ground water available for irrigation of crops during the dry season, especially after below average monsoon season rainfall (Fig. 7.27) there was a need to introduce irrigation practices that were sustainable and were able to meet crop water demands during the dry hot season with high evaporation rates. Different available irrigation technologies (sprinkler, drip irrigation, fertigation and mini pan) were tested in 2015 and 2016 to compare with farmer’s practice to evaluate the amount of water that can be saved and their profitability. The efficient technologies that were tested and that performed the best under different cropping systems were then demonstrated on farmer’s fields to directly show the benefits of using these technologies. In addition, economic evaluations were also carried out to show the benefits of using these technologies for peanut, mango and vegetables.

Effect of irrigation technologies on peanut yield and water use:

In the six irrigation experiments conducted in the spring season (Jan-April) of 2015 and 2016, the effect of sprinklers was compared with farmer’s practice (FP) of irrigation with a hand-held hose. Irrigation by both sprinklers and FP were also compared for their efficiency with and without the use of mini pan (MP) for water scheduling. The yields varied with irrigation practices tested and varied between 3 to 3.7 t/ha when irrigated by FP, however, the yields were higher when MP was used with FP (Fig. 7.38). Sprinklers performed the best when guided by MP and the yields in the two years varied ranged from 3.8 to 4.3 t/ha. Even distribution of water by sprinklers may be the main reason for greater peanut yield in comparison to FP where some of the areas in the field could be over-watered and some portions could be left dry.

The peanut experiments that were carried out in NT with same treatments as in BD had lower yield (Fig. 7.39). Yield of peanut in NT variedfrom 2 to 2.9 t/ha. Less rainfall may be the main reason for less productivity potential in NT and only ~ 500 ha of land is being used by farmers for growing peanut in this region as compared to ~ 10,000 ha in BD (Table 7.27).

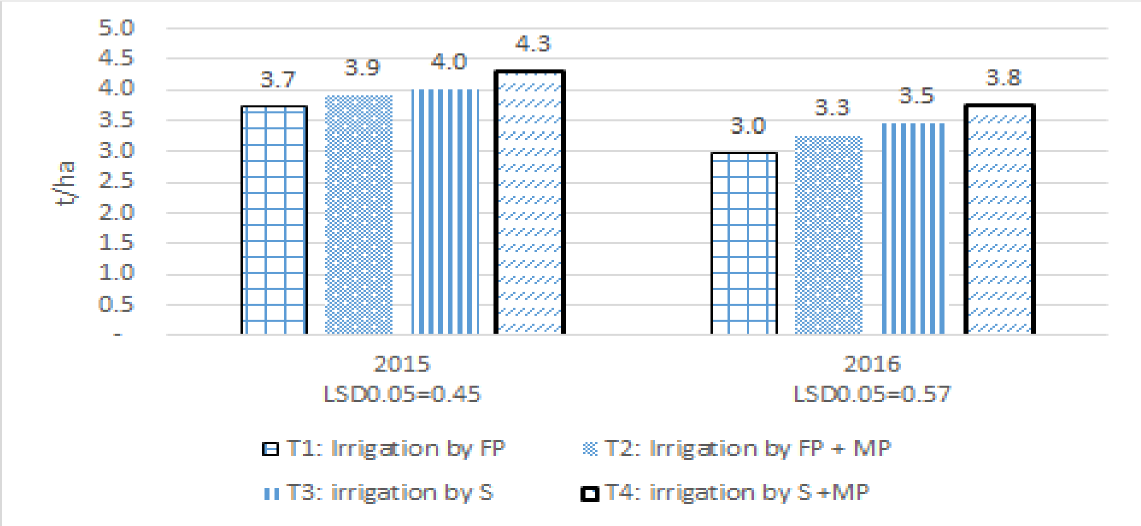


Fig. 7.38 Effects of irrigation methods on peanut yield in Binh Dinh. FP= farmer's practice; S = sprinkler; MP= mini-pan

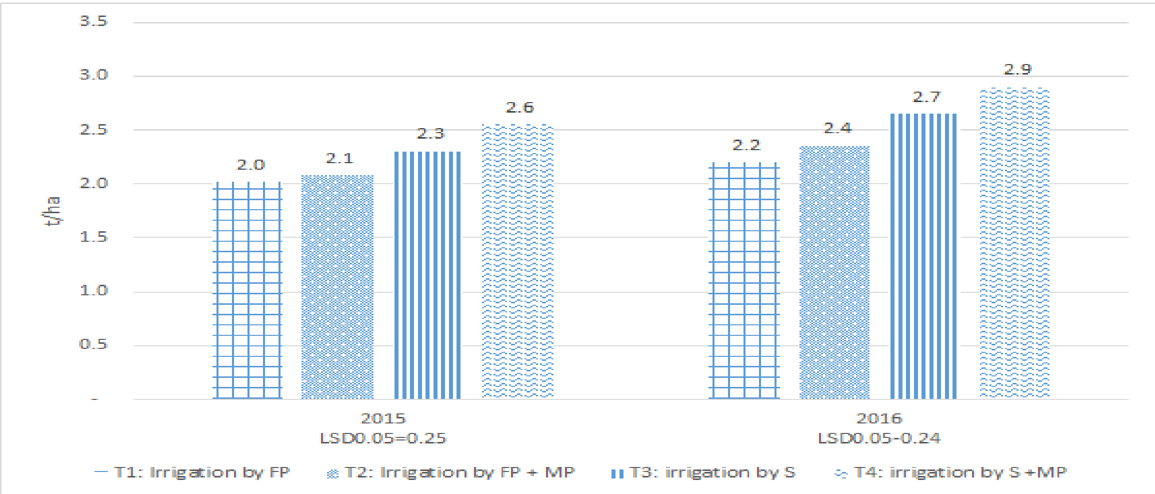


Fig. 7.39 Effects of irrigation methods on peanut yield in Ninh Thuan. FP= farmer's practice; S = sprinkler; MP= mini-pan

The amount of water savings made by use of sprinkler technologies varied with year of experiments conducted and was dependent on the rainfall during the cropping season. On average, farmer's practice of using hand-held hose applied more ground water (5,555 m^3/ha) than sprinklers (4,145 m^3) for irrigation with a saving of nearly 1,400 m^3/ha, equivalent to 25 % (Table 7.13). Use of MP to guide irrigation scheduling either by FP or sprinklers also saved water. Comparing FP with sprinklers and use of MP saved nearly 2,588 m^3/ha, equivalent to 40 % reduction in groundwater pumped for irrigating peanut.

In NT, some farmers use flood irrigation and apply more than 11,000 m^3/ha. In NT, comparing farmer's use of flooding to irrigate their fields against use of sprinklers with MP, reduced the groundwater pumped by 8,050 m^3/ha (~72 %) (Table 7.14).

Excess application of irrigation water is also likely to have an adverse impact on crop growth as a result of nutrients lost through leaching.

Table 7.13 Amount of irrigation water applied, water saving and profit margin for peanut experiments in Binh Dinh

Treatments	Amount of water (m^3/ha)			Water saving (m^3/ha)	Water saving (%)	Profit margin (million VND)	Profit increase (%)
	2015	2016	mean				
T1: Irrigation according to famers	4,410	6,700	5,555			37.2	
T2: Irrigation according to famers + Mini pan	3,000	5,280	4,140	1,415	25.5	44.9	21
T3: Sprinkler irrigation	4,050	4,240	4,145	1,410	25.4	45.7	23
T4: Sprinkler irrigation + Mini pan	3,000	2,933	2,967	2,588	46.6	50.8	37

Table 7.14 Amount of water, saving and profit margin for peanut experiments in Ninh Thuan

Treatments	Amount of water (m^3/ha)			Water saving (m^3/ha)	Water saving (%)	Profit margin (million VND)	Profit increase (%)
	2015	2016	Mean				
T1: Irrigation by FP	10,880	11,520	11,200			6.5	
T2: Irrigation by FP + MP	9,920	10,240	10,080	1,120	10.0	10.6	64
T3: irrigation by S	4,620	4,840	4,730	6,470	57.8	23.5	264
T4: irrigation by S + MP	3,100	3,200	3,150	8,050	71.9	30.4	371

Effect of irrigation technologies on mango yield and water use:

A mature mango orchard (16 year old) covering nearly 2 ha in Cat Hanh commune, Phu Cat district, BD province was chosen as the main experimental site to compare the effect of FP (farmer practice by hand held hose), drip irrigation (DI), FP + mini pan (MP) and DI + MP on mango yield over four years (2016-2019) and assess the change in groundwater required to irrigate the crop.

Drip irrigation guided by MP was the most effective technology reduced the irrigation water applied by 965 m^3/ha as well as increasing fruit yield (Table 7.15 and Fig. 7.39).

The increase in yield of mango varied with year and the irrigation technology used. Mango yield in 2017 was the highest as BD received high rainfall that was evenly distributed during the fruit growth period of February to May as is reflected by low water use for irrigation by both FP and drip irrigation (Fig. 7.40). As a result of high yield in 2017, the profit margins were also highest (Fig. 7.41).

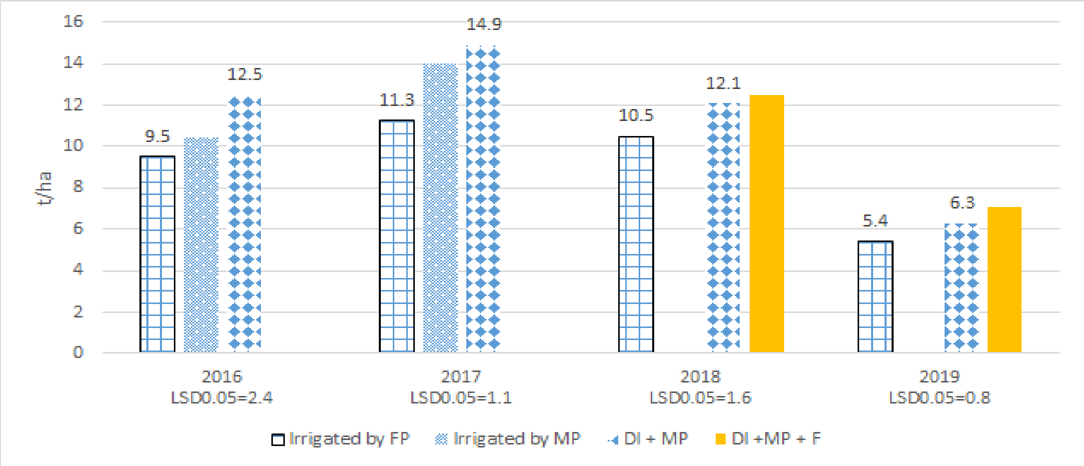


Fig. 7.40 Effects of irrigation methods on mango yield in Binh Dinh

Table 7.15 Amount of water applied (m³/ha), and water saving for mango experiments in Binh Dinh

Treatments	2016	2017	2018	2019
Irrigated by farmer's practice (FP)	499	440	520	1,709
Irrigated by mini-pan (MP)	328	132		
Drip irrigation (DI) + MP	263	130	270	744
DI +MP + Fertigation			270	744
Water saving when irrigated by MP vs FP	171	308	250	965
Water saving with DI + MP vs FP	236	310	250	965

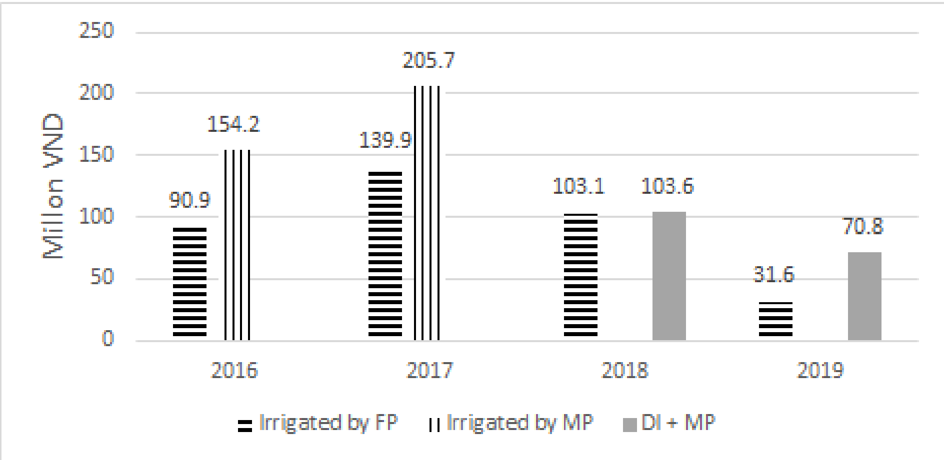


Fig. 7.41 Profit margin for mango in Binh Dinh

Effect of irrigation technologies on onion yield and water use:

Two experiments were conducted in An Hai commune of Ninh Thuan to determine the effect of irrigation technologies and reduced rates of fertilizers on onion yield. The hypothesis was that despite more than 90 % adoption of sprinklers by farmers to irrigate onion crop they over use fertilizers. Hence, the irrigation technologies only compared use of farmer's practice of using sprinkler alone and sprinklers in combination with mini pan MP which as was found to be effective in saving water for peanut and mango production. Water savings were not significant during the first season of onion growth (Fig. 7.41), however, water savings (~1,000 m^3/ha) were measured during the month of August (Fig. 7.42). Given that the crop duration lasts only 35 days, savings of water is dependent on the rainfall patterns and other climatic conditions such as duration of wind and speed influencing evaporation rates.

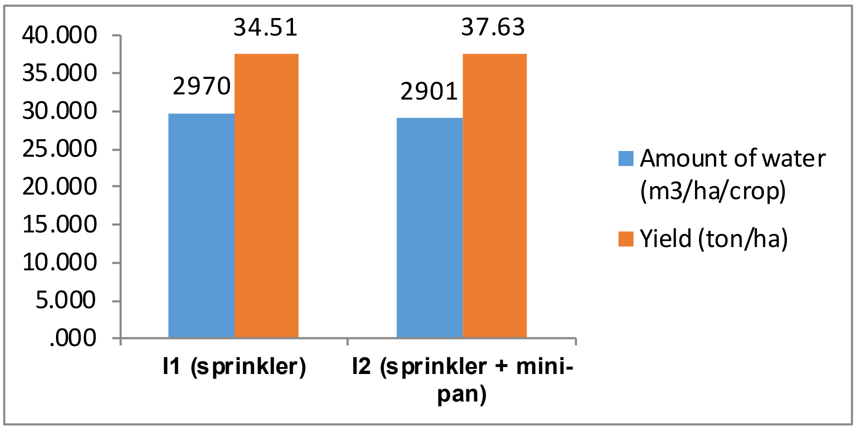


Fig.7.41. Effect of irrigation methods on yield of onion on sandy soil in Ninh Thuan (March 2018)

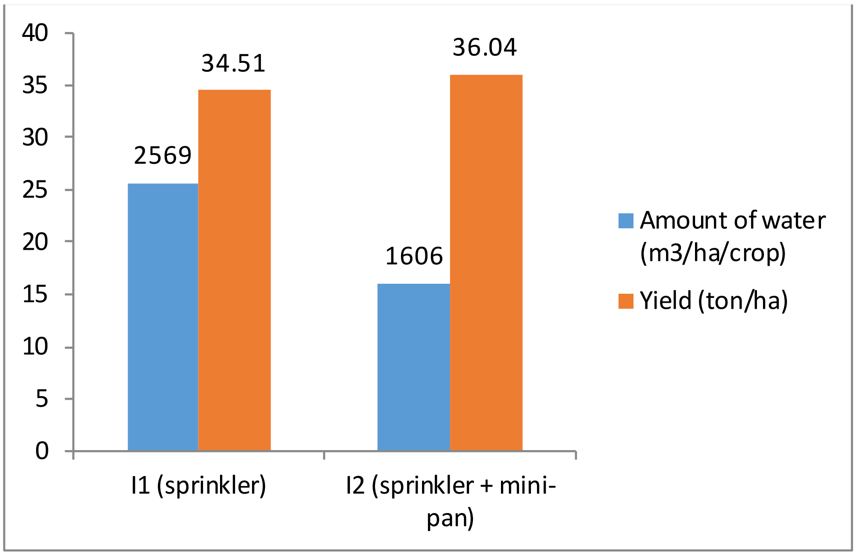


Fig.7.42. Effect of irrigation methods on yield of onion on sandy soil (August 2018) in Ninh Thuan

Demonstrating the use manure and biochar on farmer's fields

Large scale demonstration trials on farmer's fields were commenced in 2015 when the project had only started to test different water and nutrient management technologies developed in the previous project. Based on the outcomes of the previous project (SMCN 2007-109) where manure and biochar treatments and use of mini pan (MP) had shown promise in increased yields of peanut, the demonstration trials were also meant to engage farmers to learn about the benefits of different materials (manure and biochar) and MP. Use of MP in combination with manure and biochar increase yields of peanut by approximately 0.4 t/ha in both the years (Fig. 7.43).

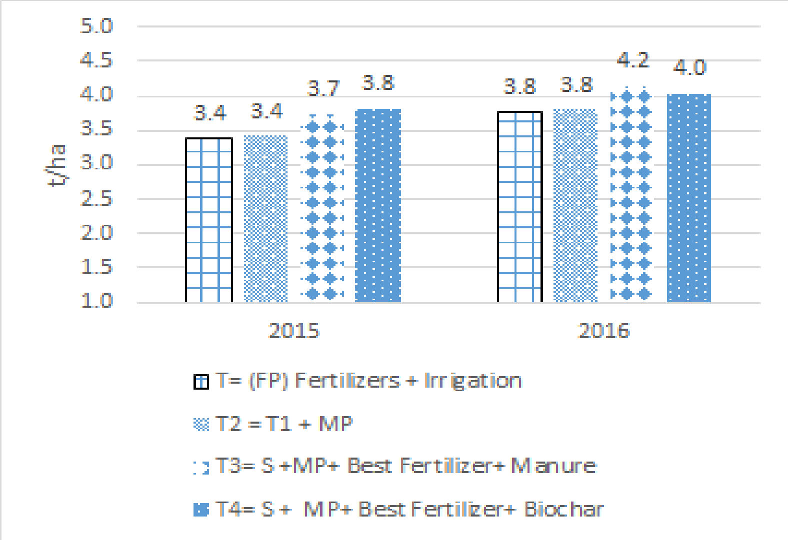


Fig. 7.43 On-farm demonstration with manure and biochar for peanut yield in Binh Dinh

The demonstration trials also tested the benefits of using manure, recommended rates of fertiliser and the MP to guide irrigation. The results showed that peanut yields increased with the package of manure + recommended fertiliser + MP compared to farmer's practice, especially in 2015 when crop yield was higher (Fig. 7.42).

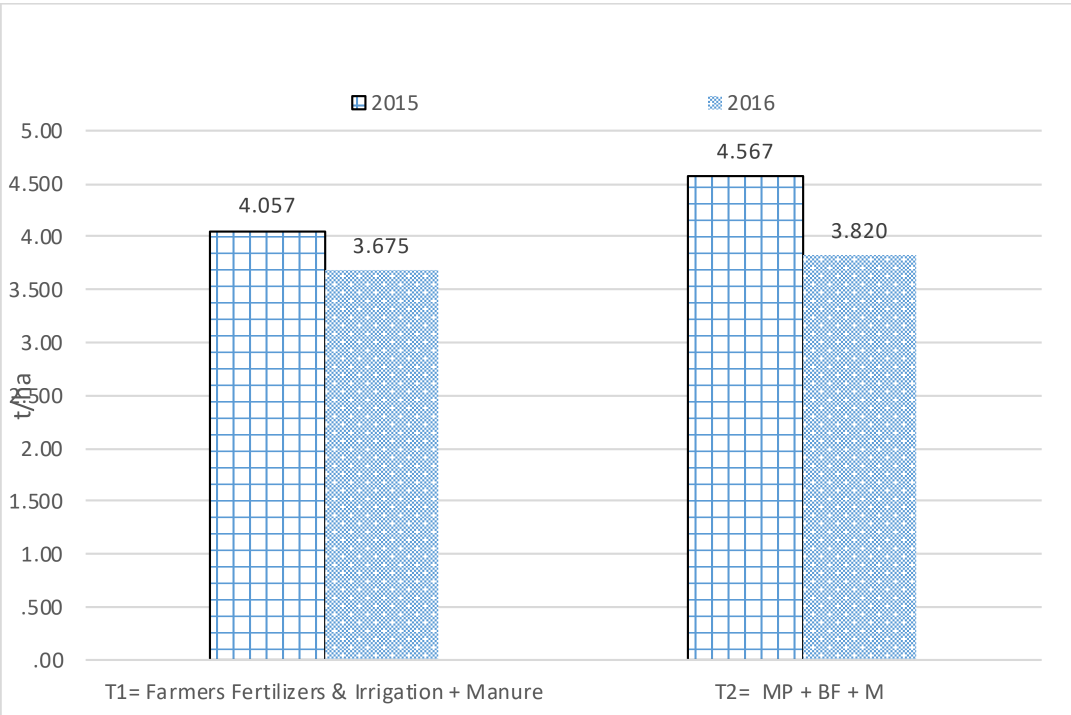


Fig. 7.42 Demonstration of irrigation types and peanut yield in Binh Dinh

BF=ASISOV fertilizer rates including K and S fertiliser, MP= mini pan, M = Manure

The demonstration of drip irrigation plus MP on mango increased fruit yield by 6.3 t/ha in 2016 (217 % increase) and by 2.6 t/ha in 2016 (26 % increase) (Fig. 7.43).

In the following two years, using fertigation to supply nutrients through the drip system increased fruit yield by 1.6 and 1.2 t/ha relative to the application of solid fertiliser .

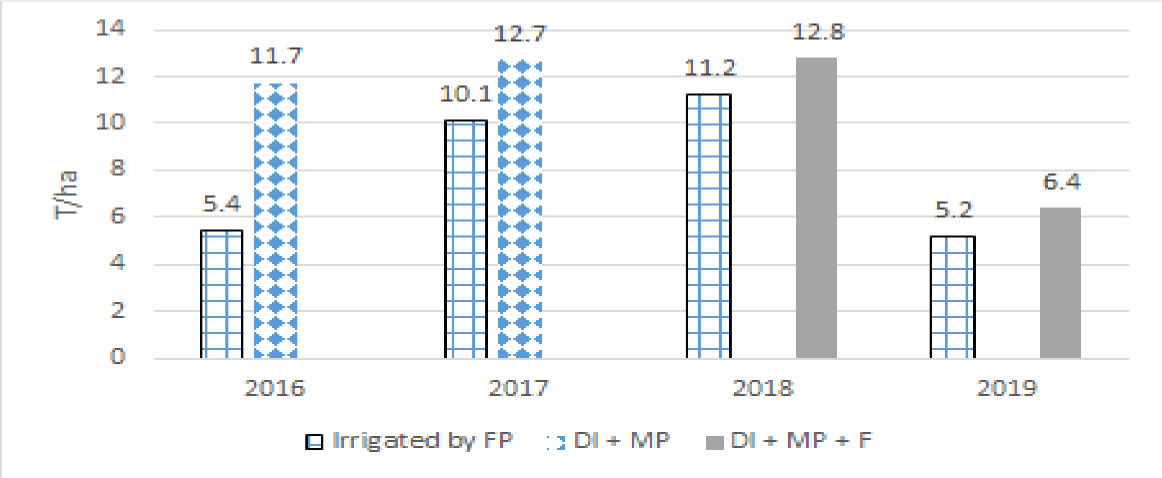


Fig. 7.43 Demonstration of irrigation technologies and best fertilizer rates on mango production in BD. FP- farmer's practice for irrigation and fertiliser; DI – drip irrigation; MP – mini-pan scheduling of irrigation; F - fertigation

Demonstrating improved irrigation and nutrient management in Quang Nam

Based on the irrigation and nutrient management technologies that proved to be water and nutrient efficient in BD, two demonstration trials were conducted in 2019 on farmer's fields in Binh Sa and Binh Trung communes, Thang Binh district, QN province. Irrigation technologies included lay flat perforated hose, upright sprinkler systems and farmer's practice of irrigation and recommended fertiliser rates included 75 kg K/ha + 30 kg S/ha in addition to N and P.

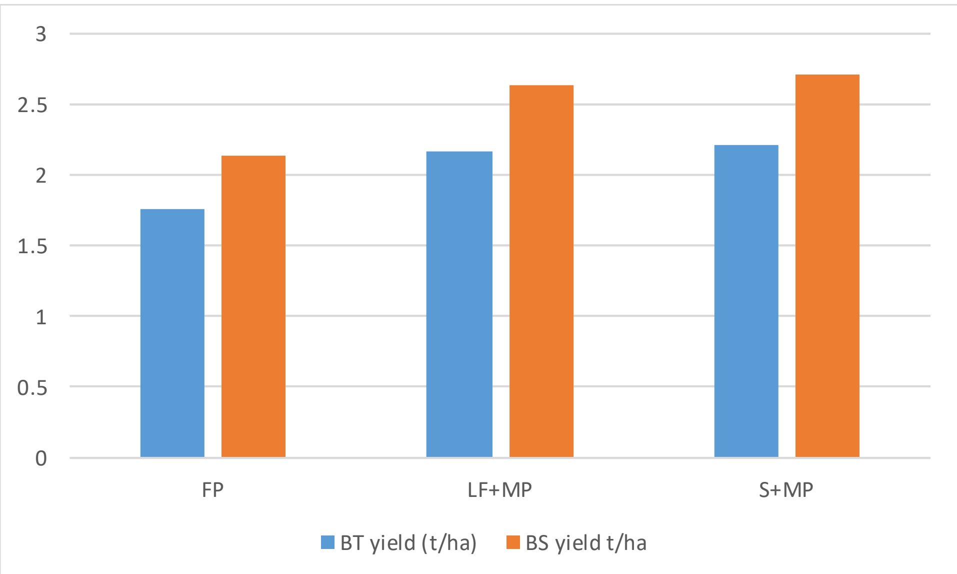


Fig. 7.44 Demonstration of irrigation types and peanut yield in Quang Nam

F(farmer practice), LF (lay flat), S (sprinkler), MP (mini pan), BT (Binh Trung), BS (Binh Sa) communes in Quang Nam

The maximum peanut yields were 2.71 t/ha in Binh Sa commune, and 2.21 t/ha in Binh Trung commune with use of sprinklers guided by MP (Fig. 7.44). Similar yields were obtained with the layflat hose plus MP, while the farmer's practice had 0.4-0.5 t/ha lower yields. Water use efficiency using sprinkler irrigation guided by MP improved by 42 - 44% in both the communes.

Demonstrating the use of integrated water and nutrient management technologies on farmer's fields

In addition to demonstrations of irrigation technologies, integrated water and nutrient management technologies were demonstrated on farmers fields in BD and QN on peanuts.

In BD, addition of manure or biochar plus MP, recommended K and S fertiliser and sprinkler irrigation increased peanut yield by 0.3-0.4 t/ha relative to farmer's practice in consecutive years (Fig. 7.45). In these demonstrations there was no yield improvement from the use of MP alone in combination with farmer's practice. In the following two years (2018 and 2019), the complete package of sprinkler irrigation, MP and recommended K+S fertiliser increased peanut yield by 0.1-0.5 t/ha (Fig. 7.46).

In 2018, 2 field experiments in the spring season at Binh Sa and Binh Trung communes, Thang Binh district, QN province tested 4 treatments of fertilizer application and 2 irrigation methods. Maximum yields with 75 kg K/ha + 30 kg S/ha + NP fertiliser were 4.74 t/ha (Binh Sa commune) and 2.85 tons/ha (Binh Trung commune) (data not shown). Total soil K, exchangeable K and S contents increased after harvest with increasing rates of K and S fertilizer application. Use of the sprinkler plus MP to schedule irrigation increased higher water use efficiency relative to farmers' irrigation by 36.4 to 40.9%.

In 2019, 2 more demonstrations were set up in the spring season at Binh Sa and Binh Trung communes, Thang Binh district, QN province comprising 3 treatments of fertilizer application and 3 irrigation methods. Peanut yields were highest with sprinker irrigation + MP and 75 kg K/ha + 30 kg S/ha + NP fertiliser(2.71 t/ha - Binh Sa commune and 2.21 t/ha Binh Trung commune) (Fig. 7.47). Water application by sprinkler irrigation with MP scheduling incresed water use efficiency relative to farmers' irrigation by 42 - 44%.

Irrigation method altered the soil K and S balance in a mango field. Soil K balance was negative in all irrigation methods, especially at drip irrigation method due to the higher yield (data not shown). By contrast, the soil S balance was positive at three irrigation methods. This suggests that further refinement of mango fertiliser rates are needed with increase in K and a decrease in S rates.

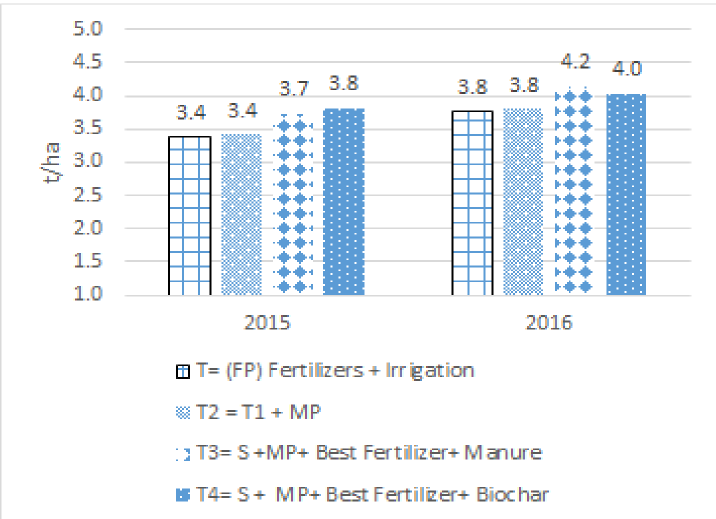


Fig. 7.43 Demonstration with manure and biochar for peanut yield in Binh Dinh

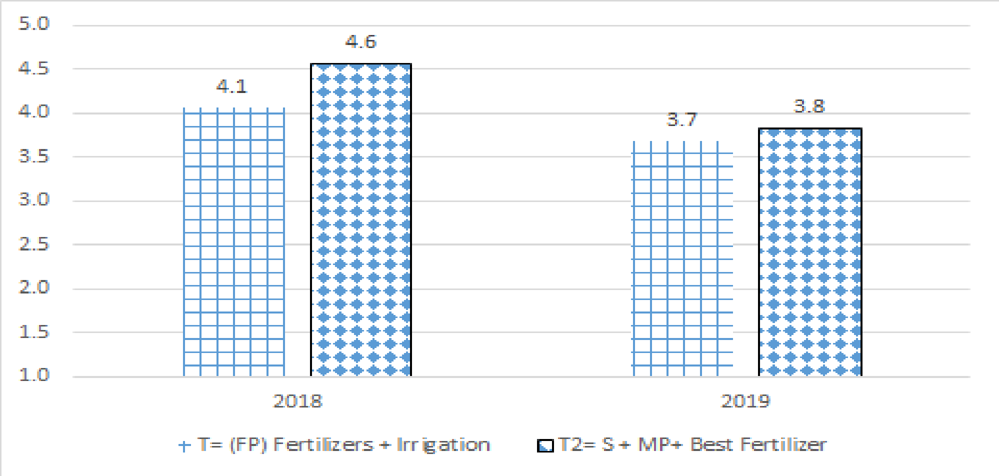


Fig. 7.44 Peanut yield (t/ha) demonstration with irrigation and fertilizer based on farmer's practice or with sprinkler and optimum fertiliser in Binh Dinh

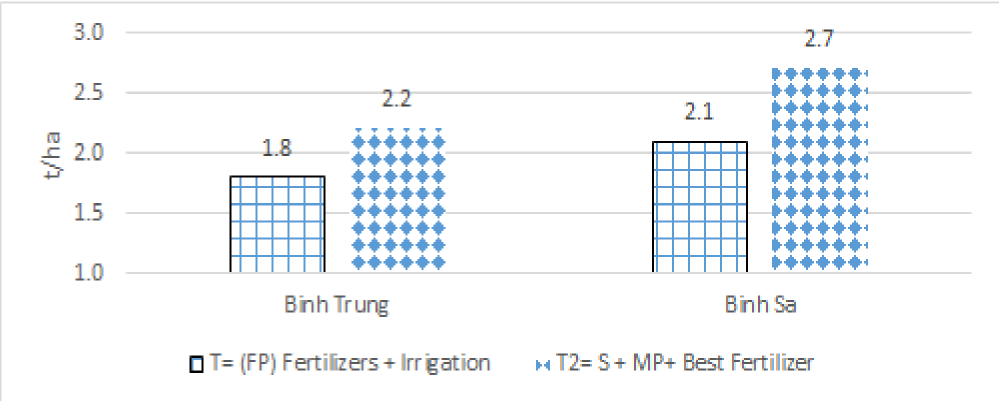


Fig. 7.45 Peanut demonstration with irrigation and fertilizer based on farmer's practice or with sprinkler and optimum fertiliser) in QN

7.2.4 Economic efficiency and water savings of crops (peanut, mango and onion)

Farm Economic Model (FEM), an Excel based program, was used to calculate the economic efficiency for different crops and compared the increase in profit margins of irrigation and nutrient management technologies relative to farmer's practice (FP) for crop production. Profit margins by use of the MP in combination with organic fertilizers (biochar and manure) and inorganic fertilizers increased the profit margins by 12 to 13.5 million VND/ha as against FP equivalent to 28-31 % increase (Table 7.15). Savings of water by use of technologies ranged between 31-40 %. In these calculations no dollar value for water has been assigned. Introduction of water pricing, as proposed by the Government of Vietnam will alter the profit margins calculated here.

Table 7.12 Water use, saving and profit margin for peanut in Binh Dinh in 2015-2016

Treatments	Amount of water (m^3/ha)			Water saving (m^3/ha)	Water saving (%)	Average profit margin (million VND)	Increase in profit margin (%)
	2015	2016	Aver-age				
T1 = (FP) Fertilizers + Irrigation	4,300	3,875	4,088			43.1	
T2 = T1 +MP	3,168	2,500	2,834	1,254	30.7	48.2	12
T3 = MP+ Best Fertilizer+ Manure	2,400	3,565	2,983	1,105	27.0	55.1	28
T4 = MP+ Best Fertilizer+ Biochar	2,400	2,500	2,450	1,638	40.1	56.6	31

Savings of water and increase in profit margins further improved during 2018 and 2019 as a result of improved water and nutrient management practices carried out for peanut in BD. Profit margins as a result of the use of 75 kg K/ha and 30 kg S/ha in combination with sprinkler and MP increased profit by 20 million VND equivalent to 71 % increase in addition to water savings of 28 % (Table 7.15).

Table 7.13 Water use, saving and profit margin for peanut in Binh Dinh in 2018-2019

Treatments	Amount of water (m^3/ha)			Water saving (m^3/ha)	Water saving (%)	Profit margin (million VND)	Increase in profit margin (%)
	2018	2019	Average				
T1 = (FP) Fertilizers + Irrigation	4,138	4,675	4,407			27.5	
T2 = MP+ Best Fertilizer	2,767	3,550	3,158	1,248	28.3	47.0	71

The rates of K and S fertiliser and the sprinkler plus MP irrigation technologies that were developed in BD were tested in QN in 2018 and 2019. The improved irrigation and fertiliser technology showed similar economic and water saving benefits to those in BD.In 2019, the increased profit margin was12.5 million VND (91 % more than FP) as against farmer's practice (Table 7.17).

Table 7.14 Water use, saving and profit margin for peanut in Quang Nam in 2019

Treatments	Amount of water (m^3/ha)			Water saving (m^3/h)	Water saving (%)	Profit margin (million VND)	Profit margini ncrease (%)
	2018	2019	Average				
T1 = (FP) Fertilizers + Irrigation	3120	3540	3,330			15,055	
T2 = MP+ Best Fertilizer	2300	2550	2,425	905	27.2	28,790	91

The profit margins over four years (2016-2019) were assessed for drip irrigation and MP based scheduling of irrigation together with increased rates of K and S. The mango crops in 2016 and 2017 were the most productive with profit margins increased by 63-66 million VND relative to farmer's practice on the same farm. In 2018, profit margins were decreased by 4 million VND, but increased in 2019 by 33 million VND (Fig. 7.48). In 2018 and 2019, addition of fertigation to the drip irrigation technology was also tested. It increased profit by only 3 million VND/ha in 2018 but by 45 million VND/ha in 2019. Hence in 2019 it was substantially more profitable than drip irrigation with solid fertiliser application. As discussed earlier, mango production and profitability is based on the climatic conditions and market price. Nonetheless, comparatively the drip or fertigation techniques proved to be beneficial with added advantage of water savings.

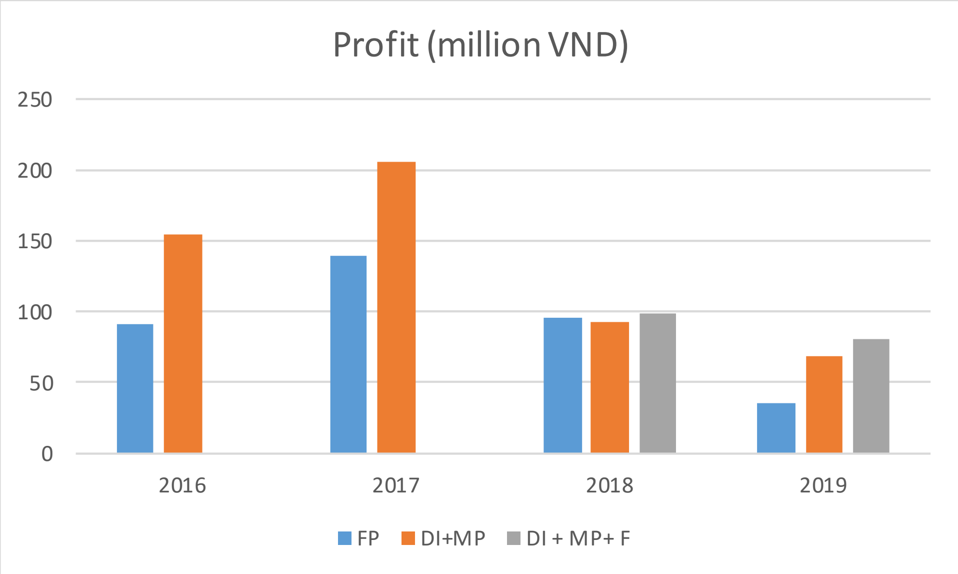


Fig. 7.48 Profit margin for mango in on-farm demonstrations in Binh Dinh

FP= farmer's practice; DI= drip irrigation; MP= mini-pan; F= fertigation

7.3 What technologies and practices can be utilized by groundwater-dependent farmers in SCC VN to improve on-farm water use efficiency and reduce nutrient loss

7.3.1 Nutrient management practices

Over 5 years the project developed improved irrigation technologies and recommended K and S fertiliser practices. It then demonstrated their combined effects on large areas to show the benefits from improved on-farm water and nutrient use efficiencies, reduced nutrient losses and gains in profitability for groundwater-dependent farmers. The following findings from the demonstration, which build on those outlined in Section 7.2, can form the basis of technologies promoted for adoption by large numbers of farmers in the SCC VN region.

The recommended K and S rates for peanut, mango and vegetables for sandy soils of BD, NT and QN are shown in Table 7.18. Rates of N and P were the current rates that farmers apply in this region and while they were not tested in the present study, there was no evidence to suggest they were inadequate. The rates of K and S showed improved productivity, addressed (partly or fully) nutrient imbalances in soils and reduced losses to groundwater. These K and S fertilizer rates are recommended in combination with 8-10 t/ha of manure incorporated in the soil before application of fertilizers (Table 7.18).

Table 7.15 Recommended nutrient rates for different crops based on project outcomes. The fertiliser rates assume addition of 10 t of manure /ha in Binh Dinh and Ninh Thuan provinces and 8 t of manure /ha in Quang Nam province.

Crop	Peanut (kg/ha)				Mango (kg/tree)				Onion (kg/ha)			
	N[a]	P[a]	K	S	N	P	K	S	N	P	K	S
Binh DInh	30	90	75	30	0.5	0.5	0.8					-
Quang Nam	40	90	75	30	-	-	-	-	-	-	-	-
Ninh Thuan	30	90	75	30	-	-	-	-	100	52.5	80	-

a. For peanut the N and P rates were established by earlier ASISOV research but found to be adequate in our experiments.

7.3.2 Amendment materials

Amendment materials (2 types of clay from natural soils, bentonite, sugarcane straw) that have high cation exchange capacities (CEC) were tested to improve the buffering capacity of sands resulting in improved water and nutrient use efficiencies after incorporation (Table 7.19).

Table 7.16 Characteristics of sands and amendment materials

Material	Texture (g/kg sand:silt:clay)	Bulk density (g/cm^3)	pH 0.01M $CaCl_2$	Electrical conductivity (dS/m)	Cation exchange capacity ($cmol_c/kg$)
Sand 1	980:10:10	1.45	6.6	0.02	0.8
Clay 1	160:330:510		6.6	0.09	26.5
Sand 2	980:10:10	1.45	6.3	0.02	1.8
Clay 2	380:370:250		6.1	0.04	14.2
Bentonite	10:280:710	1.05	8.7	0.19	22.7
Sugarcane residue	[a]		8.6	0.74	17.5

The bentonite and 2 types of clay were tested by incorporating in sandy soils of An Hai commune, NT at varying rates (100 and 300 t/ha).Sugarcane residue (SR), a waste product from sugarcane processing industry characterised by high CEC, was also tested at a rate of 30 t/ha for effects on yield and on water and nutrient use efficiencies of water melon, sweet corn and onion. The clay, bentonite and SR amended treatments increased water holding capacity at -10 kPa (WHC) of sands from 17.2 to 39.8, 31.8 and 29.8 g/kg, respectively. Even though WHC also increased at -1500 kPa, the plant available WHC increased with clay, bentonite and SR. The CEC of amended soils also improved significantly especially with the clay (Table 7.20). None of the amendments altered soil pH even through the bentonite and SR were strongly alkaline.

Crop yields (water melon, onion and sweet corn) from the two experiments carried out in NT after amendment with bentonite, clay and SR increased markedly. The relative yield increase was 30-35 % for sweet corn, 45-96 % for water melon and 104-167 % for onion (Table 7.21).

Table 7.17 Soil pH, electrical conductivity (EC), water holding capacity (WHC) and cation exchange capacity (CEC) of sand after amendmentin Ninh Thuan

Amendment application (t/ha)	pH($CaCl_2$) 1:10	EC dS/m	WHC at -10 kPa (g/kg)	WHC at -1500 kPa (g/kg)	CEC $cmol_c/kg$
Control	7.0	0.06 b	17.2 c	11.7c	1.6c
Bentonite 100 t/ha	7.3	0.14 a	31.8 a	24.7a	2.4b
Clay 2 300 t/ha	7.1	0.07 b	39.8 b	20.5b	3.0a
LSD at 0.05	NS	0.01	13.0	1.0	0.2
Control	7.0	0.06 b	16.5 c	11.9c	1.6c
Clay 2300 t/ha	7.0	0.06 b	35.8 a	20.2a	3.1a
SR 30 t/ha	6.9	0.08 a	29.8 b	16.4b	2.2b
LSD at 0.05	NS	0.01	0.5	2.6	0.3

Table 7.18 Effect of the amendment materials on yield of sweet corn, water melon and onion in Ninh Thuan

Amendment addition ($t.ha^{-1}$)	Yield t/ha			
	water melon	% increase	onion	% increase
Control	11.7c	-	2.3c	-
Bentonite 100 t/ha	17.0b	45	4.6b	104
Clay 2 300 t/ha	23.0a	96	6.1a	167
LSD at 0.05	4.7		1.3	
	sweet corn		onion	
Control	5.4b	-	6.4b	-
Clay 2 300 t/ha	7.1a	30	10.1a	59
SR 30 t/ha	7.4a	35	10.6a	66
LSD at 0.05	1.1		2.0	

In a subsequent experiment, bentonite at 60 t/ha also boosted vegetable yields by 26-30 % relative to the control (data not shown). Not withstanding the marked yield increases obtained from the bentonite amendment, it had no effect on profitability averaged over 3 consecutive crops. Indeed, relative to NPK plus manure application, the amemdment with bentonite decreased profit. Hence, bentonite is a treatment that can boost yield, improve chemical properties of sands and decrease irrigation water requirements, but its adoption by farmers will need investment by the Government to decrease the initial cost of application or to waive the interest on loans taken out by farmers to purchase the bentonite. Indeed, in a subsequent experiment, Nguyen Quang Chon (unpublished data) showed that if the cost of benonite was depreciated over 3 years (9 crops), it greatly increased crop profitability on deep sands in NT. These results again emphasise that with access to credit to pay for the intial investment cost of bentonite it could be a highly profitable amendment to sands.

7.3.3 Economic value of groundwater for SCC VN region

To calculate the economic value of groundwater, we examined scenarios based on the water savings over 4 years (2015-19) from the improved irrigation technologies developed compared to farmer's practice of flooding in NT for vegetables and hand-hose irrigation in BD, NT and QN for peanut,and in BD for mango.

From Table 7.22 that summarises peanut water savings from improved irrigation technology (sprinkler + MP) in comparison to farmer's practice, we can conclude that in BD alone, farmers growing peanut on approximately 10,000 ha can save 9.94 GL of water. The water savings is enough to irrigate an extra area of 3,312 ha. Similar estimates based on the land area (Table 7.24) used for peanut production in QN and in NT, extra land that can be irrigated are 3,512 and 1,326 ha, respectively.However, as discussed above a more prudent use of the savings would be to increase groundwater storage to secure adequate water supply in years of low monsoon rainfall.

Table 7.19 Water saving from irrigation technology vs farmer's practice (FP) for peanut in Binh Dinh, Quang Nam and Ninh Thuan provinces

Province	**Peanut area (ha)**	**Farmer's irrigation practice**	**Water used FP (m^3/ha) (see Table 7.23)**	**Irrigation technology used**	**Water use by Irrigation technology (m^3/ha) (see Table 7.23)**	**Water savings by technology (m^3/ha)**	**Total water saved under peanut in each province (GL)**
Binh Dinh	9,935	Hose	4,000	Sprinkler+MP	3,000	1,000	9.94
Quang Nam	9,851	Hose	3,120	Sprinkler+MP	2,300	820	8.08
Ninh Thuan	510	Flooding	11,520	Sprinkler+MP	3,200	8,320	4.24

Note: 1 GL=1,000,000 m3

Table 7.23 Amount of water used to irrigate for peanut in Binh Dinh, Quang Nam and Ninh Thuan

	Farmer practice			**Irrigation Technology**		
Factor	Binh Dinh	Quang Nam	Ninh Thuan	Binh Dinh	Quang Nam	Ninh Thuan
Time of each irrigation (minutes)	90	90	180	75	60	80
No of irrigation times	33	26	48	30	29	30
Amount of water pumping for 1 minute (m^3)	1.338	1.338	1.338	1.338	1.338	1.338
Total amount of water for 1ha (m^3/ha)	3974	3131	11560	3011	2328	3211

Of the total area for mango in BD (~1,500 ha), the fruiting mango trees cover an area of 1,297 ha. In BD three rainfall scenarios were considered based on the La Vi catchment water balance, namely; high (>2,000 mm), low (<1,500 mm) or average(~1,800 mm) rainfall (Table 7.25). In years of average rainfall, use of drip irrigation and fertigation can save 0.4 GL of water in mango relative to farmer's practice. The saved water is enough to irrigate an extra 2,321 ha during high rainfall, 1,680 during average rainfall and 1,117 ha during low rainfall year in BD alone. Mango on sandy soils in all the provinces of SCC VN covers 13,529 ha, so the potential impact of the improved irrigation technologies on water conservation, savings and productivity is about 10-fold those calculated for BD province.

Since mango has a much lower water requirement than peanut, increased area of mango production has much less risk of over-exploitation of groundwater, even after low monsoon rainfall.

Table 7.24 Planted area of vegetables, peanut and mango in SCC VN

Province	Crops (ha)		
	Beans/veg	Mango	Peanut
Da Nang	980	57	-
Quang Nam	18,276	191	9,935
Quang Ngai	14,184	191	6,021
Binh Dinh	16,517	1,297	9,851
Phu Yen	10,689	365	3,758
Khanh Hoa	6,239	8,052	571
Ninh Thuan	12,746	421	510
Binh Thuan	16,535	2,954	5,244
Total	96,166	13,529	35,889

Table 7.25 Water savings from improved irrigation technology vs farmer's practice (FP) for mango in Binh Dinh. Assumes 1,297 ha of fruiting mango.

Years when rainfall is high, low or normal	Farmer's Practice	Water used FP (m^3/ha) (see Table 7.26)	Irrigation technology used	Water use by Irrigation technology (m^3/ha) (see Table 7.26)	Water savings by technology (m^3/ha)	Total water saved under mango in BD (GL)
High rainfall	Hose	440	Drip irrigation + mini pan	130	310	0.40
High rainfall	Hose	440	Micro sprinkler + mini pan	198	242	0.31
Low rainfall	Hose	1,709	Fertigation + mini pan	744	965	1.25
Normal rainfall	Hose	749	Fertigation + mini pan	403	346	0.45

Table 7.26 Amount of water used to irrigate for mango in Binh Dinh

Rainfall scenario	Irrigation method	Time of each irrigation (minutes)	Amount water pumping for 1 minute (m^3)	No of irrigation times	Total amount of water (m^3/ha/crop)
High rainfall	Hose	660	1.338	5	4415
High rainfall	Hose	660	1.338	5	4415
Low rainfall	Hose	1620	1.338	8	17340
Normal rainfall	Hose	900	1.338	6	7225
High rainfall	Drip irrigation + mini pan	7	1.338	14	131

Rainfall scenario	Irrigation method	Time of each irrigation (minutes)	Amount water pumping for 1 minute (m^3)	No of irrigation times	Total amount of water (m^3/ha/crop)
High rainfall	Micro sprinkler + mini pan	10	1.338	15	201
Low rainfall	Fertigation + mini pan	15	1.338	37	743
Normal rainfall	Fertigation + mini pan	15	1.338	20	401

Most farmers now use sprinkler irrigation for vegetable production, however, not many farmers use the MP to guide scheduling of irrigationThe experiments mainly compared the use of sprinkler system with and without MP for onion production. Since the water savings were measured for one onion crop that is harvested in 35 days, the values were multiplied by four to allow for four irrigated dry season crops in a year (Table 7.27). Use of MP showed a saving of 516 m^3/ha of water with a total of 0.52 GL if mini pan was used for 1,000 ha of onion crop. If we compare farmer's practice of flood irrigation that uses more than 11,000 m^3/ha the savings in water could be more than 2GL from 1,000 ha of onion crop.

Table 7.27 Water saving from irrigation technology vs farmer's practice (FP) for vegetables in Ninh Thuan. Assumes a total vegetable production area of 1,000 ha.

Province	**Farmer Practice**	**Water used FP (m^3/ha)**	**Irrigation technology used**	**Water use by Irrigation technology (m^3/ha)**	**Water savings by technology (m^3/ha)**	**Total water saved for onion in NT (GL)**
Ninh Thuan	Sprinkler irrigation	2,770	Sprinkler irrigation + mini pan	2,250	516	0.52

Table 7.28 Amount of water used to irrigate for onion in Ninh Thuan

Factor	**Farmer's Sprinkler**			**Farmer's Sprinkler + Mini-pan**		
	0-10 days	11-20 days	21-33 days	0-10 days	11-20 days	21-33 days
Total irrigation time (minutes)	75	60	60	36	60	60
No of irrigation/day (times)	1	1	1	4	3	3
Time of each irrigation (minutes)	75	60	60	9	20	20
Amount of water pumping for 1 minute (m^3)	1,338	1,338	1,338	1,338	1,338	1,338
Amount of water for 1 ha (m^3/ha)	1004	803	963	482	803	963
Total amount of water (m^3/ha/crop)	**2.770**			**2.248**		

The total area under vegetables is 12,746 ha in NT hence the potential total water savings are over 6 GL of groundwater.Water savings are particularly important in NT province due to intensive farming of more than 12,000 ha of vegetables in a region with low rainfall (<800 mm/year) compared to other provinces. Given that the total area for vegetable production on sandy soils in all provinces of SCC VN is more than 96,000 ha, the use of such technologies can have enormous impact on the groundwater resource in Central Vietnam. Since much of the vegetable production on sands occurs over snallow coastal aquifers, there is a risk of saline water intruision into the aquifer that would damage the groundwater for irrigation and potable water uses. Hence for these coastal areas, the water savings should be used to maintain higher water levels in the aquifer and avoid the risk of saline contamination of the groundwater, especially during the years of low monsoon rainfall.

7.3.4 Training, field days, workshops, TV and newspaper clips

Trainings, field days, workshops, telecasting recordings of the field days on local TV and coverage in local newspaper, increased the awareness and knowledge of the farming community about the importance and benefits of using nutrient and water management technologies on crop production. A list of such activities carried over the years is providedbelow (Section 8.4).

7.2.7 Survey of irrigation supply chains in BD, NT and QN

The survey was conducted in the sandy zone of BD, NT and QN by selecting communes where most of the project activities and experiments were carried out. The survey showed that income from agriculture was the main source of livelihood. Most agricultural activities were dependent upon rainfall or irrigation of crops (peanut, mango, vegetables) by groundwater extraction from open wells or bores installed to different depths depending on level of water tables during the dry season. Crop production in these provinces was low in comparison to other parts of Vietnam where soils were more fertile and water availability was higher. The survey results from each of the provinces are reported below:

Binh Dinh: In Phu Cat district, where most of our experiments were conducted, 70 % of farmers in Cat Hiep, 30 % in Cat Trinh and 15 % in Cat Hanh communes now use one big sprinkler which has a coverage of 200 m^2. After 1 hr of irrigation, the sprinkler is moved to another area. Given that most farmers have only 0.2-0.4 ha of land, they are able to cover all cropped areas in one day. The remainder of the farmers irrigate their fields by pulling a hose and manually watering, mainly for crops like mango or cashew. Very few farmers (<2 %) use our tested sprinkler system as it is more expensive (~30 million VND) and requires a larger pump (~1.5 horse power). There were substantial labour savings reported by farmers from the use of sprinklers and drip irrigation but these savings in the first crop did not offset the investment cost in irrigation hardware. Additional barriers to adoption include erratic electricity supply and lack of knowledge on design, installation and use of the system. In addition, the supply chain system for irrigation ware in BD is not well developed and market access for crops is limited and that in turn discourages farmers from taking the risk of making large investments (Fig. 7.49).

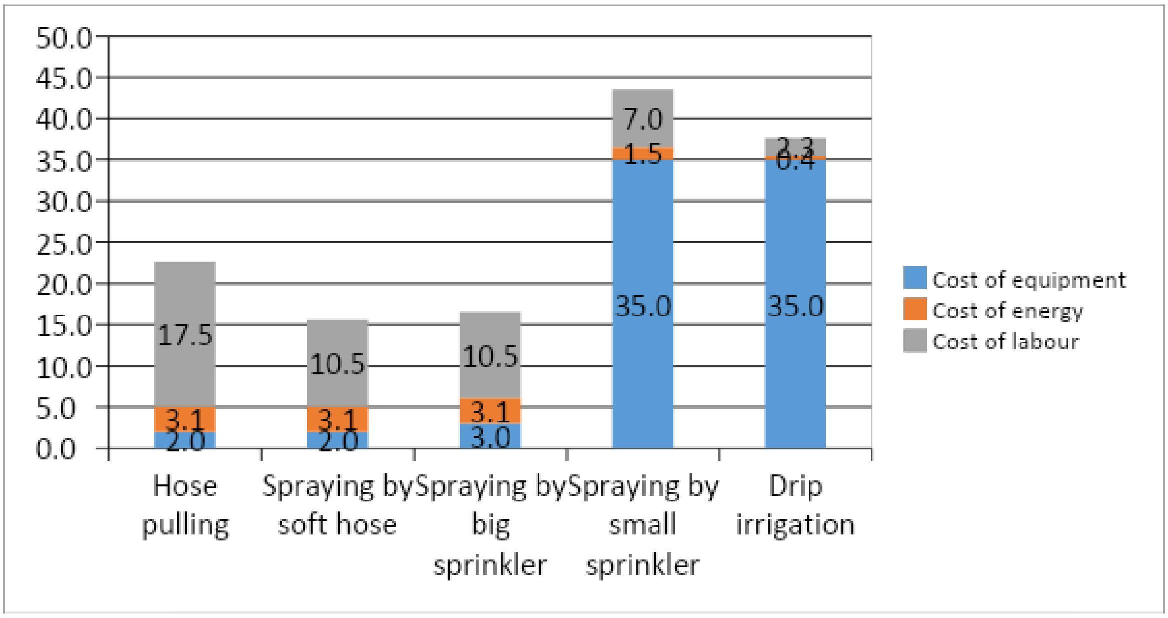


Fig. 7.49. Average costs of irrigation practices (million VND) from a survey of farmers in Phu Cat district, Binh Dinh.

Ninh Thuan: Since 2008, vegetable production, especially in An Hai commune, has intensified through the introduction of irrigation technologies (sprinklers and drip) by different NGO's, the private sector and through ACIAR project trials. The use of improved irrigation technologies by farmers has increased from 1-2 % in 2008, to 50-60 % in 2015 and >90 % in 2019. However, this only applies to An Hai commune where Dutch companies have invested in contract farming and helped to develop a reliable supply chain system for vegetables connected with Ho Chi Minh city markets.

Quang Nam: Most cropping systems in QN province are rainfed and not many farmers use improved irrigation or nutrient management technologies. Our project activities demonstrated the profitable use of irrigation and nutrient use technology. However, farmers in this region have limited access to credit for investment and the supply chain for irrigation ware is very limited. The survey identifiedonly 1-2 suppliers of irrigation systems in QN.

7.3.5 Approved peanut and mango irrigation technologies by DARD/MARD/Provincial govt

Attached (Appendix 2) are the irrigation and nutrient management technologies approved by DARD Binh Dinh from ASISOV submissions. ASISOV along with DARD have been in discussion about the scope of extending these technologies widely and are seeking funds to demonstrate, train and convince farmers to adopt these technologies for sustainable outcomes in the SCC VN region.

7.3.6 Profitable packages for water and nutrient use for crops like peanut, mango and onion

Packages for peanut, mango and vegetables have already been developed by ASISOV since 2016 and are usually updated every year based on new research.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The research of the project relates directly to 330,000 ha of sands in SCC VN. Our research was conducted on the inland sandy terrain of Phu Cat district, BD as well as the coastal sands of NT. It did not directly examine the red sand of the high dunes of NT. In addition, the present research has relevance to 220,000 ha of sands in North-central Coastal Vietnam. Large areas of sands occur on agricultural land in Cambodia, Laos and Thailand and the present finding have relevance there also.

Farmers use urea and NPK fertilizers in BD, NT and QN provinces but prior to this project researchers were not aware that K, S and micronutrients may be deficient and the implications it can have on crop productivity or the quality of the produce. Research shows consistent increases in crop yield from K and S fertiliser application and has determined optimum rates of application. This work has been published in Vietnamese and components of it have been published or is under review for international peer reviewed publications (Hoang et al. 2019, 2020).

The earlier ACIAR Project research identified B, Cu and to a lesser extent Mo and Zn deficiencies on sands in BD and NT (Hoang et al. 2015). However, the *ad hoc* use of fertilisers and soil amendments containing micronutrients by farmers in BD and NT prevented the completion of research that defined the requirement for these micronutrients, the residual value of the added fertiliser and the crop yield and quality responses that can be obtained. Preliminary results indicated that Cu fertiliser increased fruit yield and quality of mango and also increased pod yield of peanut. The field evidence of Cu response in mango and peanut are new findings for SCC VN, but have not been published yet.

Sands pose major challenges for efficient water and nutrient management especially for irrigated crops in monsoonal climates. We studied partial K balance in irrigated peanut crops in sandy soils in the monsoonal climate of south-central Vietnam to identify key factors contributing to K imbalance that need to be managedand reported on them in Hoang et al.(2019). The negative partial K balance decreased with increasing K rates but remained negative even at K rates that achieve maximum peanut yield. The negative K balance was mostly attributable to the large K removal in peanut shoots (70–143 kg K ha^{-1}) from fields at harvest for use as animal feed. The K in cattle urine and dung is not recycled to crop fields. The negative partial K balance results in depletion of soil K reserves and hence requires more efficient recycling of K from peanut shoots, plus irrigation and fertilizer practices that minimize K leaching and regular application of K fertilizers for sustainable production of irrigated crops on sands.

Sulfur supply for field crops in the semi-arid tropics is often neglected leading to negative S balances that threaten long term profitability of crops like peanut with high S demand. Sands have favourable physical properties for harvesting crops like peanut, but improving S and water use efficiency on these soils remains a challenge. We studied partial S balance in irrigated peanut crops on sands of Central Vietnam to identify key factors of S fertilizer management affecting S inputs and outputs. Sulfur balances were negative (-28.3 to 5.6 kg S ha^{-1}) at S fertilizer rates < 30 kg S ha^{-1}, while at higher rates of S fertilizer application that produced maximum pod yield (30 - 45 kg S ha^{-1}), three of four sites showed neutral to slightly positive S balance (1.5-5.6 kg S ha^{-1}). The negative partial S balance decreased with increasing S rates but was mostly attributable to the large S removal in peanut shoots (18.4 – 19.2 kg S ha^{-1} at rate of 45 kg S ha^{-1}) which are used on farms for animal feed. The negative partial S balance results in depletion of soil S reserves and hence requires more efficient recycling of S from peanut shoots, applying good irrigation practices to minimize S leaching and regular application of S fertilizers for sustainable crop production in sands of VN (Hoang et al. 2020).

Our research has shown that soil amendment materials such as clay-rich soils, bentonite clay, and sugarcane residue can all substantially increase yield of vegetables in sands by improving the nutrient and water use efficiency. The crop yield and water saving benefits persisted for at least three consecutive vegetable crops. Nitrogen use efficiency was also increased using clay and sugarcane residue amendments on sands. These findings are yet to be published.

The groundwater-surface water hydrology research highlighted the strong seasonal shifts between wet and dry seasons and their effects on changes in river flow regimes and therefore exchanges with the streambed surface (Vu et al. 2018). This seasonal variation is particularly apparent because in the tropical savannah climate of SCC VNthereare strong differences between wet and dry seasons. However, fluxes between surface water and groundwater and the impacts of these interactions on streambed dynamics are rarely investigated in tropical climates, where few surface water-groundwater field investigations have been performed. In this study, an intermittent river in south coastal Vietnam was investigated to better understand links between seasonal hydrologic shifts, human use of water resources, and streambed dynamics. During the wet and into the dry season the river was gaining (i.e. flux from the aquifer into the river) at all times and all locations with the notable exception of fluxes into the streambed only at the upstream and downstream sites during peak flow of the largest captured rain event (550 mm in 164 h). Based on 30 years of precipitation data, this suggests that water is pushed from the stream into the streambed approximately three times per year. Groundwater withdrawal by households near the cross-sections was found to have a comparatively small effect on streambed fluxes, reducing the flux by up to 3% during dry conditions, although this pumping did cause a reversal in the gradient to the stream for a short period (less than 12 h) on one occasion during the dry season.

This water balance study of a tropical, agriculture-based catchment in Vietnam with an intermittent gaining stream has shown that the flow regime strongly depends on the local climate, the hydrogeology and the human alterations of the groundwater and surface water levels. Simulating the water balance under unguaged conditions is scientifically still a complexchallenge. We have demonstrated the crucial hydrometeorological, hydrological and geographical field data for water balance modelling in an ungauged catchment in SCC VN. The scenario analysis using the water balance model has shown the dominant effect of year-to-year rainfall variability on the sustainability of groundwater-dependent agriculture. Secondly, it has shown the impact of land use choices on the water balance.The performed scenario analysis are essentially a sensitivity analysis of the groundwater system to seasonal changes in rainfall, changes in agricultural land use and changes in irrigation water use efficiency. It is noted that the relative order of sensitivity is in the order of rainfall variability > land use change > irrigation water use efficiency. This has implications to farmers in terms of crop choice using 3 monthly climate forecasts and for land use planners and local governments. It also suggests that policy makers should place more weight on the decline in groundwater supply after a low rainfall monsoon, rather than rely on irrigation technologies to prevent to exhaustion of available groundwater for irrigation.

Our research has shown large variations in quality of groundwater in agricultural catchments in SCC VN. There is limited research on this subject in Vietnam. In the La Vi catchment, BD surface and subsurface water quality, complied with the Vietnamese water guidelines for drinking and irrigation purposes with relatively low concentrations of nitrate and phosphate. Hence, no further monitoring of water quality was required in BD. However, in the coastal zone of NT, groundwater quality was variable depending on season and the total rainfall. Nitrate, phosphate and salt levels were high in the groundwater during the drought year of 2015. However, in 2017, the above-average total rainfall was > 1,200 mm and the levels of salt, nitrate and phosphate were comparatively low. Groundwater in the dry season (Jan-Sept) normally shows high levels of salt and nutrients in comparison to the wet season (Oct-Dec). High rates of nitrogen fertilisers (ranging between 375-680 kg of urea /ha) and phosphate fertilisers (ranging between 300-690 kg di-ammonium phosphate /ha) are the most likely factor in elevating nutrient concentrations in the groundwater. High salt levels in groundwater may be due to intrusion by sea water, accentuated by groundwater abstraction for irrigation. This work is yet to be published.

Our research on integrated water and nutrient management in mango on infertile sands is novel. We conclude that the use of a mini-pan to guide irrigation scheduling with drippers saved 46-70 % of irrigation water and increased yield of mango fruit by approximately 2.6 t/ha (26-32 %). However, there were negative balances for K under all irrigation methods (farmers practice, sprinkler and drip and mini pan).By contrast, partial S balances under mango were positive. This work is being prepared for publication. Fertigation (to supply both water and nutrients) to mango increased the proportion of grade 1 fruit (good quality and higher price) by 5 % which would increase profit. The water savings (57 %) were similar to the drip irrigation system but applying nutrients by fertigation reduces the labour required for fertilizer application.

8.2 Capacity impacts – now and in 5 years

Irrigation and nutrient management technologies were developed and demonstrated and training programmes on their use helped build capacity of the researchers and DARD during the project. Researchers in the project gained experience in experimentation on overcoming soil constraints, conducting experiments on farmer's fields and chosingthe right amounts of fertilizers for a profitable cropping of mango, peanut and vegetables.

In the last 5 years, more than 30 students were involved directly or indirectly through the project and completed their undergraduate or post- graduate degrees in association with HUAF, NLU, MU and FU. The titles of theses below reflect the interest the students had in management of sandy soils, nutrients, water and crop production.

Table 8.1 List of graduate/post-graduate students

Year	Name of student	Level	Title of thesis
2015	Mr. Do Thanh Nhan	PhD	Effect of K and S fertilizer application in peanut in sandy soil of Binh Dinh province
	Mr. Duong Cong Loc	Master	Effect of organic amendments and K, S fertilizer application in sandy soil of Binh Dinh province
	Mr. Nguyen Tri Hoan	Bachelor	Effect of K rates and forms on peanut yield in Cat Hanh commune, Phu Cat district, Binh Dinh province
	Mr. Nguyen Van Lam	Bachelor	Effect of K rates and forms on peanut yield in Cat Hiep commune, Phu Cat district, Binh Dinh province
	Mr. Vo Hung Phi	Bachelor	Effect of S rates and forms on peanut yield in Cat Hiep commune, Phu Cat district, Binh Dinh province
	Mr. Tran Van Son	Bachelor	Effect of S rates and forms on peanut yield in Cat Hanh commune, Phu Cat district, Binh Dinh province
	Mr. Tran Dinh Phuong	Bachelor	Effect of organic amendments and K fertilizer application in sandy soil of Cat Hanh commune, Phu Cat district, Binh Dinh province
	Ms. Le Thi Hong Ngan	Bachelor	Effect of organic amedments and K fertilizer application in sandy soil of Cat Hiep commune, Phu Cat district, Binh Dinh province
	Ms. Tran Thi Nhu Phuong	Bachelor	Effect of K and S limiting application on peanut in sandy soil of Ninh Thuan province
	Nguyen Dinh Trong	Bachelor	Effect of K and S limiting application on peanut in sandy soil of Binh Dinh province

Year	Name of student	Level	Title of thesis
2016	Ms. Truong Thi Ngoc Ai	Bachelor	Effect of K and S rates on peanut yield in sandy soil of Cat Hiep commune, Phu Cat district, Binh Dinh province
	Ms. Nguyen Thi Ut Nhi	Bachelor	Effect of K and S rates on peanut yield in sandy soil of Cat Hanh commune, Phu Cat district, Binh Dinh province
	Ms. Le Thi Hien Mai	Bachelor	Effect of K and S rates on peanut yield in sandy soil of Cat Hanh commune, Phu Cat district, Binh Dinh province
2017	Ms. Pham Thi Ngoc Anh	Bachelor	Effect of K and S fertilizer application on peanut yield in Cat Hanh commune, Phu Cat district, Binh Dinh Province
	Ms. Nguyen Th Nhan	Bachelor	Effects of K, S and irrigation methods on peanut yield in Cat Lam commune, Phu Cat district, Binh Dinh province
	Ms. Nguyen Thi Tam	Bachelor	Effect of K and S fertilizer application on peanut yield in Cat Hiep commune, Phu Cat district, Binh Dinh Province
	Ms. Nguyen Thi Tho	Bachelor	Effects of K, S and irrigation methods on peanut yield in Cat Hanh commune, Phu Cat district, Binh Dinh province
	Ms. Nguyễn Thị Thùy Dung	Master	Effects of K and S rates on peanut yield in sandy soil in Binh Dinh province
2018	Mr. Phan Van Phuoc	Master	Effects of K, S and irrigation methods on peanut yield in Thang Binh district, Quang Nam province
	Ms. Phan Thi Thuy	Bachelor	Effects of K, S and irrigation methods on peanut yield in Binh Trung commune, Thang Binh district, Quang Nam province
	Ms. Pham Thi Trinh	Bachelor	Effects of K, S and irrigation methods on peanut yield in Binh Trung commune, Thang Binh district, Quang Nam province
	Ms. Pham Thi Binh	Bachelor	Study on limiting nutrients on peanut in sandy soil of Quang Nam province
	Ms. Nguyen Thi Tam	Bachelor	Study on limiting micronutrients on peanut in sandy soil of Quang Nam province
	Ms. Phan Thi Kim Thao	Bachelor	Study on limiting macronutrients on peanut in sandy soil of Quang Nam province
	Mr. Nguyen Hong Khanh	Bachelor	Effects of K, S and irrigation methods on peanut yield in Binh Sa commune, Thang Binh district, Quang Nam province
	Mr. Le Dinh Dung	Bachelor	Effect of K, S application and irrigation method on peanut in sandy soil of Binh Sa commune, Quang Nam province
2019	Ms. Trinh Thi Ngoc Hau	Bachelor	Effect of K, S application and irrigation method on peanut in sandy soil of Binh Sa commune, Quang Nam province
	Ms. Trinh Thi Ngoc Thuong	Bachelor	Effect of irrigation method on peanut in sandy soil of Binh Sa commune, Quang Nam province
	Mr. Dao My	Bachelor	Effect of K, S application and irrigation method on peanut in sandy soil of Binh Trung commune, Quang Nam province
	Ms. Nguyen Thi Thuong	Bachelor	Survey on peanut production and irrigation method in Binh Sa commune, Thang Binh district, Quang Nam province
	Ms. Nguyen Thi Thao	Bachelor	Survey on peanut production and irrigation method in Binh Trung commune, Thang Binh district, Quang Nam province

ASISOV, the main partner organisation based in Quy Nhon, Binh Dinh gained accreditation under the Vietnam Laboratory Accreditation Scheme after being assisted by Murdoch team in the preparation for QUATEST 3 to establish quality control systems. Government organisations used ASISOV facilities and expertise to analyse samples of water, soils and plants after it gained accreditation but ASISOV let the accreditation lapse because the amount of business generated did not compensate for the annual fee that has to be paid. Nevertheless, the lessons learnt about quality control and quality assurance continue to guide laboratory practice at ASISOV.

The project team in Vietnam (ASISOV, HUAF, IAS) have built their capacity in identifying nutrient limitations associated with crop production by diagnosing deficiencies by conducting double pot, glasshouse and field experiments. They are now highly skilled in: irrigation scheduling, designing irrigation layout, choosing the right pumps, in calculating head pressure systems suited to a particular environment, fields, orchards etc. This has given them confidence to set up a business to offer services to farmers in the design and installation of irrigation systems.

Skills in communicating both in oral and written form have developed through writing reports, publishing papers (Table 8.2), presenting on TV, at field days and atconferences.

Table 8.2 Papers published by Vietnamese collaborators

TT	Title/journal	Year	Journal	Senior author/presenter
I	International peer reviewed article			
1	Sandy Soils in South Central Coastal Vietnam: their origin, constraints and management.	2010	Proceedings of the 19th World Congress of Soil Science; Soil Solution for a Changing World. ISBN 978-0-646-53783-2. Published on DVD; http://www.iuss.org; Symposium3.3.1. 2010 Aug 1 - 6. Brisbane, Australia. IUSS; 2010, pp. 251-254.	HUAF (Dr Hoang Thi Thai Hoa)
2	Crop and cattle production systems in south central coastal Vietnam	2015	ACIAR Proceedings No. 143:10-19	HUAF (Dr Hoang Thi Thai Hoa)
3	Natural organic resources and nutrient balance in the farming systems of South central coastal Vietnam	2015	ACIAR Proceedings No. 143:20-28	HUAF (Dr Hoang Thi Thai Hoa)
4	Improving the value and effectiveness of manure	2015	ACIAR Proceedings No. 143:80-90	HUAF (Dr Hoang Thi Thai Hoa)
5	Assessment of nitrogen mineralization of organic materials on sands of Central Vietnam: incubation experiments	2016	Proceedings of the 2016 International Nitrogen Initiative Conference, "Solutions to improve nitrogen use efficiency for the world", 4 – 8 December 2016, Melbourne, Australia.	HUAF (Dr Hoang Thi Thai Hoa)
6	Nutrient and Water Management on Sands and Its Role in Food Security and Environmental Sustainability in South Central Coastal Vietnam	2017	TropAg 2017- International Tropical Agriculture conference, 20-22 Nov, Brisbane, Australia	HUAF (Dr Hoang Thi Thai Hoa)
7	K management strategies to achieve K balance in sandy soils of South central coastal Vietnam	2018	Proceedings of 21 World congress of Soil science, 12-17 August, Brazil	HUAF (Dr Hoang Thi Thai Hoa/ R Bell)

TT	Title/journal	Year	Journal	Senior author/presenter
8	Partial potassium balance under irrigated peanut crops on sands in a tropical monsoonal climate	2019	Nutrient Cycling in Agroecosystems. 114(1):71-83	HUAF (Dr Hoang Thi Thai Hoa)
9	Improving Water and Nutrient Use Efficiency of Crops through New Fertiliser and Irrigation Technologies	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	HUAF (Dr Hoang Thi Thai Hoa)
10	Impact of Agricultural Practices on Groundwater Quality	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	IAS (Dr Nguyen Quang Chon)
11	Pathway to adoption of technologies for sustainability of resources and farmer's income	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	ASISOV (Dr Ho Huy Cuong)
12	A remote sensing supported land cover and land use change analysis of La Vi Catchment, Binh Dinh Province, Vietnam	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	NLU (Thong Nhat Tran)
13	Modeling crop irrigation water requirement using FAO-CROPWAT and GIS in La Vi Catchment, Binh Dinh Province, Vietnam	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	NLU (Liem Nguyen Duy)
14	Use of irrigation technologies for sustainable water use in dry season for crop production in South Central Coastal Vietnam	2019	Proceedings of Vietnam International water weeks- VACI 2019, 22-25 March, Hanoi, Vietnam	ASISOV (Hoang Vinh)
II	Vietnamese Journal			
1	Study to determine nutrients restricting fertility of sandy soils in the SCC VN.	2014	Journal of Soil Science. No. 43:43-48	HUAF (Dr Hoang Thi Thai Hoa)
2	Study to use crop residues in agriculture and balance of nutrients in crop system in the SCC VN.	2014	Proceedings of National Conference on solutions to improve fertilizer use efficiency in Vietnam. Hanoi Agricultural Publisher. 163-172	HUAF (Dr Hoang Thi Thai Hoa)
3	Study effect of combined application of organic fertilizers and K fertilizer on yield of peanut on sandy soil of Binh Dinh province.	2016	Science and Technology Journal of Agriculture & Rural Development. No. 22:61-66	HUAF (Dr Hoang Thi Thai Hoa)
4	Effect of rates and forms of S on yield of peanut on coastal sandy soils of Binh Dinh province.	2017	Science and Technology Journal of Agriculture & Rural Development. 74-80	HUAF (Dr Hoang Thi Thai Hoa)
5	Effect of rates and forms of K on yield of peanut on coastal sandy soils of Binh Dinh province.	2017	Science and Technology Journal of Agriculture & Rural Development. 81-86	HUAF (Dr Hoang Thi Thai Hoa)
6	Efficiency of K and S fertilizers on peanut at Cat Hanh commune, Phu Cat district, Binh Dinh province.	2017	Journal of Science of Hue University. 126(3D): 75-84	Do Thanh Nhan and HUAF
7	Effect of omitting application of K, S on growth of peanut on coastal sandy soils in net house condition.	2018	Journal of Soil Science. No. 54:18-24	HUAF (Dr Hoang Thi Thai Hoa)
8	Study effect of rates of K and S	2018	Science and Technology	Do Thanh Nhan

TT	Title/journal	Year	Journal	Senior author/presenter
	on yield of peanut in Phu Cat commune, Binh Dinh province.		Journal of Agriculture & Rural Development. No. 13:41-46	and HUAF

Capacity inwater balance methodology was developed for agricultural areas in the SCC VN study area for assessing groundwater resources quantity and quality, including the determination of the sustainability of groundwater use under different agricultural development scenarios. Dr Vu Hai obtained a PhD from Flinder University in the use of these approaches and is in a good position to apply them in other work in SCC VN by his Institute.

An extensive process of data collection was setup by NLU for obtaining basic hydrometeorological, hydrological, hydrogeological, landuse, soil, and other geographical data. This approach has been recored in a Manual that can be used for other similar projects in Vietnam.

8.3 Community impacts – now and in 5 years

In project working areas of BD, NT and QN, small landholders are now aware of the benefits of using improved irrigation and fertiliser management technologies - labour savings, increased productivity, decreased water usage, better quality produce resulting in higher profit margins. For example, the previous project (SMCN 2007-109) reported that average yield of peanut in BD used to be ~2 t/ha, however, on project demonstrations the average yield of peanut is ~3.5 t/ha. Given that peanut in BD provincecovers 9,000 ha, and each farmer has on average 0.75 ha of land, the project in future can benefit more than 30,000 farmers and the advance in peanut technologies, partly as a result of this project, can increase the supply of peanut by 13,500 t/ year.

Increase in use of irrigation ware, balanced fertilizer etc will create opportunities for local business to establish supply chains. In fact, ASISOV staff, seeing the opportunity, are establishing such a business in Phu Cat district, BD to retail irrigation equipment and supplies, fertilisers, seeds and toprovideadvice to farmers on irrigation design and installation for peanut, mango, vegetables etc.

Conservation of water by improving water use efficiency using technologies will secure more water availability for farmers dependent on groundwater irrigation. This minimises the risk of crops failing to reach maturity when groundwater runs out, as currently happens for peanut crops after low monsoon rainfalland reduced groundwater recharge. Importantly, water use efficient technologies are essential in order to achieve future sustainable groundwater use. While there may be pressure to expand the area under irrigation using the water savings, our scenario anlaysis suggests the need for a more cautious approach to ensure that even in years after low monsoon rainfall that there is still sufficient water for irrigation as well as for sustained stream water flow.

In addition, improved irrigationtechnologies that save water, and soil amendments such as clay or sugarcane residue have beenshown to reduce leaching of nitrate which should improve the quality of drinking water in communities that rely on groundwater for household water use. Since nitrate levels well above the threshold for human consumption were measured, there is potential for human health benefits from the improved irrigation and nutrient use efficiency. Alternatively, public water utilities may need to provide potable water to communiities threatened by high nitrate levels in groundwater used for drinking.

8.3.1 Economic impacts

Peanuts provide 2.5 to 5 times more income per hectare than crops such as rice and cassava. Price stability has also a part in boosting economic returns to farmers frompeanut production. Peanuts are considered to have a major role in raising farmer incomes on sandy soils of the SCC VN. However, limited availability of groundwater during the dry season and unbalanced nutrition can limit production and quality of peanuts.Efficient use of groundwater and balanced fertilizer application are pathways to improve farmer's income. Similarly for mango production, efficient management of water and nutrients can further improve profit margins.

Using the MP and sprinklers for peanut or drip irrigation and MP for mango and fertigation are promising examples of technologies developed with positive impacts on farmer's income. For example, use of sprinklers and MP which increases the yield of peanut by 0.3 t/ha, can increase total production of peanut by 2,700 tonnes on 9,000 ha of peanut grown in BD province, generating extra income for farmers equivalent to 48,600 million VND or 3.16 million AUD. Spreading the use of sprinklers and mini-pan for peanut production in QN province where peanut covers more than 10,000 ha, and where the average peanut yield is <2 t/ha, can generate for farmers an extra AUD 7 million/yr. Quang Nam has shown promising results from the use of sprinklers and MP for two consecutive years (2018/2019) in Binh Sa commune with an average yield of ~3.5 t/ha, however, imposition of a ban on extraction of groundwater near coastal areas in QN to avoid intrusion of salts is a limitation that can prevent adoption of irrigation technologies.

Combined nutrient and water management are critical for maintaining nutrient balances, reducing leaching and in increasing productivity, to achieve a more sustainable approach to irrigation of crops using groundwater. Reducing rates of N and P by 25 % for onion production in NT irrigated with sprinklers guided by MP was able to improve the profitability by > 50 million VND. Water savings in NT for onion is more than 516 m^3 /ha/crop as a result of using MP with sprinklers by contrast with farmer's use inAn Hai ofsprinklers without MP.

Similarly, use of drippers and MP to irrigate mango fields can increase the yield by over 6.3 t/ha and if used for all the 1,500 ha under mango cultivation will increase the total yield by 9,450 tonnes, and increase the income of the farmers in BD by 70,200 million VND (AUD 4.2 million) in comparison to the currentpractices of irrigation. Drip irrigation has also been shown to improve the quality of mango fruit and can further increase the profit margin. These improved irrigation technologies can also be applied to a range of other irrigated crops (water melon, chillies, citrus, coconut) to generate additional benefits for farmers in SCC VN. Further improvement of drip irrigation with fertigation may help improve profit margin under mango plantation. Use of fertigation for asparagus production has been tested at ASISOV head office in BD. Fertigation in NT for asparagus has become quite common as a result of international private agencies.

The adoption of improved irrigation and nutrient managementtechnologies will generate businesses tosupply the right products to farmers. For example, ASISOV, the main institute that carried out the research on irrigation design, irrigation ware, suitability and efficiencies, have started their own business model and established a centre to train, advise and supply of appropriate materials for the benefit of farmer's in Phu Cat district.

Farmers have realised that mango is more profitable as a cash crop in BD than cashew. As a result, farmers are now replacing old cashew trees with mango, using grafted mango and installing irrigation technologies to achieve higher yields and market-quality fruit. The present results on drip irrigation come at a good time to attract the interest of new mango farmers. In addition, use of fertigation under young mango plantation looks to be promising to save labour costs and improve yield and quality of fruits.

In NT, farmers near Phan Rang city are relativelyprogressive and are intensively growing vegetables (onion, garlic, chillies, asparagus). Fertigation to grow asparagus is being now used by farmers to further improve profit margins. Blockages in the drip lines has emerged as a significant barrier to adoption of fertigation, possibly because the farmers are using low solubility commercial fertilisers. Co-operative farming is now becoming popular in NT and QN and may become an option for farmers in such regions by sharing technology, knowledge and help provide resources for poor farmers to opt for technologies that have proven to be sustainable.

However, cost for the purchase of irrigation ware (>30 million VND/ha), non- availability of credit from banks, and erratic electricity supply are some impediments in adopting the improved irrigation technologies. Currently, quite a few of the farmers in BD have switched to using large sprinkler system because of low cost (~3 million VND/ha) even though there is limited labour saving from using these sprinklers compared to a hand-held hose. However, the large sprinkler is able to irrigate only 200 m^2 at a time and there is still labour involved in moving the sprinklers from one spot to the other during each day (Fig. 7.49). While the large sprinklers are more durable than perforated hose pipes, and involve less drudgery to use, they do not save on labour or purchase price.

Spin-offs from ACIAR project work

Outside of the direct interventions of the present project, there are numerous spin-offs where the technologies are being used on other crops and in other locations due to the promotional work of ASISOV. The main examples are as follows:

Cat Hai commune north of Quy Nhon

This commune grows irrigated peanut for the boiled peanut market supplying tourist outlets in Quy Nhon. Sixty percent of the area uses sprinkler irrigation introduced by ASISOV together with the improved ASISOV peanut cultivar. The farmers don't use the MP as they argue water is still abundant. They grow 2 to 3 peanut crops per year with onion as a break crop. We did note some instances where root diseases maybe limiting the peanut crop due to lack of crop diversity in the rotation. Patches of S deficiency were also identified. The total area is 170 ha but only 90 ha of that is planted during the monsoon season since some of the soils are excessively wet.

Drip irrigation of mango

During 2016-2017, 5 ha of mango has been installed with drip irrigation in Kahn Hoa province.Another 5 ha of seedling mango was established with drip irrigation. This uses the drip and MPtechnology developed by the ACICR project. The project in Kahn Hoa province was supported by MARD.

High Tech Agriculture Plan for NT

ASISOV collaborated with DARD NT to develop a high tech land use plan for NT based on variations in soil, water and weather. In January 2019, the plan was released. In the high tech land use plan for NT An Hai and Ninh Hai will bothbe developed for production of 200 ha each of vegetables including asparagus. A series of surface water ponds lined with plastic will be constructed to store surface water from rivers and canals to reduce the dependence of irrigated agriculture on ground water.

This surface water will only be used for agricultural production not for households use. There is a plan to develop a reticulated water supplyto pipe potable water to each household to avoid the problem of nitrate pollution ingroundwater.

Each pond will supply water for irrigation to 30 ha surrounding it and the farmers will be linked to private sector markets and input suppliers for market-led vegetable production.

Other examples of application of the improved irrigation technologies.

A 7 ha block of water melon was established under drip irrigation in Phu Cat.

Sprinkler irrigation set up for peanut at Cat Hiep research station as well as drip irrigation 20 ha of mango, coconut.

Wet season peanut has been established under sprinklers in Cat Lam instead of cassava

Forages and mung bean irrigation established in Binh Thuan province by ASISOV for a US funded project

Irrigation business

The demonstrations and field day programmes run by ASISOV have created farmer demand for irrigation hardware in Phu Cat district. Farmers have requested access to credit so that they can invest in the irrigation ware.

ASISOV through its Cat Hiep shop has obtained commitments from investors which will enable them to offer a 30 to 50 % line of credit for irrigation ware purchased in the next season. ASISOV through its business has a plan to supply 200 ha of irrigation installations with credit. In addition they are hopeful of supplying up to 200 ha of irrigation hardware to a peanut promotion project that they will run using funds supplied by MARD.

The ASISOV shop will sell the irrigation ware (pipes, drippers, sprinklers etc). They in turn are able to obtain irrigation equipment from suppliers on credit.

Investment in irrigation hardware has become feasible for smallholder farmers in SCC VN because of a drop in price from about 70 million Vietnam dong to 35 million/ha due to competition and cheaper materials.

Currently ASISOV supports the development of the business through the salaries of 6 staff and the building. However, the agreement is that once the business starts to turn a profit that a percentage of the profit will be contributed to ASISOV. The other investors will also receive profit shares. Hence, farmers who receive credit pay no interest on that loan. The agreement is signed jointly by ASISOV, the farmer and a Commune official. However, competition for supply of irrigation hardware is emerging from other private sector suppliers.

8.3.2 Environmental impacts

If sprinkler and MP irrigation technologies are adopted by all farmers growing peanut on 9,000 ha in BD, there can be a saving of 8.5-15.3 million m^3 of water. Similarly, if drip irrigation and MP technology can be used to irrigate all mango farms (currently 1,500 ha of land), saving of nearly 0.52 million m^3 of water can be achieved in BD alone. If these technologies can be extended to other peanut production areas, such as 10,000 ha in QN and mango production areas, such as Khan Hoa with 7,000 ha of mango production, then water savings and profitability can be huge in the SCC VN. Using these technologies should also decrease leaching of nutrients and prevent groundwater from contamination by soluble agrichemicals. Using efficient irrigation technologies, such as sprinklers and MP for peanut and drippers plus MP for mango, leaching of N, K and S have shown to decrease from 14 to 3 kg N/ha/crop, 41 to 16 kg K/ha/crop and 17 to 8 kg S/ha/crop in BD.

Surface and groundwater quality is an indicator of environmental impacts of land use in BD and NT provinces. Results of groundwater samples collected in 2014 and 2015 from An Hai and Nhon Hai communes of the coastal zone of NT showed that more than 75 % of the samples in Nhon Hai exceeded the maximum permissible limit (MPL) for nitrate and EC whereas phosphate was less of a concern. In An Hai, around 30-50 % of the samples exceeded MPL for nitrate, 30 % for EC and almost none for phosphate. Intensive agriculture in NT (e.g. 4 crops of onion or 2 crops of garlic per year) with high use of chemical fertilisers appears to be the source of contamination of groundwater. Of the groundwater samples collected in 2017 in NT, >50 % of samples were reported to exceed the MPL for nitrate (nitrate, 50 mg/L) and 25 % for EC (3 dS/m). However, homesteads and animal housing sheds could also be sources of nutrient contamination.

The water balance model developed for assessing scenarios of groundwater use show very clear difference between current and future agricultural development scenarios. Intensification of irrigation and its further spread in La Vi catchment raise the prospect for water shortages and the cessation of river flows in dry years and hence potential environmental degradation of riverine and groundwater dependent ecosystems. These powerful tools provide the opportunity for Provincial authorities to make better informed decisions on the future directions of the agricultural sector. They can inform policies designed to direct water, land and irrigation management such that the valuable groundwater resource will not be over-drawn and secured for the benefit of future generations.

8.4 Communication and dissemination activities

The project team over the last 4 years (2015-19) carried out 36 training activities on irrigation and fertilizer management and field days on farmer's fields where irrigation and nutrient management technologies were demonstrated on peanut, mango and vegetables(Table 8.3). These were attended by 1157 farmers of which 68 % were female farmers. Women are extensively involvedas labour in these areas, whereas, men are more involved in other jobs/activities to earn extra off-farm income.

Over 23 media events on provincial and national TV reported on the work and activities of the project (Table 8.4).

Table 8.3 Training, workshops, and field day activities (July 2014-June 2019)

No.	Activities	Date	Location	Participants				
				Gov.	Farmer	INGO, NGO, private sector	Project team	Total No. Men/ women
1.	Farm Economic model (FEM) training	3-5 Sept. 2014	ASISOV, Quy Nhon	5			10	11/4
2.	QA/QC	5th Sept 2014	ASISOV, Quy Nhon				5	3/2
3.	Soil and plant sampling in the field	6th Sept 2014	Phu Cat, Binh Dinh				5	3/2
4.	Irrigation management for peanuts	23 Sept	ASISOV, Quy Nhon				8	5/3
5.	Assessing irrigation technologies for water use efficiency	22 Dec 2014	ASISOV, Quy Nhon	5	10		5	14/6
6.	Integrated irrigation and nutrient management	5 Jan 2015	Cat Hiep commune	5	25			22/8
7.	Introducing new varieties and technologies	20 April 2015	Binh Dinh	5	60		5	56/14
8.	Demonstration of	25 April	Cat Hiep	4	40		4	40/8

No.	Activities	Date	Location	Participants				
	irrigation methods and nutrient use	2015	commune					
9.	Water sampling and analysis	19 March 2015	La Vi river catchment, BD				11	8/3
10.	Field day workshop on introducing the techniques to cope with climatic change condition in SCC	March, 2015	An Nhon distr, Binh Dinh prov.	5	70	2	3	40/40
11.	Field day workshop on Demonstration of irrigation methods and nutrient use for peanut	March – April, 2015 and 2016	Phu Cat, Binh DInh	5	80	2	3	40/50
12.	Field day workshop on demonstration of irrigation methods and nutrient use for mango	March – April, 2015 and 2016	Phu Cat, Binh DInh	5	140	2	3	62/88
13.	Field day workshop on solutions cope with drought condition in SCC	March 2016	Phan Rang thap Cham city, Ninh Thuan prov.	5	90	2	3	27/73
14.	Midterm review workshop of project	26-29 July, 2016	Quy Nhon, Binh Dinh, Vietnam	3	7	3	27	30/10
15.	Training on Water saving for mango crops on sandy soils	25 September, 2016	Cat Hanh commune, Phu Cat Distric, Binh Dinh prov.,Vietnam	6	30		6	17/25
16.	Training on irrigation technologies, fertigation, management strategies for mango production	17 Nov, 2016	Quy Nhon, Binh Dinh, Vietnam	5		10	5	10/10
17.	Training on Water saving and integrated nutrient management for peanut crops on sandy soils	25 Dec., 2016	Cat Hiep commune, Phu Cat Distric, Binh Dinh prov.,Vietnam	5	30		5	15/25
18.	Training on Integrated nutrients and irrigation management for vegetable crops on sandy soil	11 April, 2017	Cat Hiep commune, Phu Cat Distric, Binh Dinh prov.,Vietnam	10	25	2	10	22/15
19.	Training on Integrated	13 April,	Nhon Hai commune,	10	30	1	8	20/19

No.	Activities	Date	Location	Participants				
	nutrients and irrigation management for vegetable crops on sandy soil	2017	Ninh Phuo Distric, Ninh Thuan prov. Vietnam					
20.	Water saving and irrigation technologies, management strategies for mango production on sandy soils	3 May, 2017	Cat Hanh commune, Phu Cat Distric, Binh Total No. Men/women (approx.)Dinh prov.,Vietnam	7	50	1	5	40/23
21.	Integrated nutrients and irrigation management for vegetable crops on sandy soil	11 April, 2017	Cat Hiep commune, Phu Cat Distric, Binh Dinh prov.,Vietnam	10	25	2	10	22/15
22.	Integrated nutrients and irrigation management for vegetable crops on sandy soil	13 April, 2017	Nhon Hai commune, Ninh Phuo Distric, Ninh Thuan prov. Vietnam	10	30	1	8	20/19
23.	Training on management of nutrition and irrigation water in intensive cultivation of peanut in Binh Dinh	21 March, 2018	Cat Hiep commune, Phu Cat Distric, BinhDinhprov.,Vietnam	1	39		6	46/21
24.	Training on management of nutrition and irrigation water in intensive cultivation of peanut in Binh Dinh	21 Mar, 2018	Cat Trinh commune, Phu Cat Distric, BinhDinhprov.,Vietnam	2	36		6	44/24
25.	Field workshop of Training on Water saving and integrated nutrient management for peanut crops on sandy soils	6 April, 2018	Cat Trinh commune, Binh Dinh, VN	7	35		8	24/26
26.	Attending the Market Place 25 years Anniversary ACIAR in Vietnam	11 April, 2018	Hanoi, Vietam				2	2/0
27.	Field workshop of Water saving and irrigation technologies management strategies for mango production	8 May, 2018	Cat Hanh commune, Binh Dinh, VN	7	35		8	27/23

No.	Activities	Date	Location	Participants				
	on sandy soils							
28.	Workshop on irrigation scheduling and design	12-13 July 2018	ASISOV	14	4	2	10	12/18
29.	Training on integrated nutrient and water management on peanut in Quang Nam province	6-7 January , 2019	DARD Quang Nam	3	40		3	15/31
30.	Field visits on integrated nutrient and water management on peanut in Binh Sa commune, Thang Binh district, QN province	3-4 April, 2019	Binh Sa commune, Quang Nam	2	40		2	16/26
31.	Field visits on integrated nutrient and water management on peanut in Binh Trung commune, Thang Binh district, QN province	5-6 April, 2019	Binh Trung commune, Quang Nam	2	40		2	20/22
32.	Training on Integrated nutrients and irrigation management and operating irrigation systems in intensive cultivation of peanut and mango in Binh Dinh	11 Jan 2019	Cat Hiep commune, Phu Cat Distric, BinhDinhprov.,Vietnam	2	32		8	42/10
33.	Training on Integrated nutrients and irrigation management and operating irrigation systems in intensive cultivation of onion in Ninh Thuan	14 Jan 2019	An Hai commune, Ninh Phuoc Distric, Ninh Thuan prov.,Vietnam	3	37		8	48/21
34.	Workshop on Integrated water, soil and nutrient management for sustainable farming systems in South Central Coastal Vietnam	20 March 2019	Quy Nhon city, Binh Dinh prov.,Vietnam	25			26	51/10
35.	Workshop on Integrated nutrients and irrigation	10, April, 2019	Cat Hanh commune, Phu Cat Distric, Binh	4	35		4	43/11

No.	Activities	Date	Location	Participants				
	management and operating irrigation systems in intensive cultivation of peanut in Binh Dinh		Dinh prov.,Vietnam					
36.	Workshop on Integrated nutrients and irrigation management andoperating irrigation systems in intensive cultivation of peanut in Binh Dinh	10, April, 2019	Cat Hiep commune, Phu Cat Distric, BinhDinhprov.,Vietnam	4	32		4	40/9
	Total			**186**	**1147**	**30**	**246**	**1157/ 784**

Table 8.4 News on TV about the ACIAR project activities in Binh Dinh, Ninh THuan and Quang Nam, clips of field days and press releases

No.	Communication Activity	No of clips or workshops	Location	Month/year
1.	TV report on water saving technique for crop in SCC	2	National TV and Provinces TV of Farmers' friend column	May – Aug 2015 and 2016
2.	TV report on solutions to cope with drought condition in SCC	2	National TV and Provinces TV of Farmers' friend column	May – June 2016
3.	TV short news on Field trip workshop Demonstration of irrigation methods and nutrient use for peanut	2	National TV and Provinces TV of Farmers' friend column	March – April, 2015 and 2016
4.	TV short news on Field trip workshop of irrigation methods and nutrient use for mango	2	National TV and Provinces TV of Farmers' friend column	March – April, 2015 and 2016
5.	TV report on water saving technique for mango in SCC	1	National TV and Provinces TV of Farmers' friend column	July – Aug 2016
6.	TV report on solutions to cope with drought conditions in SCC	2	Several times on national TV and Provinces TV of Farmers' friend column	July 2016- July 2017
7.	TV short news on Mid-term review workshop of project	1	Several times on Binh Dinh Provinces TV	July 2017
8.	TV short news on Field trip workshop on Integrated nutrients and irrigation management for crops on sandy soil	2	Several times on Binh Dinh Provinces TV	April, 2017
9.	TV short news on Field trip workshop on Integrated nutrients and irrigation management for crops on sandy soil	2	Several times on Ninh Thuan Provinces TV	April, 2017

No.	Communication Activity	No of clips or workshops	Location	Month/year
10.	TV report on Water saving and irrigation technologies, management strategies for mango production on sandy soils	2	Several times on Binh Dinh Provinces TV	May, 2017
11.	TV short news on Midterm review workshop of project	1	Several times on Binh Dinh Provincial TV	July 2017
12.	TV short news on Field trip workshop on Integrated nutrients and irrigation management for mango crop on sandy soil	2	Several times on Binh Dinh Provincial TV	May, 2018
13.	TV short news on Field trip workshop on Integrated nutrients and irrigation management for peanut crop on sandy soil	2	Several times on Ninh Thuan Provincial TV	April, 2018
14.	Short communication news on Field trip workshop on Integrated nutrients and irrigation management for peanut crop on sandy soil in Quang Nam province	1	DARD Quang Nam	April, 2019
	Total	**23**		

Further information about the Project and its technologies can be found on the ASISOV web site: http://www.asisov.org.vn

An example of project outputs is available at http://www.asisov.org.vn/giong-tbkt-moi/su-dung-chao-boc-thoat-hoi-nuoc-cho-san-xuat-dieu-349.html

9 Conclusions and recommendations

9.1 Conclusions

1. The inclusion of hydrology, remote sensing, soil science, agronomy and farm economics expertise in the project provided novel insights in groundwater resource use in SCC VN for agriculture.
2. A methodology was developed for agricultural areas inthe SCC VN study area for assessing groundwater resources quantity and quality, including the determination of the sustainability of groundwater use under different agricultural development scenarios.
3. An extensive process of data collection was setup for obtaining basic hydrometeorological, hydrological, hydrogeological, landuse, soil, and other geographical data. The approach is recorded in a Manual available from NLU. The collected data is now available and can be of great value for improving evidence-based management of land and water resources in SCC VN.
4. The water balance modelling shows the main drivers of groundwater availability are (in order of decreasing influence): rainfall, land use, and irrigation technology. Our findings highlight the need for agricultural land use in sandy terrain in SCC VN to ensure there is adequate groundwater storage even following the years of low monsoon rainfall, otherwise water shortages will hamper or threaten crop production.
5. In the La Vi catchment, Binh Dinh, during 2015 to 2017, both surface and subsurface water quality, complied with the Vietnamese water guidelines for drinking and irrigation purposes with relatively low concentrations of nitrate and phosphate. Hence, apart from point sources of high nitrate around settlements and cattle holding pens, no further monitoring of water quality was required in BD.
6. However, in the coastal zone of NT, groundwater quality was variable depending on season, land use and the total rainfall. Nitrate, phosphate and salt levels were high in the groundwater during the drought year of 2015. However, in 2017, the total rainfall was almost double the long term average (> 1,200 mm vs 500-700 mm) and the levels of salt, nitrate and phosphate were comparatively low. Groundwater in the dry season (Jan-Sept) normally contains higher levels of salt and nutrients than in the wet season (Oct-Dec).
7. Farmers growing vegetables, grapes or jujube in NT tend to apply very high rates of nitrogen fertilisers (ranging between 375-680 kg of urea /ha) and phosphate fertilisers (ranging between 300-690 kg di-ammonium phosphate /ha) and this seems to be the most likely factor in elevating nutrient concentrations in the groundwater. High salt levels in groundwater may be due to intrusion by sea water, accentuated by groundwater abstraction for irrigation.
8. Intensive groundwater abstraction was reported by farmers in La Vi catchment during the dry season (from January to August), particularly for the main cropping period from the end of December to the beginning of April, accounting for up to 70 % of total annual abstraction. The basin-wide water extraction was compared to estimated water use based on the land use classifications and crop water requirements, which showed a total annual extraction for the base scenario of 40.5 x 10^6 m^3/yr.
9. Simulation of groundwater recharge showed that it was highly seasonal. High net recharge was estimated for the rainy season, from September to December, with an average net recharge for the whole catchment equivalent to 100–160 mm per month. Total net recharge for the four months of the wet period was 497 mm, accounting for 81 % of the annual recharge in the base scenario.

10. A coupled water balance (WetSpass-M) model and groundwater flow model (MODFLOW) was set up and applied for the base case conditions of the La Vi catchment. It was concluded with respect to the sustainability of the groundwater resources, that in wet years groundwater pumping is less than 46 % of the recharge, which is important for maintaining minimum ecological conditions in river valleys. In a year with average precipitation, the groundwater pumping increases to 75 % of recharge. In dry years with low precipitation the groundwater pumping exceeds the natural recharge, i.e. 116 %, thereby reducing the baseflow to practically zero and effectively reducing groundwater storage by about 7 M m^3/yr.
11. A SWAT daily surface water model for the La Vi catchment was developed, and successfully calibrated and validated. It is also coupled to the groundwater flow model. The results show that recharge into the aquifer, occurs principally between November and February. Groundwater contributions to river flow is mainly occurring during the wet season. Moreover, the results show that the effect of groundwater pumping on the groundwater resources cause significant reductions in the groundwater storage between February and June. This transient flux pattern confirms the presented average water balance results of the above base case scenario.
12. The landuse mapping of 2005, 2010 and 2016 shows a significant decrease in bare soil and rice paddy fields over time and a strong increase in other cropped areas in La Vi catchment. In total, 12 land cover scenarios were developed from the base scenario. The first eight scenarios involve the introduction of water-saving irrigation techniques in combination with changes in cropping. The next three scenarios looked at the conversion of the water-intensive crops in La Vi catchment, paddy rice and peanut, to the water-efficient crops, maize and cassava, as well as the filling in of bare land by non-irrigated cassava. The final scenario, is based on the prediction of a growing market for vegetables. From the 12 scenarios, five were selected, which had the largest range of associated groundwater extractions. Those five scenarios, as well as the base case, were simulated for assessment of the sustainability of groundwater use.
13. A comparison is made of the base case and the five simulated agricultural development scenarios in terms of the sustainability of the used groundwater resources. Groundwater balance fluxes for each scenario for dry, average and wet year rainfall conditions were simulated with the coupled WetSpass-M – MODFLOW model. It shows that the recharge to the groundwater does not vary a lot among the scenarios, but much more among levels of monsoon rainfall. Groundwater pumping varies significantly over the scenarios, with five scenarios having an abstraction higher than the recharge to the aquifer system, hence depleting the groundwater system. Eight scenarios have an abstraction between 100 and 50 % of the recharge, while five scenarios have an abstraction less than 50 % of recharge. Further analyses of the sustainability shows that the only sustainable development scenario is one in which rainfed crops like cassava increase in their area coverage. It is the only scenario, which is under wet and average climatic conditions in a ‘safe’ groundwater management space, while being close to this under dry climatic conditions. If the cropping patterns were not changed compared to the base scenario, but the amount of water consumed for irrigating peanut and mango was reduced by 50 % the risk of abstraction exceeding recharge was less than the present case. However, substantial increase in the area of irrigated peanut, even with more water efficient irrigation, would still exacerbate the risk of over use in dry years.
14. The optimum K fertiliser rate was determined from field experiments to be 50-75 kg K/ha for peanut. At these rates K inputs were below outputs resulting in depletion of soil K. Most of the net loss of K was attributed to the removal of shoots of peanut from fields for use as a cattle feed.
15. The optimum S fertiliser rate was determined from field experiments to be 20-30 kg S/ha for peanut. At these rates S inputs were approximately equal to outputs.

16. Improved irrigation technologies (sprinklers based on MP evaporation rates) and balanced use of nutrients (75 kg of K/ha and 30 kg of S/ha) in BD, showed water use decreased on average by 25 to 47 % and peanut yield increased by 16-26 % in comparison to farmer's practice. Negative balances of K and of S were measured on different sandy soils of BD with farmer's practice of applying N and P fertilisers only (i.e. little of or no application of K and S) in combination with farmer's irrigation. Hence farmers' practices are not sustainable for long term peanut production.
17. For peanut, profit margins varied among sites, but the mean value was 19 million VND/ha (AUD 1,140/ha) higher where MP and sprinkler irrigation were used together with application of 75 kg of K/ha and 30 kg S/ha in comparison to farmer's irrigation and fertilizer practice.
18. Amendment materials such as sugarcane residue, bentonite, clay-rich soil and manure were trialed in NT to assess the impact of these materials on yield of vegetables and water use efficiency. The results from three consecutive onion trials showed that at the current price of bentonite (2.2 million VND/t) with an application rate of 60 t/ha, the use of bentonite as an amendment material is no more profitable than farmer's practice, however, it is effective in improving the water and nutrient use efficiencies, and decreasing irrigation water requirements. Some form of incentive payment or credit payment would be necessary to motivate farmers to take up this technology even though its long term benefits for farmers on sands would likely be highly positive.
19. From 4 years of results on a 16-year-old mango orchard established on an infertile sand of Phu Cat district BD, we conclude that the use of a MP to guide irrigation scheduling with drippers saved 46-70 % of irrigation water and increased yield of mango fruit by approximately 2.6 t/ha (26-32 %). However, there were negative balances for K under all irrigation methods (farmer's practice, mini-sprinkler or drip with mini pan). The cost of irrigation technologies varies based on the irrigation technology used. For example, farmer's practice of using an hand-held hose costs only 1 million VND/ha, however, the cost of labour to apply the water is very high (200,000 VND/day/labour). The cost of large sprinklers is ~3 million, but the operating cost with labour and power is also high. The cost of upright sprinkler (~ 25 million VND/ha) and drip (~35 million VND/ha) systems are high, but there are significant savings in operating and labour costs. With sprinkler and drip irrigation system, farmers can generate 15 and 45 million VND extra income /ha, respectively. Drippers with MP generate enough increase in profit per hectare relative to farmer's practice that farmers could recover the cost of investment in approximately one year. In addition, saving of 46-70 % water by using drip technology conserves water when supply is limited especially during the peak season of flowering and fruiting for crops.
20. Water savings of 40-70 % for peanut and mango cropping areas which cover more than 10,000 ha in Binh Dinh can be substantial and provides opportunity for extra areas of crop to be irrigated during the dry season. However, water balance modelling suggests that expansion of the area of water-demanding crops like peanut is not sustainable given the frequency of low monsoon rainfall which depresses groundwater recharge. Expansion of low water-use crops like mango pose less of a threat to the sustainability of the groundwater resource.
21. In 2018 and 2019, the project examined the effect of fertigation (to supply both water and nutrients) on a 9-year-old mango orchard. Fertigation increased the proportion of grade 1 fruit (good quality fetching higher market price) by 5 % which would increase profit. The water savings (57 %) were similar to the drip irrigation system but applying nutrients by fertigation reduces the labour required for fertilizer application.
22. Large on-farm demonstrations (1 ha each) were conducted in 2018 and 2019 in three communes (Cat Hanh, Cat Hiep and Cat Lam) of Phu Cat district in BD to compare the benefits of sprinklers guided by MP with farmer's irrigation practice

for peanut. On average 30 % water was saved using sprinklers guided by MP . In addition,12 % higher peanut yields, varying between 4.5 to 4.65 t/ha, were achieved using the project's new irrigation technology as against farmer's practice. On-farm demonstrations also showed higher profit margins (~55 million VND/ha) with an increased cost to benefit ratio of 1.24 as against farmer's practice. Labour was the main item (~55 %) of the total input costs (57.2 million VND/ha) associated with farmer's practice, whereas, the labour cost using irrigation technology was 42 % of the total input costs (45 million VND/ha). The cost of the irrigation system, MP, pump and energy use accounted for 30 million VND/ha, which is 13.6 % of the total input costs. Given that profit margin from one peanut crop using irrigation technology is approximately 47 million VND/ha, the cost of investment in irrigation technology can be recovered from two peanut crops.

23. Small landholders in these areas recognize the benefits of using the tested technologies, however, there is a history of waiting by farmers for Government to introduce subsidies for adoption of new technologies. Leadership from national and provincial Governments of Vietnam in extending these technologies to other coastal provinces and in supporting the adoption of the technologies can help in rural poverty alleviation in SCC VN.
24. There has been tangible capacity building among all partners through writing reports, publishing articles and papers in VN and international journals, training programmes, field days, engagement with mass media (TV, newspapers), conference, study tours etc.

9.2 Recommendations

On the basis of the research and demonstration results of the Project, ASISOV should develop proposals to the DARD in BD and QN for new peanut fertiliser and irrigation technologies, to DARD in BD and Kanh Hoa for mango fertiliser and drip irrigation technology and mango fertigation technology and to DARD NT for vegetable sprinkler irrigation and fertiliser technology. If more demonstrations and experiments are needed to support these applications, they should be undertaken as soon as possible.

More site-specific testing for nutrient status on sands is warranted to achieve the best crop productivity. Double-pot technique is suitable for this task until laboratories are developed to analyse a wider range of elements accurately and interpretation criteria are well developed for soil testing and plant analysis of key crops in SCC VN.

Simulating the water balance under ungauged conditions is scientifically still a huge challenge. Hence, collecting data and maintaining measurement stations for crucial hydrometeorological, hydrological and geographical field data is of utmost importance in SCC VN. An expanded network of measurement stations for crucial hydrometeorological and hydrological data are needed in SCC VN to underpin water resource planning, especially in the areas of groundwater-dependent agriculture.

Groundwater modelling and improved knowledge of the regional groundwater balance and its economic value for agriculture in SCC VN needs to be built across the varied landscapes and land uses of SCC VN. There is particular urgency to water balance modelling for coastal catchments under threat of saline water intrusion.

Water balance modelling needs to be developed for sustainability evaluation of groundwater-dependent agriculture in SCC VN including scenario analysis for reduced agricultural water use (more efficient irrigation), increased water use (land use change to more irrigated crops), climate variability and climate change.

There were significant knowledge gaps about the groundwater resources of the study area and more broadly in SCC VN. Widespread dependence on groundwater for irrigation in SCC VN suggests that greater understanding of this resource was needed. The size of the groundwater resource needs to be quantified, together with annual recharge rates and the underlying hydrogeological structure of the aquifers needs to be determined. Studies should examine the sustainability of this resource given current and projected future rates of exploitation. The impact of low monsoon rainfall on rechgarge is a threat to the availability of groundwater. The risk from pollution of groundwater and surface water by fertiliser and agricultural chemicals, animal holding pens and household sewerage needs to be more thoroughly investigated.

Binh Dinh province is a medium rainfall zone of the SCC VN region and is well suited to crops like peanut, mango, cashew, cassava, corn and vegetables etc. However, the production constraints to crop production are more evident during the dry seasons which can be managed by integrated use of irrigation and nutrient management technologies. Savings of 40-70 % water from use of sprinklers or drip irrigation technologies show promise for managing water availability during the dry season if adopted by most farmers in this region. Large scale programmes to encourage or incentivise farmers to adopt these technologies are needed.

The positive responses of peanut on sandy soils in Phu Cat to a range of nutrients (K, S) and manure suggests that optimising nutrient supply will depend on an integrated nutrient management approach. A systematic research programme was followed over the years by the project to optimise nutrient and water supply for annual and perennial crops on sands of SCC VN. Such programmes should be carried out in other provinces for range of crops, soils and other variables, such as climatic conditions that affect nutrient supply and water requirements. Technologies for improvements in yield and water savings should be examined in Binh Thuan, Khahn Hoa, Quang Nam, and Quang Nghai provinces in the SCC VN region. Most aspects of the integrated water and nutrient management technology developed in the present project should be applicable also in North-Central Coastal Vietnam.

The low rainfall zone in NT remains a challenge for research and for boosting agricultural productivity. Ninety percent of the farmers in An Hai commune of NT have adopted sprinkler irrigation technology for vegetable production and are beginning to adopt the use of drip irrigation for high value cash crops like asparagus. However, overuse of fertilizers still remains an issue that needs to be managed. We gathered evidence that reduced rates of N and P (the main contaminants found to be a cause of concern in groundwater) without affecting vegetable crop yield. Realising the unpredictable rainfall and limited ground water available for crop production in NT, the Government of Vietnam has allocated a budget for a new dam on the Cai river to divert surface water for irrigation of vegetables and other high value crops in NT. The plans to provide surface water for irrigation in An Hai commune are already well advanced. Secondly, many NT farmers are reliant on livestock production which supports the increased demand for meat consumption in Vietnam. Increased livestock production is another approach to overcome water constraints in low rainfall areas and needs to be further investigated for other low rainfall zones of SCC VN provinces.

The SCC VN needs continued investment in building institutional capability to mount and maintain a research and development programme that improve profitability and sustainability of agriculture in this environment.

Most of the crops in QN province are reliant on rainfall and there is still limited use of irrigation technologies. One of the limitations in the coastal zone of QN is that previous abstraction of ground water for irrigation had a dramatic affect on intrusion of salts from the ocean and hence a ban was placed on over extraction of ground water. Further research is needed to determine whether water efficient irrigation by sprinklers would preserve groundwater levels and hence avoid salt intrusion to the aquifer. These findings would be relevant to the future sustainability of groundwater-dependent irrigated agriculture on a large area of the long coastal zone of central Vietnam.

In NT, nitrate contamination of groundwater was prevalent and attributed to high fertiliser N rates applied on sands and inefficient irrigation practices such as flood irrigation. In Phu Yen, an earlier survey identified nitrate contamination in groundwater. This was attributed to pollution from household sewerage and livestock pen waste. It is recommended that the human health implications of high nitrate in groundwater be investigated more thoroughly in the coastal zone.

To provide effective signals to farmers on water conservation, we support plans of the Government of Vietnam to introduce a water pricing policy by 2020 and its application to groundwater use. The value of water savings reported consistently from our irrigation experiments will have added significance for farmers when water pricing policy (currently planned for implementation by 2022) comes into effect. In addition, given that labour costs are increasing over time, labour-saving irrigation technologies will become more attractive in the farming community.

On-farm demonstration established that sprinklers and drip irrigation were highly profitable for farmers to use. However, the initial investment cost is a barrier. Programmes for provision of credit for purchase of irrigation hardware are urgently needed for SCC VN. The provision of credit needs to be linked to the development of supply chains for irrigation hardware and programmes by DARDs to create more demand for these technologies from farmers.

Research found striking increases in crop yield from amendments of sands such as clay-rich soil, bentonite and sugarcane residue. However, the initial investment cost needs decreased for farmers to adopt these long term approaches to boosting productivity of sands. The provision of credit facilities or low interest loans for farmers should be considered.

In the present study, we were able to develop and water balance model for the La Vi catchment and use this to test various land use scenarios involving change in cropping intensity, and water use efficient crop choices. The usefulness of water balance models for regional land use planning would be enhanced by their application across larger land areas. We propose that the Kone River basin plan be selected to develop a water balance model so that the implications of a broader range of land use options for surface and groundwater sustainability on a greater diversity of soils and landforms can be examined.

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2. Do Thanh Nhan, Hoang Thi Thai Hoa, Hoang Minh Tam. (2018). Effect of Potassium and Sulfur on peanut in sandy soil of Binh Dinh province. Journal of Agriculture and Rural Development. No. 13:41-46.
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5. Hoang Minh Tam, Cai Dinh Hoai and Nguyen Thi Hang Ni (2016) Annual report-ASISOV, results of implementing demonstration model of technologies of water and nutrient management for peanuts.
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11 Appendixes

Appendix 1:

List of project participating staff and organisation

Name	Organization
Prof. Richard Bell	Murdoch University
Dr Surender Mann	Murdoch University
Prof. Okke Batelaan	Flinders University
Dr Margaret Shanafield	Flinders University

Agricultural Science Institute for Southern Central Coastal Vietnam (ASISOV)

Dr Ho Huy Cuong	ASISOV
Dr Hoang Minh Tam (retired 2016)	ASISOV
Mr Pham Vu Bao	ASISOV
Mr Nguyen Thai Thinh	ASISOV
Mr Hoang Vinh	ASISOV
Mr Do Thanh Nhan	ASISOV
Mrs Nguyen Thi Thuong	ASISOV
Dr Vu Van Khue	ASISOV
Dr Nguyen Truong Giang	ASISOV
Mrs Truong Thi Thuan	ASISOV
Mrs Le Thi Trang	ASISOV
Mrs Nguyen Thi Nhu Thoa	ASISOV

Hue University of Agriculture and Forestry (HUAF)

Prof. Hoang Thi Thai Hoa	HUAF
Dr. Nguyen Quang Co	HUAF
Mrs. Tran Thi Anh Tuyet	HUAF
Mr. Do Dinh Thuc	HUAF

Nong Lam University (NLU)

Prof. Nguyen Kim Loi	NLU
Dr Tran Thong Nhat	NLU
Dr Nguyen Duy Liem	NLU

Institute of Agricultural Sciences (IAS)

Dr Nguyen Quang Chon	IAS
Mrs Do Thi Thanh Truc	IAS

Department of Agriculture and Rural Development (DARD), Binh Dinh

Dr Phan Trong Ho	DARD
Mr Đao Van Hung	DARD

Department of Agriculture and Rural Development (DARD), Ninh Thuan

Mr Phan Quang Thuu	DARD

Department of Agriculture and Rural Development (DARD), Quảng Nam

Mr Vo Van Nghi	DARD

Central Vietnam Division of Water Resources Planning and Investigation (CEVIWRPI)

Dr Vu Manh Hai	CEVIWRPI

Mr Duy Le	CEVIWRPI

Department of Natural Resources and Environment(DONRE)

Mr Ho Van Hiep	DONRE

Hue College of Economics (HUE)

Dr Nguyen Nau Chau	HUE
Mr Tuyen Mai Chiem	HUE

Consultants

Dr Ho Thanh Dang	NSW-Primary Industries
Dr Truyen Vo	WA Vegetable Growers Association
Mr Bruce Cussen	ASEAN Irrigation Supplier

Appendix 2:

(1) Approved package of integrated nutrient and irrigation management for peanut production in Binh Dinh province.

UBND TỈNH BÌNH ĐỊNH
SỞ NÔNG NGHIỆP VÀ PTNT

CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập - Tự do - Hạnh phúc

Số: 1053 /SNN-TrTrBVTV
V/v công nhận quy trình quản lý dinh dưỡng, nước tưới tổng hợp cho cây lạc trên đất cát ở tỉnh Bình Định

Bình Định, ngày 29 tháng 3 năm 2017

Kính gửi: Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ

Ngày 20/3/2017 Sở Nông nghiệp và PTNT Bình Định nhận được Công văn số 149/CV-VNTB ngày 15/3/2017 của Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ về việc công nhận tiến bộ kỹ thuật về tưới nước và phân bón cho cây lạc trên đất cát tỉnh Bình Định. Sau khi xem xét, Sở Nông nghiệp và PTNT Bình Định có ý kiến như sau:

1. Đồng ý thông qua kết quả và công nhận "Quy trình quản lý dinh dưỡng, nước tưới tổng hợp cho cây lạc trên đất cát ở tỉnh Bình Định" của Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ.

2. Đề nghị Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ phối hợp với các đơn vị có liên quan tiếp tục bổ sung hoàn thiện "Quy trình quản lý dinh dưỡng, nước tưới tổng hợp cho cây lạc trên đất cát ở tỉnh Bình Định" để được công nhận tiến bộ kỹ thuật theo hướng dẫn của Thông tư số 13/2015/TT- BNNPTNT ngày 25/3/2015 của Bộ Nông nghiệp và PTNT.

3. Sau khi kết thúc phải có nghiệm thu đánh giá kết quả và báo cáo kết quả gửi về Sở Nông nghiệp và PTNT Bình Định (qua Chi cục Trồng trọt và BVTV) để theo dõi, chỉ đạo.

Sở Nông Nghiệp và PTNT Bình Định đề nghị Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ tổ chức triển khai thực hiện đúng các nội dung trên./.

Nơi nhận:
- Như trên;
- Giám đốc Sở (b/c);
- PGĐ Sở phụ trách khối;
- Lưu: VT, CCTrTrBVTV.

KT. GIÁM ĐỐC
PHÓ GIÁM ĐỐC

SỞ NÔNG NGHIỆP VÀ PHÁT TRIỂN NÔNG THÔN TỈNH BÌNH ĐỊNH

Nguyễn Văn Trượng

(2) Approved package of integrated nutrient and irrigation management for mango production in Binh Dinh province.

UBND TỈNH BÌNH ĐỊNH
SỞ NÔNG NGHIỆP VÀ PTNT
Số: 542 /QĐ-SNN

CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập - Tự do - Hạnh phúc
Bình Định, ngày 12 tháng 7 năm 2018

QUYẾT ĐỊNH
Về việc công nhận quy trình kỹ thuật

GIÁM ĐỐC SỞ NÔNG NGHIỆP VÀ PHÁT TRIỂN NÔNG THÔN

Căn cứ Quyết định số 4673/QĐ-UBND ngày 24/12/2015 của UBND tỉnh Bình Định ban hành Quy định chức năng, nhiệm vụ, quyền hạn và cơ cấu tổ chức của Sở Nông nghiệp và PTNT;

Căn cứ văn bản số 123/CV-VNTB ngày 14/3/2018 của Viện Khoa học kỹ thuật nông nghiệp Duyên hải Nam Trung bộ về việc công nhận tiến bộ kỹ thuật về kỹ thuật trồng và thâm canh xoài cát Hoà Lộc tại Bình Định;

Căn cứ văn bản số 1276/SNN-KHKT ngày 18/6/2018 của Sở Nông nghiệp và PTNT về việc thẩm định Quy trình kỹ thuật trồng và thâm canh xoài cát Hoà Lộc tại tỉnh Bình Định;

Căn cứ Biên bản cuộc họp Hội đồng khoa học kỹ thuật lĩnh vực trồng trọt của Sở Nông nghiệp và PTNT ngày 05/7/2018;

Xét đề nghị của trưởng phòng Khoa học kỹ thuật Sở và Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ,

QUYẾT ĐỊNH:

Điều 1: Công nhận Quy trình kỹ thuật trồng và thâm canh xoài cát Hoà Lộc tại Bình Định *(phụ lục kèm theo)*;

Điều 2: Các đơn vị trực thuộc Sở, Viện Khoa học Kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ và các đơn vị liên quan chịu trách nhiệm hướng dẫn, phổ biến quy trình trên áp dụng trong sản xuất;

Điều 3: Trưởng phòng Phòng Khoa học kỹ thuật Sở, Thủ trưởng các đơn vị và lãnh đạo Viện Khoa học kỹ thuật Nông nghiệp Duyên hải Nam Trung bộ chịu trách nhiệm thi hành Quyết định này./.

Nơi nhận:
- Như điều 3;
- Giám đốc;
- PGĐ Sở Đào Văn Hùng,
- Lưu: VT, KHKT.

GIÁM ĐỐC

Phan Trọng Hổ

Appendix 3:

Certificate of Aquatest 3 to improve QA/QC protocols and skills to analyse water, soils, plant and fertilisers for ASISOV staff (example shown)

Appendix 4:

(1) Appoved decision of the People Committee of Binh Dinh province for the Second prize of the Creative Contest(2018-2019)

ỦY BAN NHÂN DÂN
TỈNH BÌNH ĐỊNH

Số: 2855/QĐ-UBND

CỘNG HOÀ XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập - Tự do - Hạnh phúc

Bình Định, ngày 15 tháng 8 năm 2019

QUYẾT ĐỊNH

V/v phê duyệt Giải thưởng cho các giải pháp đoạt Giải Hội thi Sáng tạo Kỹ thuật tỉnh Bình Định lần thứ XI, năm 2018 - 2019

CHỦ TỊCH ỦY BAN NHÂN DÂN TỈNH

Căn cứ Luật Tổ chức Chính quyền địa phương ngày 19/6/2015;

Theo đề nghị của Ban Tổ chức Hội thi tại Tờ trình số 129/TTr - LHH/BTCHT ngày 09/8/2019,

QUYẾT ĐỊNH:

Điều 1. Phê duyệt kèm theo Quyết định này Giải thưởng cho các giải pháp đoạt Giải Hội thi Sáng tạo Kỹ thuật tỉnh Bình Định lần thứ XI, năm 2018 - 2019 của 06 lĩnh vực dự thi, bao gồm: 06 giải nhất, 06 giải nhì, 06 giải ba và 18 giải khuyến khích *(như phụ lục cụ thể kèm theo)*.

Điều 2. Giao Ban Tổ chức Hội thi Sáng tạo Kỹ thuật tỉnh Bình Định lần thứ XI, năm 2018 - 2019 chủ trì, phối hợp với các cơ quan liên quan tổ chức trao thưởng cho các giải pháp có tên tại Điều 1.

Tiền thưởng cho các giải pháp nêu tại Điều 1 thực hiện theo Quyết định số 3310/QĐ-UBND ngày 28/9/2018 của Chủ tịch UBND tỉnh về việc phê duyệt Thể lệ Hội thi Sáng tạo Kỹ thuật tỉnh Bình Định lần thứ XI, năm 2018 - 2019.

Điều 3. Chánh Văn phòng UBND tỉnh, Chủ tịch Liên hiệp các Hội Khoa học và Kỹ thuật tỉnh, Ban Tổ chức Hội thi Sáng tạo Kỹ thuật tỉnh Bình Định lần thứ XI, năm 2018 - 2019 và Thủ trưởng các cơ quan, đơn vị có liên quan chịu trách nhiệm thi hành Quyết định này kể từ ngày ký./.

Nơi nhận:
- Như Điều 3;
- CT, các PCT UBND tỉnh;
- PVP QT;
- Lưu: VT, K16.

KT. CHỦ TỊCH
PHÓ CHỦ TỊCH

Trần Châu

(2) Aproved decision of the 15th National Technical Creativity Contest for the Consolation prize (2018-2019)

LIÊN HIỆP CÁC HỘI KH&KT VIỆT NAM
QUỸ HỖ TRỢ SÁNG TẠO KỸ THUẬT VIỆT NAM (VIFOTEC)

Số : 09 /VP

V/v: Thông báo các công trình đoạt Giải Hội thi Sáng tạo Kỹ thuật toàn quốc lần thứ 15

CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập - Tự do - Hạnh phúc

Hà Nội, ngày 7 tháng 1 năm 2020

LIÊN HIỆP CÁC HỘI KH&KT BÌNH ĐỊNH
ĐẾN Số: 21
Ngày: 15/01/2020
Chuyển: Thục CP.

Thông báo các tác giả biết

Kính gửi: Liên hiệp các hội khoa học & kỹ thuật tỉnh Bình Định

Quỹ Hỗ trợ Sáng tạo Kỹ thuật Việt Nam (VIFOTEC) – cơ quan thường trực của Hội thi Sáng tạo Kỹ thuật toàn quốc lần thứ 15 (2018 – 2019) xin được vui mừng thông báo: Ngày 19/12/1019, Ban Tổ chức Hội thi Sáng tạo Kỹ thuật toàn quốc lần thứ 15 (2018 – 2019) đã họp và thống nhất trao thưởng cho 90 công trình xuất sắc nhất trong đó đơn vị có 03 .. công trình đoạt giải (Có danh sách kèm theo).

Để chuẩn bị tốt cho Lễ tổng kết và trao giải Hội thi Sáng tạo Kỹ thuật toàn quốc lần thứ 15 (2018 – 2019) thời gian tổ chức ngày 14 tháng 4 năm 2020 tại Hà Nội dưới sự chứng kiến của các đồng chí Lãnh đạo cao cấp của Đảng, Nhà nước và các nhà khoa học công nghệ trên toàn quốc, Quỹ VIFOTEC kính đề nghị Qúy cơ quan thông báo và chỉ đạo đơn vị có tác giả đoạt giải phối hợp với Quỹ trong các hoạt động Lễ trao giải diễn ra tốt đẹp

Rất mong nhận được sự hợp tác của Qúy cơ quan!

Nơi nhận:
- Như trên;
- Lưu VP

T/M QUỸ HỖ TRỢ SÁNG TẠO KỸ THUẬT VIỆT NAM (VIFOTEC)
PHÓ GIÁM ĐỐC

QUỸ HỖ TRỢ SÁNG TẠO KỸ THUẬT VIỆT NAM VIFOTEC

Nguyễn Xuân Tiến