IMPACT OF GLOBAL CLIMATE CHANGE AND DESERTIFICATION ON THE ENVIRONMENT AND SOCIETY IN THE SOUTHERN CENTRE OF VIETNAM (CASE STUDY IN THE BINH THUAN PROVINCE)

FINAL REPORT

Anne Gobin, Le Trinh Hai, Pham Ha Linh, Luc Hens, Pierre Ozer, Le Thi Thu Hien, Nguyen Thanh Binh, Pham Quang Vinh

Final report of the bilateral Belgian - Vietnamese project on

"Impact of global climate change and desertification on the environment and society in Southern Centre of Vietnam (case study in Binh Thuan province)"

July, 2012

Table of contents

List of Tables

List of Figures

Impact of global climate change and desertification on the environment and society in Southern Centre of Vietnam
(a case study in Binh Thuan province, Vietnam)

1 Project specifications

1.1 Context

The effects of climate change on terrestrial ecosystems includes drought and desertification. Extended droughts in arid lands have been linked to desertification (Hulme and Kelly 1997, Sivakumar 2007, Wang and Eltahir 2000). Climate change has strong impact on the vegetation cover of drylands since vegetation depends on precipitation, temperature and soil. Human activities intensify the effects of climate change on the environment. The types of vegetation cover in turn affect the lifestyle of the communities that live in the area. Climate change is a major contributing factor to desertification. An increase in weather extremes such as droughts and heavy rains as a result of climate change will lead to further land degradation (UNCCD 2008).

Vietnam is one of the countries in South-East Asia that is severely affected by climate change. The country has about 21 million hectares of agricultural and forest land, and the surface affected by drought is approximately 9.34 million hectares (approx. 45%) of the total agricultural land. Of these, about 7.8 million hectares (or approx. 30% of the total country's agricultural and forest land) are severely degraded. Desertification and drought mainly occurs in the Southern part of Central Vietnam, including the provinces of Binh Thuan, Ninh Thuan, and Khanh Hoa, which cover about 300,000 hectares.

During recent years, the Binh Thuan Province has been seriously affected by prolonged drought. The areas near the coast of this province have an arid and hot climate with an annual rainfall of 500-700 mm in the worst affected areas. The lack of water for households and agricultural production during the 6-month dry season offers a serious threat to rural life. In addition the communities face difficulties due to prolonged droughts that affect all traditional land and water resource uses such as water storage, farming activities, and upland cultivation. In the Binh Thuan province unsustainable farming practices and deforestation are reported as the main reasons for initial land degradation and desertification.

In response to increasing adverse impacts of climate change on desertification, the Vietnamese government has issued a series of policies. In 2006, the "Vietnamese Action Plan against desertification for the period 2006 – 2010 with an outlook to 2020" was adopted. The Decree 1819/QD-BTNMT issued on 16 November 2007 details tasks to respond to global climate change, integrating the global climate change issues into policies, plans, programmes and projects. The next logical steps are to undertake research into the possible impacts of climate change in different regions in Vietnam and translate research results into adaptation and mitigation strategies for sustainable development, which will guide the formulation and implementation of actions on the ground.

A National Conference on "The Vietnamese National Action Plan on Combating Desertification" organised on the 28th June 2007 in Hanoi by the Ministry of Agriculture and Rural Development concluded that there should be more research on the desertification process in Vietnam to build a basis for the action plan to combat desertification.

In December 2008, the approval of the "National Target Program to respond to climate change" took place with 9 tasks and solutions. The programme will be implemented in the period 2009-2015 with the total budget of 1,965 billion VND (more than 85 million EUR). This decision clearly states that the responses to climate change should be organised based on the sustainable development principles and both adaptation and mitigation approaches should be used.

International, regional and Vietnamese studies show that scientific, technological, and policy responses are needed to combat climate change and desertification. In Central-Southern Vietnam, research interests in these subjects is most recent. Projects have been implemented to study climate change and its effects. In these studies, the main focus was on sea level rise, floods, storms, and drought. However systematic and integrated research on desertification and its impacts on the biophysical and social environment, and the policy responses have not fully been done yet. The project aims to address this gap.

1.2 Study Area

Binh Thuan is located in the central part of southern Vietnam. The neighbouring provinces are Ninh Thuan, Lam Dong, Dong Nai and Ba Ria – Vung Tau. It has a total area of 7,971 km^2 and about 250 km of coastline. The province is divided seven districts (Figure 1).

Figure 1 - Location of Binh Thuan province in Southern Vietnam

The province is characterised by an arid and semi-arid climate and around 43.26% of its area is arid or semi-arid. These areas face 6 to 9 dry months per year with less than 500 mm rainfall. The province is also subject to high temperatures and strong winds that contribute to drought and desertification.

The Binh Thuan Province is located in South-Central Vietnam with a total area of 781,292 ha, of which 40% or 313,028 ha is agricultural area and 47% is forest. The 2010 population is 1,171,675 persons and the population density is 150 pers/km².

Drought is a common phenomenon in Binh Thuan for a long time but the situation is worsening during the past 10 years. Two districts in the North-East of the province (Tuy Phong and Bac Binh) are the most affected regions by drought.Lack of water for household use and irrigated agriculture are of serious concern. In 1998 around 203,000 people suffered from severe shortage of drinking water. Drought also threatens 20% to 25% of the cultivated area, and many previously cultivated plots turn are abandoned every year. Sandstorms threaten agricultural fields, villages and roads. Inconsistent short-term land-use and development policies, deforestation for fire and illegal logging, unsustainable cultivation practices, and inefficient water management contribute to drought and desertification in the area.

With climate change the process of desertification in Binh Thuan may increase, which will in turn influence the socio-economic and environmental pattern of the province. It is therefore important to understand the current desertification processes with all the contributing factors accounted for, and to forecast future desertification scenarios such that suitable policies and measures can be put in place to deal with the desertification problem.

1.3 Objectives

1.3.1 General objectives

The main objective of the project is to enhance the understanding of the impacts of drought and desertification using a multi-factorial approach and integrating both biophysical and socio-economical aspects. The results contribute to policy making and to mitigate adverse impacts of the global climate change and desertification on the human welfare in Southern Central Vietnam. The focus is on an adaptation strategy to increase the resilience of the local communities and a more rational use of the agricultural resources in environmental sensitive areas.

1.3.2 Specific objectives

To realise these general targets, the project entailed four major work packages. A fifth package integrates the results and lists the main conclusions and recommendations of the project as a whole. The specific objectives for each of the work packages are:

WP1: describing and analysing the primary information for indicators and related aspects of desertification in Binh Thuan. More specifically this WP allows:

- collecting physical and social-economic data related to desertification and drought;
- selecting indications on natural and human impacts of desertification and drought;
- establishing a database relating data and indicators to desertification and drought.

WP2: assessing the current status of drought stress in Binh Thuan based on the (long term) analysis of meteorological data, land use changes and drought characteristics. The WP equally aims at forecasting drought related climate parameters. More specifically this WP allows.

- identifying the impacts of these factors and characteristics which contribute to drought;
- identifying the impacts of these factors and characteristics on drought and desertification in the future. Special attention is given to the meteorological and hydrological aspects and soil sensitivity to vole gradation in the study area.

WP3: studying the impacts of drought stress on selected socio-economic aspects: water availability and accessibility, shifts in agricultural crops, income, expenses, poverty and migration. These aspects are framed in the bio-physical and general socio-economic background of the province.

WP4: concluding on policy measures based on an analysis of integrated and complementary policy assessment methods. More specifically this WP offers:

- a synthesis of the natural, environmental and socio-economic factors related to drought;
- a recommended list of adaptation strategies to cope with changes in desertification at the provincial and local scale;
- a recommended list of adaptations for local stakeholders, including policy makers.

WP5: providing an executive summary of the aims, methods, results, managerial aspects and conclusions of the projects as a whole. The conclusions make a distinction between general, research and policy conclusions.

1.4 Overall methodology

The project adopted a working framework (Figure 2) that shows the interlinkages between the different project components each addressing specific objectives. In addition, the results of each work package is used by other work packages.

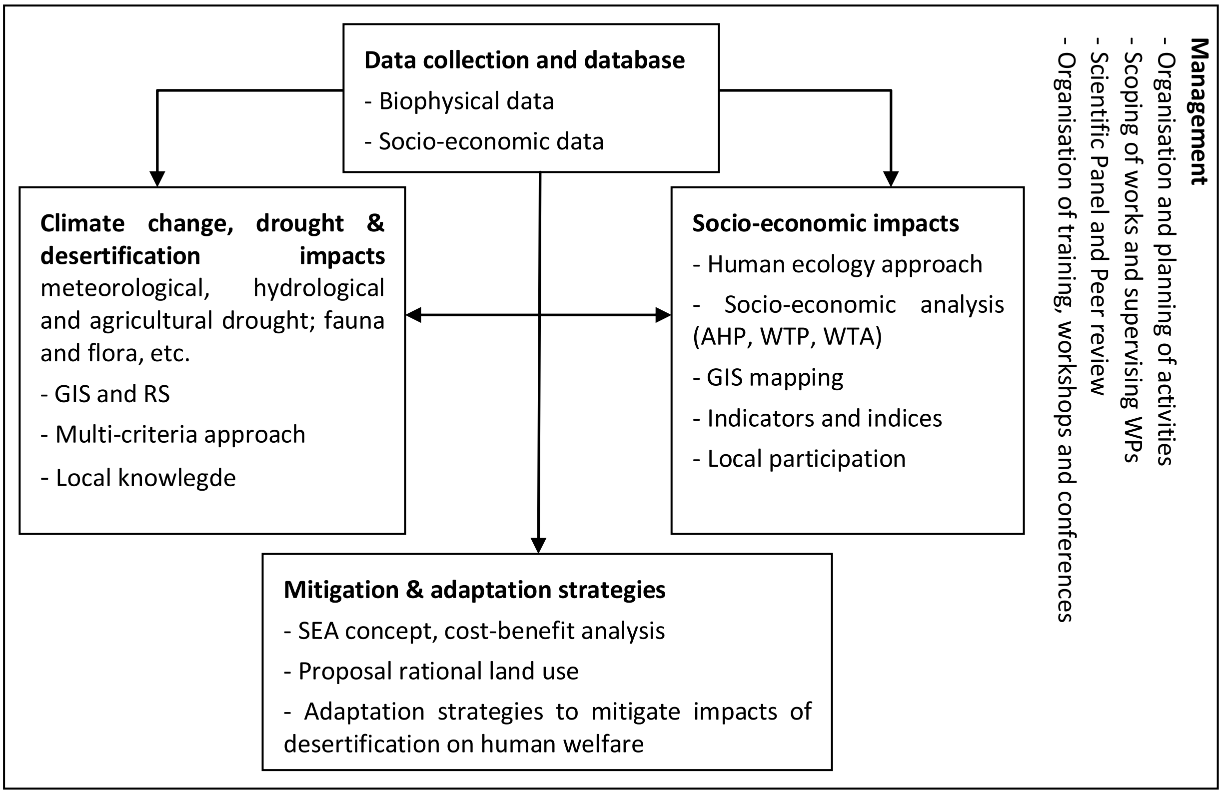


Figure 2 Working framework of the project.

2 Geo-atlas for the Binh Thuan Province (WP1)

2.1 Methodology

2.1.1 Data collection

- Primary data collection in the study area included geodata on hydro-meteorology, land cover, land use, land use changes, cultivation methods, soil quality, topography, geology, geomorphology, hydrology, and other data related to desertification processes and climate change. Existing maps, satellite and aerial photos are collected and processed in a geodatabase.
- Statistics were obtained on demography, economics, health, agriculture and education;
- Five field trips allowed to accomplish the following tasks:
  - ✓ Soil and water samples were collected for the analysis of the physical chemical parameters;
  - ✓ 208 household questionnaires were completed mainly targeted at the analysis of the socio-economical situation of the families;
  - ✓ Semi-structured interviews were organised with the provincial and district authorities, local scientists, government officials from the water board and farmers;
  - ✓ Farmers' interviews were conducted along transects throughout the worst affected villages and districts;
  - ✓ Hydro-meteorological data were collected for the period 1976-2009 in two stations in Binh Thuan and 4 stations in the vicinity;
- Secondary data:
  - ✓ Literature and official statistics on topography, geomorphology, hydrology, vegetation, soil, land use, drought, biological resources, sensitive areas;
  - ✓ Overview of the 3 published IPCC climate change scenario's currently in use in Vietnam by the Ministry of Natural Resources and the Environment (MONRE).

2.1.2 Relational geo-database

A geodatabase was established to accommodate all spatial data obtained for the Binh Thuan Province. A geodatabase is the common data storage and management framework for GIS and it combines spatial reference ("geo") with a data repository ("database") to create a central data repository for spatial data storage and management. Within a map frame, geographical entities are presented as a series of thematic map layers that cover a given map extent. Thematic map layers from the Binh Thuan province were obtained from the Geographic Institute of the Vietnam Academy of Science and Technology (VAST).

Different thematic layers were made available in different projection systems and in different GIS file formats (e.g. Micro Station, MapInfo, tables with lat/lon coordinates), resulting in a variety of different inputs to the geodatabase. The different spatial data were available as base maps at 1:100000 and 1:50000 scale. Base maps encompassed the administrative boundaries at province, district and community level; the location of weather stations; topography and river network; vegetation and land use; geology, geomorphology and hydrology; irrigation and drainage networks; transportation network.

Each base map layer consists of discrete features such as collections of points, lines and polygons. Since accurate location forms the basis for all GIS operations, first order data processing consisted of projecting all thematic map layers and features in one common coordinate system, i.e. WGS 1984 UTM Zone 48N, to integrate and combine information from the multiple map layers. The attributes of each feature are stored in tables which are based on relational database concepts enabling coupling through common fields. The tables attached to each map layer were uniformed according to data type (e.g. integer, string). All data and fields were translated from Vietnamese to English. A quality assessment and quality control of the table content entailed an iterative process which involved numerous communications with the Geographic Institute of VAST where the data originated from.

Further spatial analysis of the base maps enabled the production of Digital Elevation Model (DEM); hydro-meteorological maps; prediction maps of drought; prediction map of soil degradation and desertification; and maps of drought prediction. Statistical data on population, economics, health and education were coupled to the base map tables and enabled further analysis into environmentally sensitive area (ESA) maps.

Because layers are spatially referenced, they overlay one another and can be combined in a common thematic map displays.The design and data storage in the geodatabase was accomplished using both MapInfo for the base maps at VAST in Vietnam and ArcGIS for further processing at VITO in Belgium. The geodatabase was subsequently used for all the other analysis required within the project.

2.2 Results

2.2.1 GIS database

The GIS database contained the following information:

- Topography: elevation data, slope, angle;
- Geology: geo-morphology, hydrogeology, groundwater, water analysis data;
- Soil: composition, depth transects, texture, moisture, soil analysis data;
- Hydrology: surface water, water flows, water reserves, water capacity;
- Climate: rain, wind, temperature, evapotranspiration, (30 years period; 6 climate stations);
- Vegetation: spatial distribution of plants and forests;
- Land use (2005, 2010);
- Basic socio-economic data: population, population density, ethnicity, agricultural crops economics, education, health care (1995-2012).

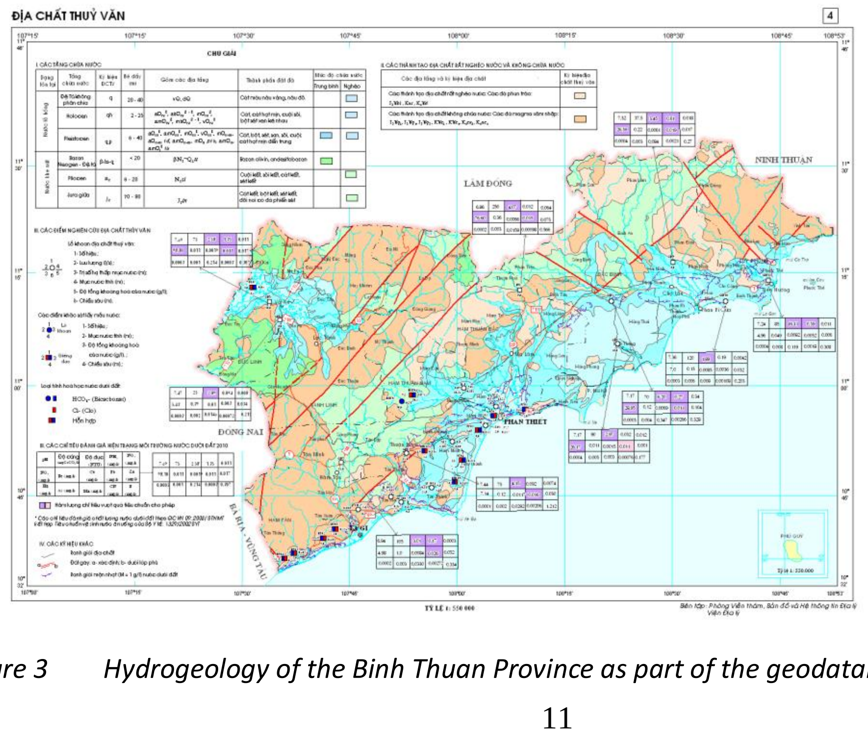


Figure 3 Hydrogeology of the Binh Thuan Province as part of the geodatabase.

2.2.2 Atlas: 25 maps

- Climate change: temperature, rainfall, start and end of the rainy and dry seasons;
- Drought: meteorology, hydrology, agriculture, water, changes in forest cover, distribution of related plant species, land degradation, desertification;
- Water resources: flows during the dry season, crop losses and drought;
- Agriculture: crop changes, productivity loss;
- Socio-economics: water scarcity, income, poverty, migration;
- Mitigation: priority projects, irrigation, groundwater use. Maps for the province are at a scale 1:100000. Maps for the Tuy Phong and Bac Binh districts are at a scale 1: 50000.

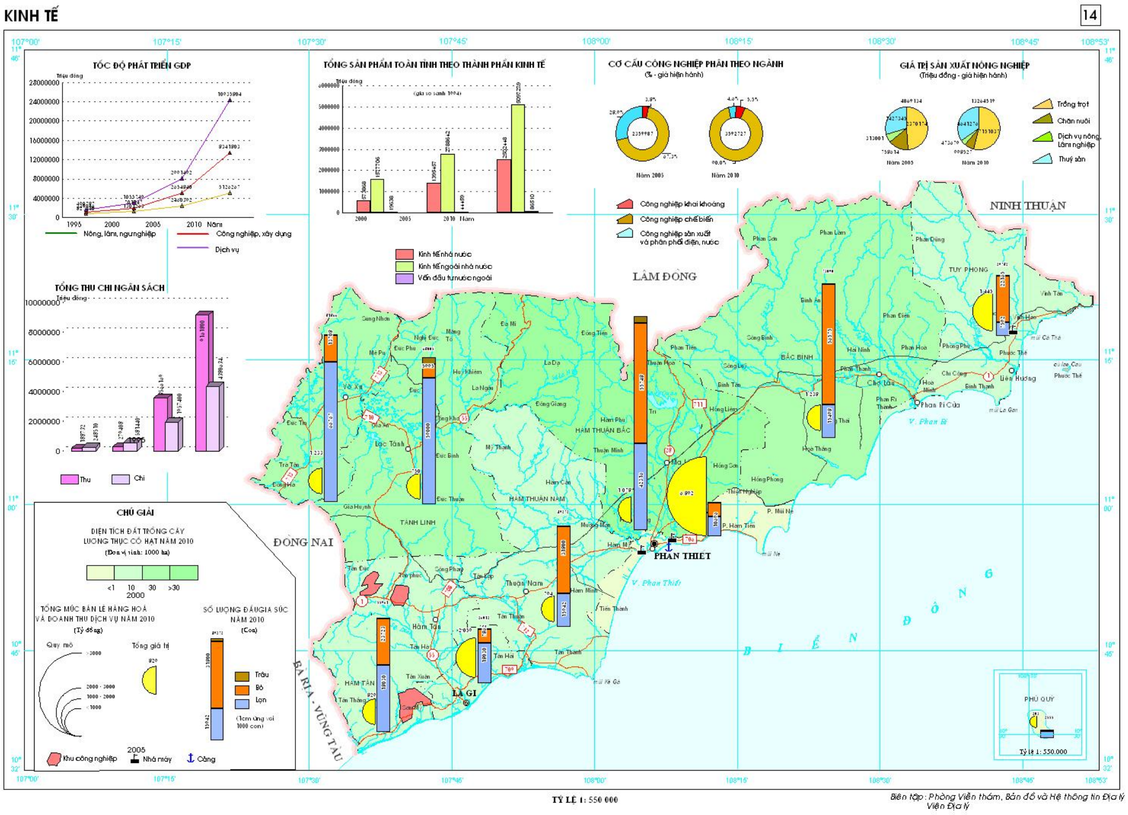


Figure 4 Economics and major production (predominantly agriculture) of the Binh Thuan Province as part of the geo-atlas.

2.2.3 Framework for Environmentally Sensitive Areas

Different factors contributing to desertification were integrated such that environmentally sensitive areas (ESAs) prone to desertification could be spatially delineated. This method allows for policy analysis in a what if frame and projection of potential vulnerable areas under future climate change in Binh Thuan Province of Vietnam. The different factors that determine ESAs in the region, are climate, topography, geology, soil, vegetation, water resources and human activities. Each of these factor comprise several subfactors that are combined into indices according to the scheme presented in Figure 5. Four types of ESAs are distinguished: critical, fragile, potential and non-ESA according to the classification put forward by the MEDALUS project.

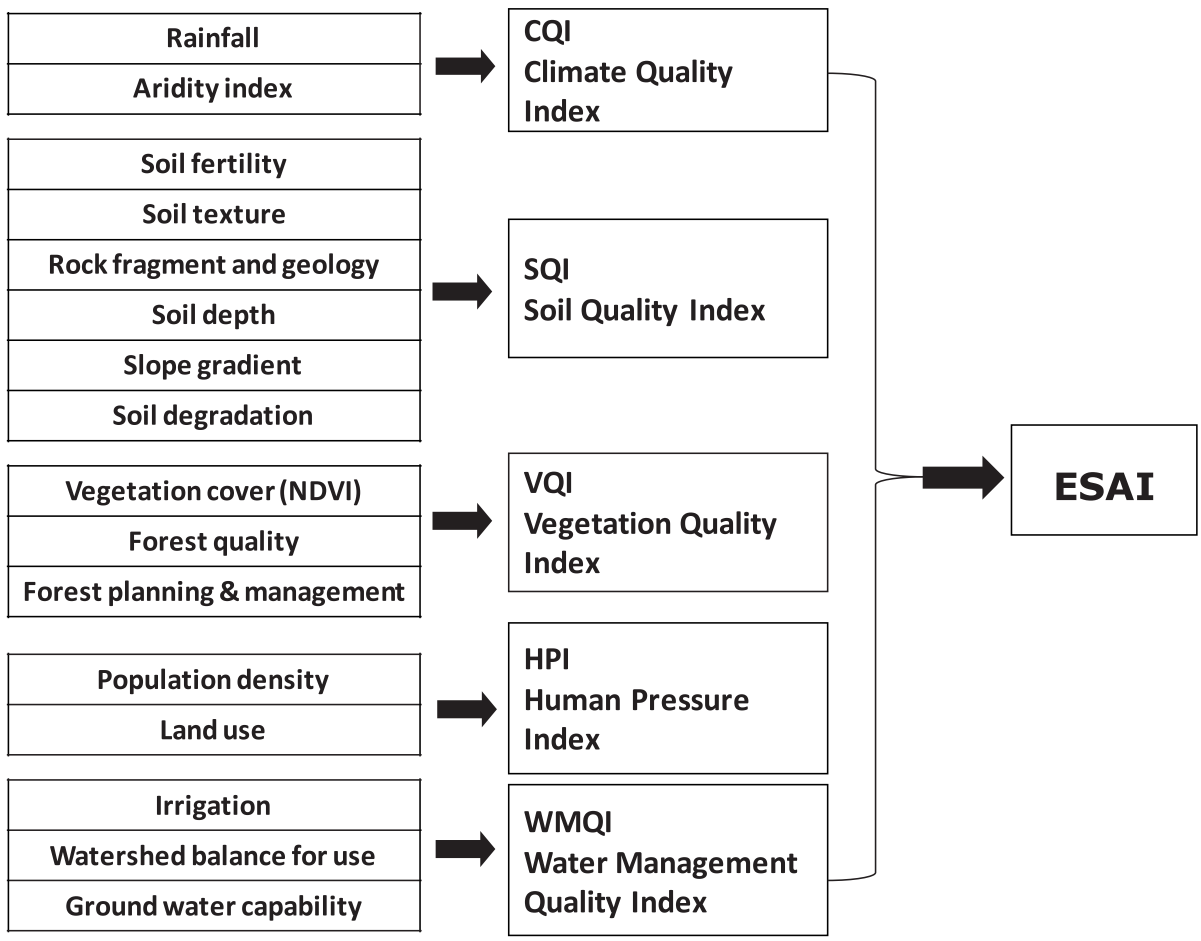


Figure 5 Spatially distributed factors for delineating environmentally sensitive areas to desertification

Currently, Binh Thuan has two types of ESAs - Fragile and Potential, and these are encroaching the centre and southeast, and the trend seems increasing to critical ESA type with three types of ESAs; in the northeast the trend is decreasing. The key factors to desertification are drought (or aridity index), soil texture and water availability (Figure 6).

An overlay analysis of the desertification map with population density and land use demonstrates that the most vulnerable areas are located in the human settlements along the coastal areas of the Northern districts of Tuy Phong, Bac Binh and the centre of Ham Thuan Bac. The trend, however, is towards the southwest (in Ham Thuan Nam and NaGi).

The approach of using ESAs (environmental sensitive areas) to describe current and projected desertification is suitable for the Binh Thuan Province. Moreover, the method allows for uncovering the key factors that contribute to desertification and for projecting trends as demonstrated through including different climate and land use scenarios. The established approach is a powerful decision support system for policy makers of the Binh Thuan Province.

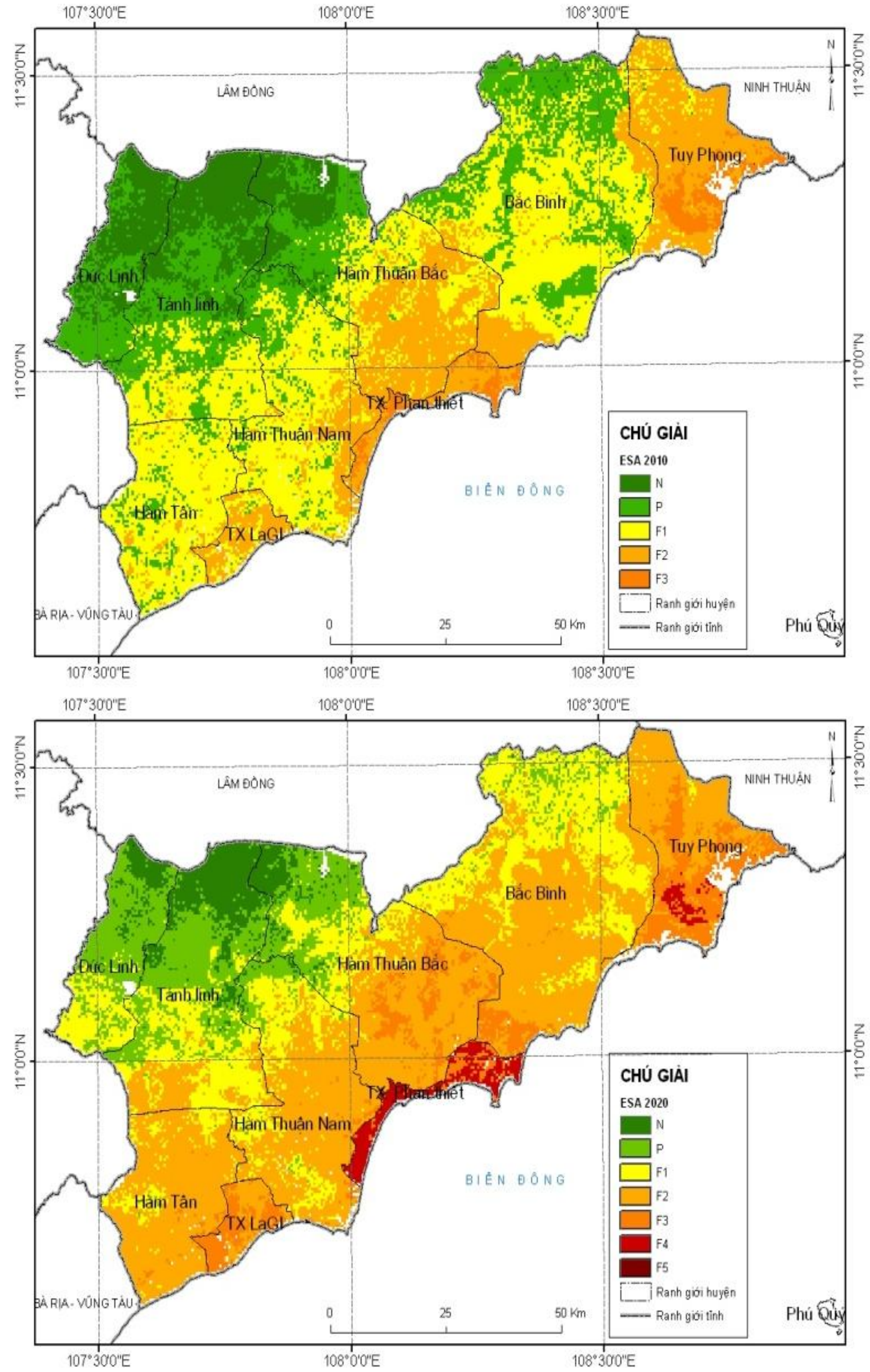


Figure 6 Environmentally Sensitive Areas to desertification as calculated for 2010 (top) and under projected climate change (2030).

2.3 Conclusions

- The two most North – Eastern districts (Bac Binh and Tuy Phong) of the province are most vulnerable to drought;
- More data are available on the bio-physical than on the socio-economic aspects of Binh Thuan;
- Meteorological data are available for a period of 30 years (1978-2009). This should be sufficient to reflect climatic changes, that according to Vietnamese researches, become manifest from 1990 – 1995 on. However as compared to the international literature, this period is short;
- Application of the IPCC drought scenario's to Binh Thuan shows that the province will face less rain and more extreme climate events during the decades to come;
- Coastal groundwater resources are threatened by salinisation.
- Four ecosystems have been described: the coastal area, the sand dune ridge, the agricultural belt and the forest. In particular this latter was described in terms of biodiversity.
- Different types of environmentally sensitive areas are described in the Binh Thuan Province: critical, fragile, potential and not sensitive;
- Technical and managerial options to cope with drought are proposed. Among the technical ones are more efficient irrigation systems and rational water use.
- Among the managerial options, specific attention is paid to the selection of crops in association with the soil type and the varying onset and duration of the rainy season.

2.4 References used for this chapter

Le Thi Thu, H., Gobin, A., Huong, P.T.T., 2012. Indicators of environmentally sensitive areas (ESA) to desertification in the Binh Thuan province, Vietnam. In preparation.

Pham Quang, V., Le Thi Thu, H., Gobin, A., 2012. A geo-atlas of Binh Thuan Province, Vietnam. Poster presented at the final workshop of the project held on 15 March 2012 at Belspo, Brussels.

3 Climate modelling (WP2.1)

3.1 Methodology

Data used for climate change detection were collected from the **weather station of Phan Thiet**. They cover the 1978-2007 period for daily rainfall and the 1979-2007 period for daily minimum, maximum and mean temperatures.

In order to assess recent changes in rainfall, **several indices** were calculated and analysed: annual total precipitation, monthly total precipitation, number of wet days, annual number of very heavy and extremely heavy precipitation days and annual maximum 1-day precipitation amount. For minimum, maximum and mean temperatures, only annual and monthly averages were analysed (Table 1). A much more detailed analysis of precipitation and temperature extremes could have been performed based on percentile but the relatively short period of available data made it impossible since at least 30 years of data are needed to do so.

Table 1 Precipitation and temperature indices with their definitions and units

Index	Indicator name	Definition	Unit
PRCPTOT	annual total precipitation	annual total precipitation	mm
PRCP[Jan-Dec]	monthly total precipitation	monthly total precipitation from January to December	mm
WDAY	number of wet days	annual count of days with precipitation >= 1mm)	days
RX1d	max 1-day precipitation amount	annual maximum 1-day precipitation	mm
R20mm	number of very heavy precipitation days	annual count of days when precipitation >= 20mm	days
R50mm	number of extremely heavy precipitation days	annual count of days when precipitation >= 50mm	days
ATN	average annual Tmin	annual average value of daily minimum temperature	°C
ATX	average annual Tmax	annual average value of daily maximum temperature	°C
ATM	average annual Tmean	annual average value of daily mean temperature	°C
ATN[Jan-Dec]	average monthly Tmin	monthly average value of daily minimum temperature from January to December	°C
ATX[Jan-Dec]	average monthly Tmax	monthly average value of daily maximum temperature from January to December	°C
ATM[Jan-Dec]	average monthly Tmean	monthly average value of daily mean temperature from January to December	°C

For each index, **trends** from 1978 (1979) through 2007 were estimated by linear regression with time (years) as independent variable. The regression slopes were recorded either for the rainfall or for temperatures indices and were qualified in five classes indicating highly statistically significant or statistically significant positive or negative and stable trends. The regression procedure supplies a Student t-test and its resulting significance p-level to analyze the hypothesis that the slope is equal to 0. This p-level was used as a criterion to define the class boundaries. The trends for the parameters were labeled as ‘highly statistically significant’ if the p-level exceeded 0.01 for the one-tailed t-test, ‘statistically significant’ if the p-level is ranged between 0.01 and 0.05 and otherwise ‘stable’ if the p-level is up to 0.05.

The **ECMWF and NCEP-NCAR reanalysis models** are global models which calculate the past climate with a forcing of meteorological observations including radiosondes, balloons, aircraft, buoyes, satellites, scatterometers. The reanalysis is the best available representation of the past climates. In this study, we used the 30-year period extending from January 1970 through December 1999. The advantages of using such datasets is that the entire world is covered by one set of meteorological data. The disadvantage is that data over one region are interpolated compared with the real observation data in a meteorological station. The interpolation is proportional to the spatial resolution of the model (see Table 1). The local observations represent the climate of one site and are very difficult to apply to an entire region because site measurements have specific characteristics that may not be similar to the surrounding area. Therefore we rather compare two models and not local observations with a global model.

The **IPCC has selected 24 models** in its last report (Table I) that are forced by none observational data. All of these models have initial conditions, which are created randomly and upon which runs are based until they equilibrium conditions reached. According to their internal configurations, the models are different and may not be consistent with the real climate. Each IPCC selected model has a different spatial resolution (Table I) which in turn affects data interpolation. Some models have a relatively precise spatial resolution, e.g. INGV model, other models have a coarse spatial resolution, e.g. GISS–EH model with. The IPCC models have different time hirozons. Firstly, the IPCC models have a scenario called 20C3M which calculates past climate over the 1961-2000 period. As mentioned above, we used this scenario over the 1970-1999 period in the two sorting to compare with the reanalysis models. Secondly, the IPCC models forecast different time periods in the future using different scenarios. In this work, we used the 20-year periods 2046-2065 and 2081-2100 for three different scenarios: B1, A1B, A2. So we eliminated two intermediate scenarios (B1 and A1T) as well as the worst case scenario (A1FI) although recent trends in global GHG emissions show that the latter scenario is far from being unlikely.

In order to project future temperatures and precipitations in South-Eastern Vietnam during the 21st century, output from climate models selected by the IPCC were used. The first step was to test the ability of each model to **simulate the past climate** (1970-1999) in South-Eastern Vietnam in order to select the best models. The second step was to use the future projections of these selected models to obtain future trends of temperatures and precipitations. Tests were performed on the 24 different models available. From the beginning, we rejected the BCCR, INMCM, HADCM3 and HADGEM1 models because all required data for this study were not available. All models are not suitable to analyse the future projections. So, the first step was to sort them and select the models which best simulate past climate in the Province of Binh Thuan. For this aim, we compared the IPCC models with the ECMWF and NCEP-NCAR reanalysis. We sorted the models two successive steps. The first sorting was performed to eliminate the worst models and the second sorting was done to keep the best models and obtain some models from which we used the projections of future climatic parameters and their evolutions.

For the first sorting, we used daily data of the IPCC models, the ECMWF and NCEP-NCAR reanalysis during the 1970-1999 period. For each IPCC model, we calculated the monthly mean temperature at 2 meter-height and the monthly sum of precipitations. We also calculated the monthly standard error (σ) of temperatures and precipitations for the reanalysis models. Then we plotted the IPCC models data on a climograph with superimposed ±2σ results of each reanalysis model. The method to retain the most appropriate IPCC models for the region was based on the correspondence between temperature and rainfall curves during both the dry and wet seasons as defined by a ±2σ deviation from the reanalysis models. The IPCC models that fitted the criteria were retained for further processing. Future climate projections (i.e. 2046-2065 and 2081-2100) were compared to historical data 1970-1999) through assessment of climate statistics (annual mean temperature, annual amount of precipitation, standard deviation of temperature and precipitation, maximum and minimum of temperature and precipitation) and analysing the beginning and the end of the rainy season.

Table 2 Models and reanalyses used in this study with their short name and spatial resolution. Data source: the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3).

Data name	Short name	Spatial resolution
BCCR–BCM2.0	BCCR	$2.8^\circ \times 2.8^\circ$
CCCMA–CGCM3.1(T47)	CCCMA–T47	$3.7^\circ \times 3.7^\circ$
CCCMA–CGCM3.1(T63)	CCCMA–T63	$2.8^\circ \times 2.8^\circ$
CNRM–CM3	CNRM	$2.8^\circ \times 2.8^\circ$
CSIRO–Mk3.0	CSIRO–0	$1.9^\circ \times 1.9^\circ$
CSIRO–Mk3.5	CSIRO–5	$1.9^\circ \times 1.9^\circ$
GFDL–CM2.0	GFDL–0	$2.6^\circ \times 2.0^\circ$
GFDL–CM2.1	GFDL–1	$2.6^\circ \times 2.0^\circ$
GISS–AOM	GISS–AOM	$4.0^\circ \times 3.0^\circ$
GISS–EH	GISS–EH	$5.0^\circ \times 4.0^\circ$
GISS–ER	GISS–ER	$5.0^\circ \times 4.0^\circ$
IAP–FGOALS–g1.0	IAP	$2.8^\circ \times 2.8^\circ$
INGV–SXG	INGV	$1.1^\circ \times 1.1^\circ$
INM–CM3.0	INMCM	$5.0^\circ \times 4.0^\circ$
IPSL–CM4	IPSL	$3.8^\circ \times 2.5^\circ$
MIROC3.2 (hires)	MIROC–HR	$1.1^\circ \times 1.1^\circ$
MIROC3.2 (medres)	MIROC–MR	$2.8^\circ \times 2.8^\circ$
MIUBECHO-G	MIUB	$3.7^\circ \times 3.7^\circ$
ECHAM5/MPI–OM	MPI	$1.9^\circ \times 1.9^\circ$
MRI–CGCM2.3.2	MRI	$2.8^\circ \times 2.8^\circ$
NCAR–CCSM3	CCSM3	$1.4^\circ \times 1.4^\circ$
NCAR–PCM1	PCM1	$2.8^\circ \times 2.8^\circ$
UKMO–HadCM3	HADCM3	$3.8^\circ \times 2.5^\circ$
UKMO–HadGEM1	HADGEM1	$1.9^\circ \times 1.2^\circ$
ECMWF 40 Year Reanalysis	ERA–40	$1.1^\circ \times 1.1^\circ$
NCEP/NCAR Reanalysis 1	NCEP1	$2.5^\circ \times 2.5^\circ$

3.2 Results

3.1.1 Trends for Phan Thiet Meteo Station

Trends were performed for all precipitation indices over the 1978-2007 period. The annual total precipitation has increased by 10.8% or 117.6 mm over the 30-year period, but this is a statistically insignificant change (Table 3). The dataset presents only four years of drought (that is >= 1 standard deviation below average). Monthly precipitations during the rainy season (May to November) show different trends: declining during June and October, increasing during the months of May, July, August, September and November. Only May presents a statistically significant increasing trend in precipitations. For the other indices: number of wet days, annual number of very heavy and extremely heavy precipitation days and annual maximum 1-day precipitation amount; no particular changes are noticed.

Table 3 Trends of precipitation indices (= statistically significant; NA = no application).*

Index	Average [1978-2007]	Absolute trend [1978-2007]	Trend % [1978-2007]
PRCPTOT	1150,9	+117,6	+10,8
PRCP-Jan	0,2	+0,5	NA
PRCP-Feb	0,2	+0,2	NA
PRCP-Mar	7,8	-18,2	NA
PRCP-Apr	26,1	+3,5	NA
PRCP-May	159,9	+94,4	+86,3 *
PRCP-Jun	156,6	-61,5	-32,4
PRCP-Jul	181,6	+43,1	+27,2
PRCP-Aug	181,8	+35,8	+22,0
PRCP-Sep	193,1	+23,6	+13,1
PRCP-Oct	157,4	-92,1	-44,6
PRCP-Nov	66,9	+58,2	+162,7
PRCP-Dec	19,2	+30,1	NA
WDAY	86,7	+1,6	+1,9
RX1d	87,4	-2,1	-2,3
R20mm	17,6	+1,0	+5,6
R50mm	3,0	+0,8	+31,6

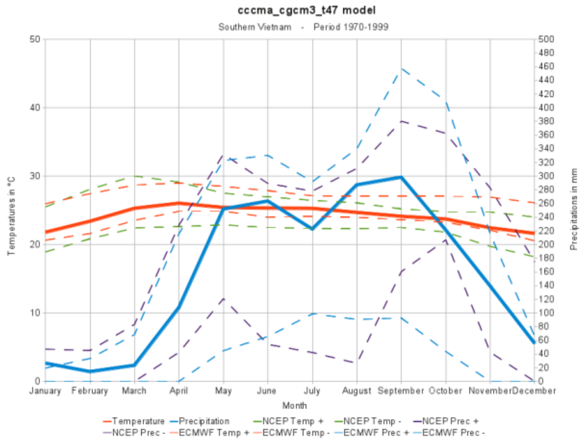
Minimum, maximum and mean temperatures trends were analysed at both annual and monthly scales (Table 4). Annual Tmin, Tmax and Tmean all increased at a rate of +0.30, +0.15 and +0.22°C per decade, all statistically significant. At the monthly scale, all Tmin, Tmax and Tmean present increasing trends over the 1979-2007 period with the exception of Tmax for the months of July and August which present an insignificant decrease of 0.04 and 0.02°C per decade. The largest increases are observed in January and December for Tmin with over +0.7°C per decade.

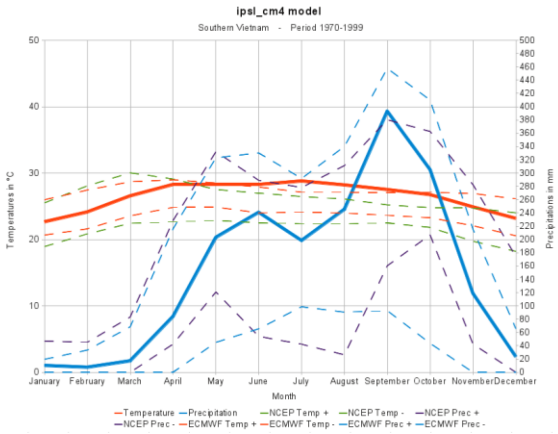
Table 4 Trends in temperature indices (& ** = statistically & highly statistically significant).*

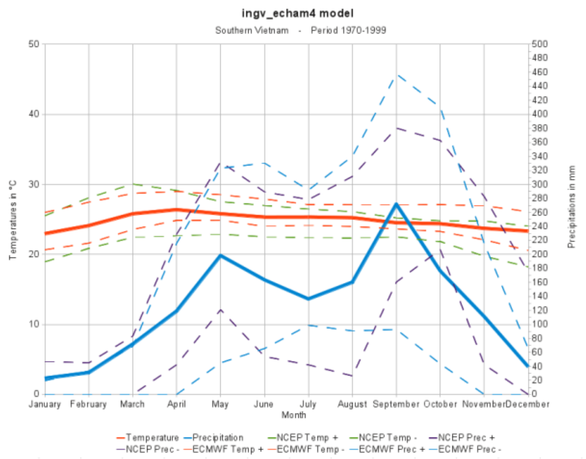
Index	**Average [1979-2007]**	**Trend (°C per 10 years)**	**Index**	**Average [1979-2007]**	**Trend (°C per 10 years)**
ATN	24,0	+0,30 **	**ATX**	31,2	+0,15 *
ATN-Jan	21,4	+0,72 **	**ATX-Jan**	29,4	+0,22
ATN-Feb	22,1	+0,38 *	**ATX-Feb**	29,8	+0,17
ATN-Mar	23,7	+0,47 **	**ATX-Mar**	30,8	+0,15
ATN-Apr	25,5	+0,15 *	**ATX-Apr**	32,2	+0,22
ATN-May	25,8	+0,04	**ATX-May**	32,9	+0,13
ATN-Jun	25,3	+0,15	**ATX-Jun**	32,3	+0,24
ATN-Jul	24,7	+0,10	**ATX-Jul**	31,6	-0,04
ATN-Aug	24,7	+0,03	**ATX-Aug**	31,5	-0,02
ATN-Sep	24,6	+0,20 **	**ATX-Sep**	31,5	+0,23
ATN-Oct	24,3	+0,18 *	**ATX-Oct**	31,1	+0,22 *
ATN-Nov	23,4	+0,23	**ATX-Nov**	30,9	+0,03
ATN-Dec	22,0	+0,73 **	**ATX-Dec**	30,0	+0,29 *

3.1.2 Climate projections for Phan Thiet Meteo Station

Future projected changes in climate statistics for periods 2046-2065 and 2081-2100 compared to past records (1970-1999) were performed for the three selected IPCC models using scenarios A1B, A2 and B1 (Figure 7). All models under different scenarios agree that extreme maximum temperature and rainfalls (99th percentile) will increase in the Province of Binh Thuan.







The continuous blue and red curves represent monthly precipitations and temperatures of the models. The discontinuous blue and violet curves represent the ±2σ monthly precipitations in the ECMWF and the NCEP-NCAR reanalysis models. The discontinuous red and green curves represent the ±2σ monthly temperatures in the ECMWF and the NCEP-NCAR reanalysis models [*].

Figure 7 Climographs of the 3 selected IPCC models with the reanalysis models error curve of ±2σ.

The analysis of the length of the rainy season indicates that the dry season is likely to be longer in 2046-2065 owing to a delay in the onset of the rainy season (up to 15 days) accompanied by an earlier end of the rainy season (up to 30 days). The annual rainfall total will remain stable but the seasonal distribution of rainfall will change for both the 2046-2065 and 2081-2100 periods (Figure 8).The future climate of the Province of Binh Thuan will therefore be characterised by a longer dry season and rainfall concentrated in the summer with an increase in extreme rainfall events.

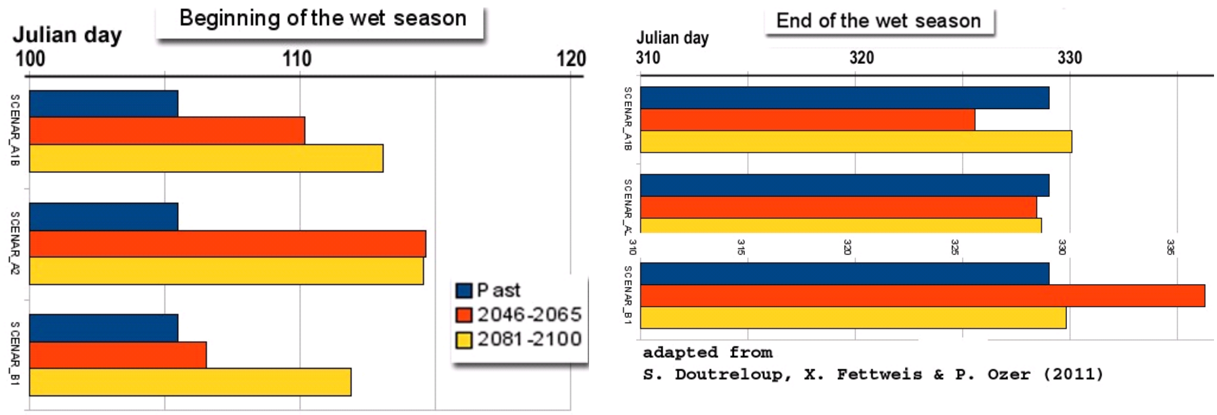


Figure 8 Projected beginning and end of the wet season for Phan Thiet station.

3.3 Conclusions

The assessment of climate change was based on historical climate records (1970 – 1999) and projections for the future (2046-2065; 2081-2100). The following conclusions could be made:

- All precipitation indices calculated for Phan Thiet indicate a relative stability over the past three decades. Only the number of extremely heavy precipitation days (R50mm) has increased by 31.6% but the trend remains not statistically significant. The statistically significant increase at a rate of +0.30°C for Tmin, +0.15°C for Tmax and +0.22°C for Tmean per decade, is inaccordance with recent studies in southeast Asia.
- Binh Thuan experiences a rainfall of an average 1130 – 1340 mm per year, which might drop during the next decades. 90% of this rain is provided during the wet season. An increase in the duration of the dry season is forecasted for the period 2046-2065.
- An increase of the average temperature of 1.6 °C (by 2046-2065) to 2.5° C (by 2081-2100) is projected. Extreme temperatures and rainfall events need to be taken into account. In combination with the declining rainfall, this well intensify drought.
- The general climate that emerges from this analysis is that Binh Thuan is a dry area and among the driest in Vietnam. However, the historical data do not point to more droughts during the past 30 years. On the other hand, climate models allow projecting an increase in temperature, less rain, a longer dry period and more extreme weather events.

3.4 References used for this chapter

Doutreloup, S., Erpicum, M., Fettweis, X., & Ozer, P., 2011. Analysis of the past (1970-1999) and future (2046-2065 and 2081-2100) evolutions of precipitation and temperature, in the Province of Binh Thuan, South East Vietnam, based on IPCC models. Proceedings of the 1st International Conference on Energy, Environment and Climate Change, August 26-27 2011, Ho Chi Minh City, Vietnam. Available at http://hdl.handle.net/2268/96759

Ozer, P., 2011. Recent trends and perceptions of 'climate change' in the Binh Thuan Province, Vietnam (1978-2007). WP2.1 Report.

4 Drought and agricultural impact (WP2.2)

4.1 Methodology

Daily **meteorological data records** from six weather stations (Table 1) were collected from the Vietnam Institute of Meteorology Hydrology and Environment. Out of the six stations, one station had data for 30 years (Bao Loc station), one station had data for 18 years (Xuan Loc station), one station had data for 15 years (Phanrang station) and for the remaining stations the data period was 28 years (Nha Trang, Phan Thiet and Vung Tau stations). Baoloc and Xuanloc stations are humid (average annual rainfall is more than 2000 mm). Phan Rang and Phanthiet stations are dry (i.e. in 2004, average annual rainfall is only 803 mm). Phan Rang and Phan Thiet are the driest stations in Vietnam. The Phanthiet station is representative for the dry climate of the Binh Thuan province. The entire data set was subjected to quality control checks. The data consists of daily of air temperature (maximum and minimum), daily air humidity (average relative and minimum), daily sunshine duration, total of daily rainfall and daily wind speed maximum. The FAO modified Penman-Monteith evapotranspiration (ET0) was calculated using the ET0 calculator software. The aridity index (AI) was calculated as the ratio between average annual precipitation and reference evapotranspiration. Values below 0.2 are classified as arid, between 0.2 and 0.5 as arid, between 0.5 and 0.65 as dry subhumid, between 0.65 and 1 as subhumid and above 1 as humid. The rainfall intensity (RI) was defined as the square root of monthly rainfall devided by the annual rainfall with higher values corresponding to higher rainfall intensities. The length of the humid period (or wet period) is taken as the period (in days) during which the precipitation (P) exceeds half the potential evapotranspiration (ET0). In addition, the rainfall data were subject to homogeneity tests prior to determining probabilities of exceedance and selecting dry (P20), mean (P50) and wet (P80) years for rainfall. The results were also interpolated in a GIS.

Soil water balances were calculated using the daily climatic data of of Phantiet and Xuanloc to assess the drought stress and risk for salinisation and alkalinisation. We considered a growing period of 120 days, a maximum rooting depth of 60 cm, and a moderate tolerance level to water stress (drought) for two soil types:

- ✓ A clayey soil with as soil texture sandy loam in a layer from 0-20 cm; sandy clay loam for a depth from 20 to 100 cm; and sandy clay for a depth of 100-200 cm. Such a pattern of soil texture would be typical for the Ferralsols and most of the Acrisols. These are the most common soils types on the well drained parts of the mountains and inland plains.
- ✓ A sandy soil with a sandy texture for the upper 20 cm, and a loamy sand texture for the depth of 20-200 cm. These textures would be typical for the Arenosols commonly found along the coast of the study area.

The onset of the growing season was taken as any period with a cumulative rainfall of at least is 50 mm, starting after the 1st May.

Analysis of the agro-climatology for 6 weather stations within or in the close vicinity of the Binh Thuan Province and water balances run for typical soil profiles enabled an assessment of the most **vulnerable soils** in the area as well as the susceptibility of soils to natural hazards such as desertification, drought, erosion, salinisation, alkalinisation and laterisation. All of these soil processes can be related to climate conditions and management.

4.2 Results

4.1.1 Agro-meteorological characterisation of the Binh Thuan Province

Daily meteorological data records from six climatic stations were collected by the Vietnam Institute of Meteorology Hydrology and Environment. The data consists of daily of air temperature (maximum and minimum), daily air humidity (average relative and minimum), daily sunshine duration, total of daily rainfall and daily wind speed maximum (Table 5). Out of the six stations, Bao Loc had data for 30 years, Xuan Loc for 18 years; Phan Rang for 15 years and the other stations (Nha Trang, Phan Thiet and Vung Tau) had data for 28 years. The rainy season is defined as the period when rainfall is higher than half of evaportranspiration (Table 6); the appropriate time for planting can be taken as the point from where rainfall is higher than evapotranspiration. The onset of the rainy season is markedly different between the stations, while the end of the rainy season is similar.

Table 5 Rainfall, ET0 and length of humid period with different probabilities of exceedance (20%, 50% and 80%) representing dry, normal and wet years for six climatic stations in South East Vietnam.

Station	LON (East)	LAT (North)	ALT (m)	Rainfall (mm)			ET0 (mm)			Length humid period		
				Wet year	Mean year	Dry year	Wet year	Mean year	Dry year	Dry year	Mean year	Wet year
Bao Loc	$11^{0}32^{\prime}$	$107^{0}49^{\prime}$	840	2195	2949	5262	1441	1368	1298	206	230	255
Nha Trang	$12^{0}13^{\prime}$	$109^{0}12^{\prime}$	3	803	1266	2552	1752	1705	1656	80	92	103
Phan Rang	$11^{0}35^{\prime}$	$108^{0}59^{\prime}$	7	449	838	1332	1929	1868	1807	54	78	102
Phan Thiet	$10^{0}56^{\prime}$	$108^{0}06^{\prime}$	9	784	1142	1768	1833	1761	1685	122	144	166
Vung Tau	$10^{0}22^{\prime}$	$107^{0}05^{\prime}$	4	931	1490	1970	1885	1699	1491	142	162	186
Xuan Loc	$10^{0}56^{\prime}$	$107^{0}14^{\prime}$	161	1652	2076	2597	1711	1648	1581	161	182	207

Table 6 Start and end of rainy season with different probabilities of exceedance representing late, normal and early rainy seasons for six climatic stations in South East Vietnam.

Station	**P_{20} - Late**		**P_{50} - Normal**		**P_{80} - Early**	
	Start (d/m)	**End (d/m)**	**Start (d/m)**	**End (d/m)**	**Start (d/m)**	**End (d/m)**
Bao Loc	20/4	30/11	1/4	18/11	13/3	5/11
Nha Trang	19/9	22/12	9/9	9/12	31/8	26/11
Phan Rang	9/10	18/12	21/8	27/11	23/7	7/11
Phan Thiet	19/6	7/11	26/5	21/10	2/5	3/10
Vung Tau	25/5	18/11	11/5	1/11	28/4	15/10
Xuan Loc	29/5	2/12	14/5	14/11	29/4	28/10

The annual rainfall was interpolated using inverse distance weighting and accounting for the orographic effect present in the region (Figure 9). The map shows the location of the six climatic stations in relation to the isolines. Phan Thiet, in the middle of the provincial coastline, has a sub-humid climate. Vung Tau, located along the coast in the south-western part has a similar climate; Nha Trang in the north-eastern extremity of the study area also has a sub-humid climate. Phan Rang, also in the northeastern part of the study area and along the coast, has the driest climate (dry sub-humid). Xuanloc, west of the province, has a very humid climate; and, Bao Loc has the most humid climate located in the mountains in the northern part of the study area.

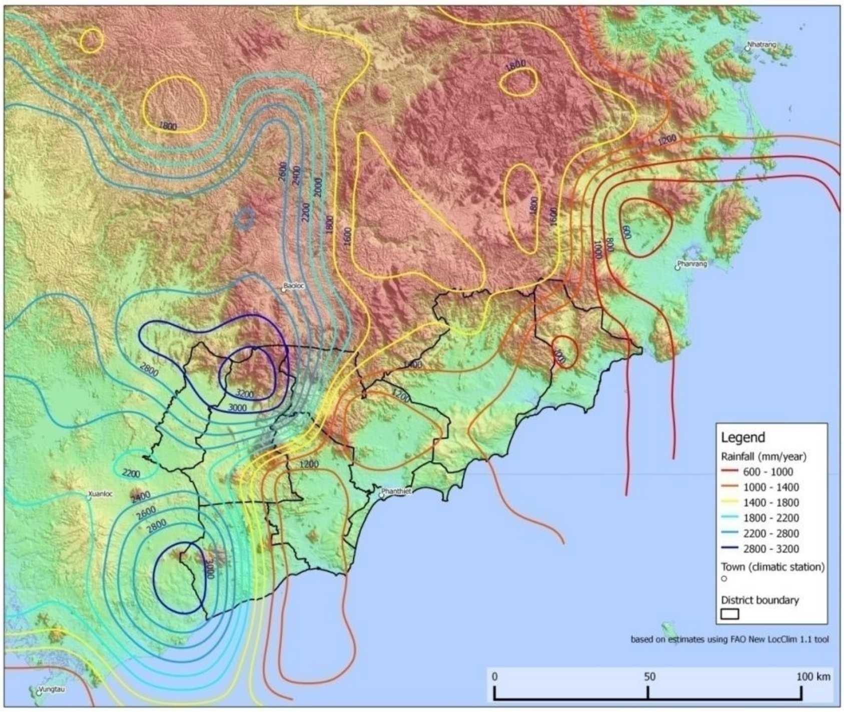


Figure 9 Annual interpolated rainfall

Due to lack of direct measurements of rainfall intensity, the annual rainfall intensity is calculated as:

$$RI = \frac{\sum Pm^2}{P}$$

Where *RI* is the rainfall intensity, *Pm* is the monthly rainfall and *P* is the annual rainfall. A higher value of *RI* corresponds to a year with higher rainfall intensity. Bao Loc has the highest rainfall intensity (Figure 10).

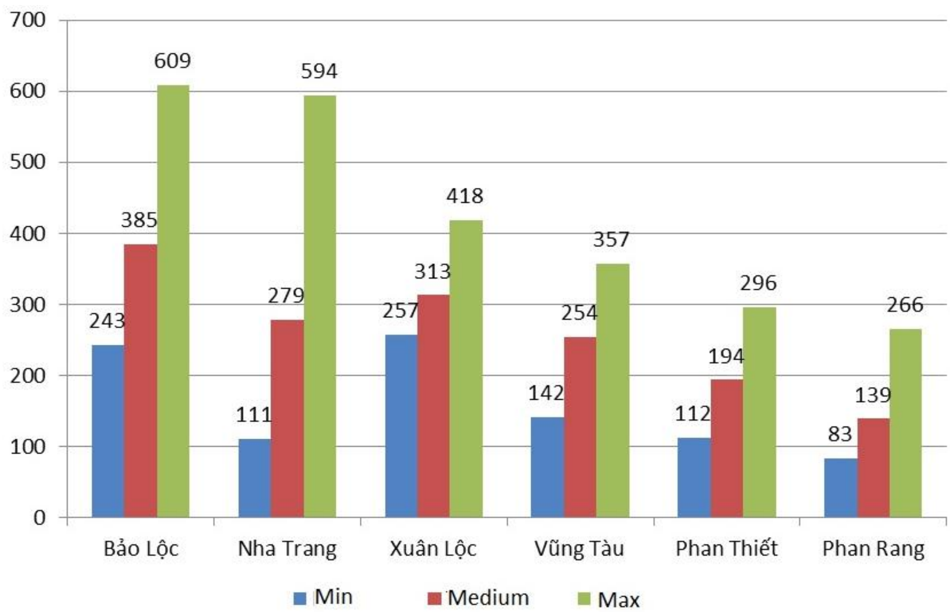


Figure 10 Rainfall Intensity for six meteorological stations. The data for Bao Loc are not homogeneous, all the others are.

The rainfall to reference evapotranspiration ratio, the Aridity Index (*AI*), shows two contrasting climates for the Binh Thuan Province (Figure 11): humid in the western region (*AI* index > 1.2) and semi-dry in the coastal area and in the East (*AI* < 0.8).

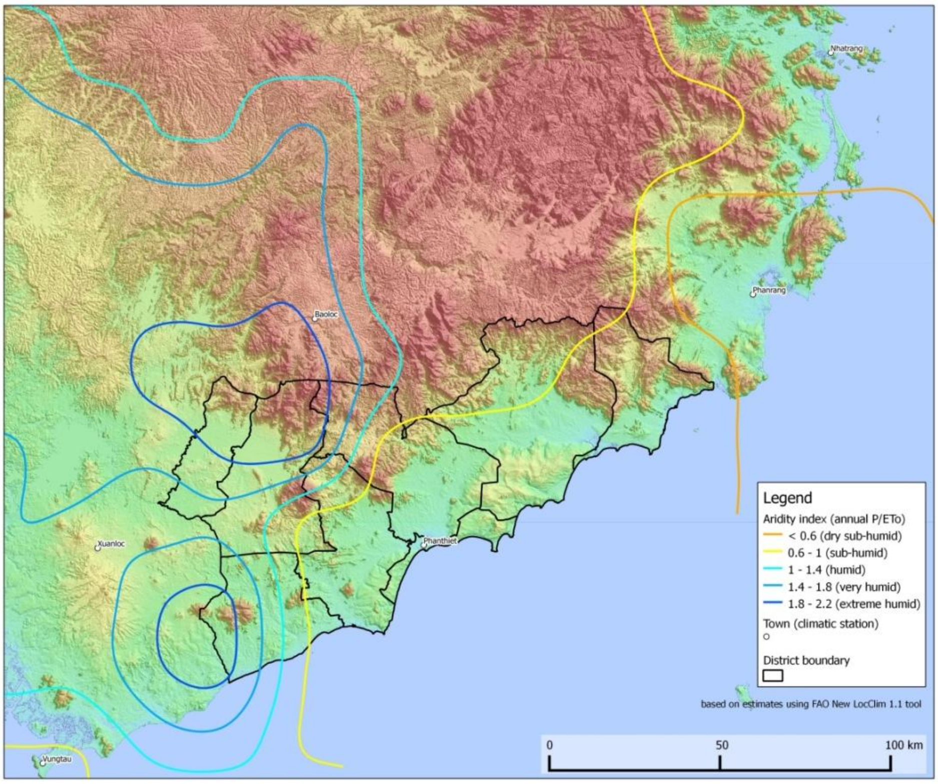


Figure 11 Interpolated aridity index (AI)

4.1.2 Soil suitability

The soil map shows an area of nearly 1259 km² of sandy soils (**Arenosols**) along the coast as part of huge coastal dune complexes (Figure 12). Spectacular gullying and ravine erosion attracts tourists to the area whereas cultivation of drought tolerant crops such as cassava, cashew and mango are found on ferralic Arenosols. Of interest are the economically interesting lizard farms in the dry sandy areas.

Along the major rivers alluvial plains are found with **Fluvisols** (994 km²) and locally **Gleysols** (51 km²). The two zones are along the coast around Phan Thiet and around Phan Ri; a third large alluvial plain is found inland around Tanh Linh (Figure 12). These alluvial soils have a variable texture depending local conditions of sedimentation: they can be very clayey or very sandy depending on their position in the landscape and vicinity to the main river. The alluvial soils around Phan Thiet, where the climate is dry, are often used for the cultivation of the dragon fruit (Hylocereus undatus). Where the climate is more humid, as in Tanh Linh the alluvial soils are often used for wetland rice cultivation.

Rhodic **Ferralsols** are the dominant soils of the mountains; these are highly weathered, red, clayey soils that cover 45% of the soils in the Binh Thuan Province or 3490 km² (Figure 12). The Ferralsols are mostly under tropical humid rainforest. Leptosols, mostly formed on granite outcrops, cover 1.2 % of the entire area or 936 km².

Between the coastal dunes and the mountains an undulating plain is found with clay enriched subsoils (Figure 12), comprising Haplic **Acrisols** (1542 km², 20% of the area), **Luvisols** (2210 km² or 3% of the area) and **Lixisols** (96 km², less than 2%). These are highly weathered soils, with an increasing clay content in the subsoil and a predominantly low base content. Most of the agricultural activities take place on these soils, the majority of which is rainfed. A minor percentage of soils is saline (0.3% or 238 km²) and occur mainly at the transition between sand dune areas and plains where evapotranspiration rates outweigh rainfall thereby encouraging salt accumulation.

Irrigated agriculture takes place on 46,160 ha mainly on Acrisols (56%), followed by Ferralsols (18%), Luvisols (14%) and Fluvisols (12%). The major staple food crop is rice and priority is given to rice for irrigation. Dragon fruit is gaining importance as a cash crop grown for both local consumption and export. A further 113,600 ha of irrigation perimeters are planned mainly located on Fluvisols (45%) and Acrisols (24%) followed by Luvisols (15%).

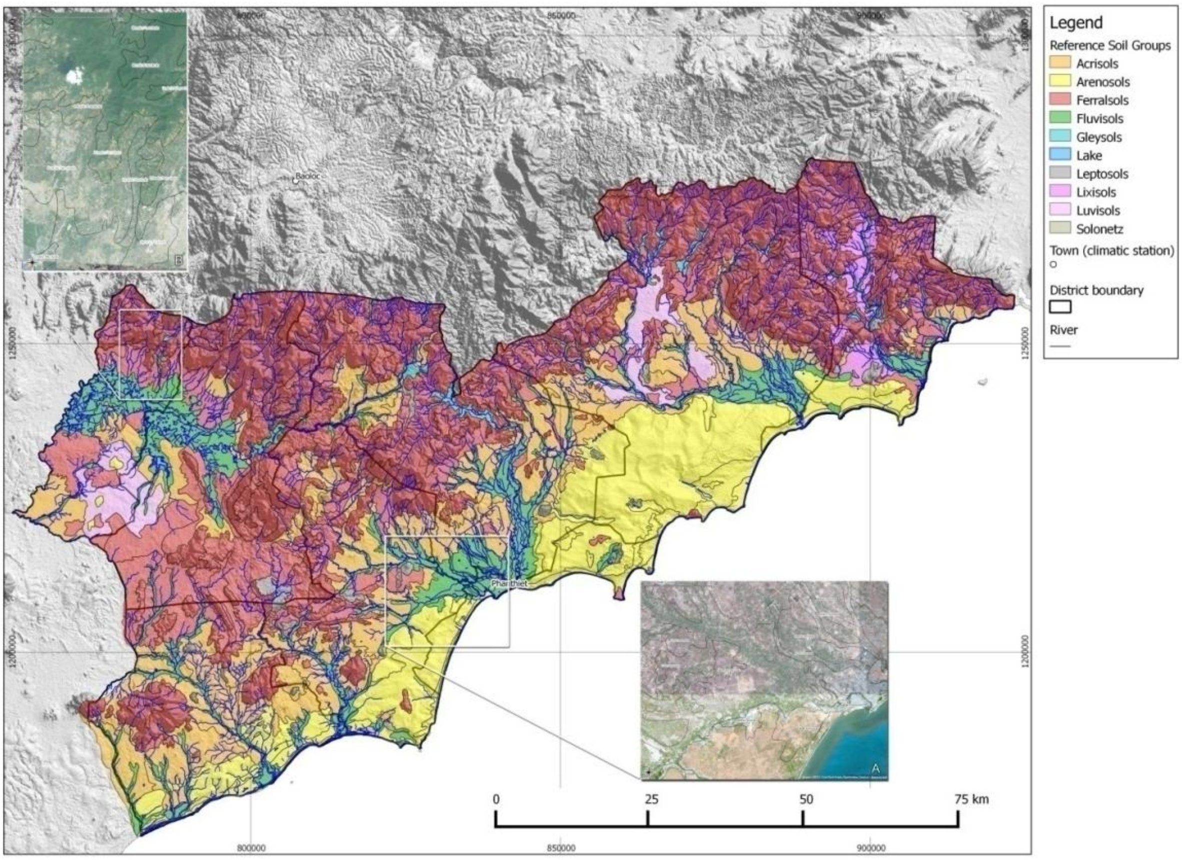


Figure 12 The soil map of the Binh Thuan Province

4.1.3 Soil water balance affecting yield of rainfed crops

The soil water balance was calculated for two contrasting but well drained soils in the area; and for two meteorological stations:

- ✓ Clay soil with three different horizons: sandy loam (0-20 cm), organic sandy loam (20-100 cm) and sandy clay (100 -200 cm). This soil profile may be typical for Ferralsols and Acrisols. These are well-drained soils, common in the mountains and plains.

- ✓ Sandy soil with two different horizons: a 20 cm thick sandy layer and a -200 cm thick loamy sand layer. This soil profile is typical for Arenosols, are usually found along the coast of the study area.

Due to the higher content of loam and sand, the water retention capacity of the clay soil is higher and results in a lower drainage but higher runoff. The favourable soil water balance results in higher yields on the clay soil. Erratic rainfall during the cropping season result in poor crops unless there is access to irrigation; this is even more pronounced on sandy soils.

Table 7 Percentage of potential of water affected yield, runoff and drainage for different probabilities of exceendance

Station	**P_{20} - Wet**			**P_{50} - Normal**			**P_{80} - Dry**		
	Yield (%)	**Runoff (mm)**	**Drainage (mm)**	**Yield (%)**	**Runoff (mm)**	**Drainage (mm)**	**Yield (%)**	**Runoff (mm)**	**Drainage (mm)**
Deep clayey soil									
Phan Thiet	88.6	64.2	193.6	74.0	34.6	112.6	54.6	15.9	58.1
Xuan Loc	100	226.6	601.7	97.9	173.4	523.3	94.6	132.6	445.0
Deep sandy soil									
Phan Thiet	64	55.1	289.7	45.9	30.9	200.4	25.7	15.1	121.7
Xuan Loc	94.3	179.2	694.3	90.8	134.0	614.0	85.2	95.3	538.6

4.1.4 Soil degradation

The present forms of land degradation related to desertification cover almost 90,000 ha (Figure 13; first legend items) and include sand dune formation and severe erosion (56,740 ha or 63%), soil degradation due to laterisation (12,490 ha or 14%), salinisation (11,410 or 13%), and rock outcrops (9,355 ha or 10%). Desertification in the central part of Southern Vietnam is of increasing importance.

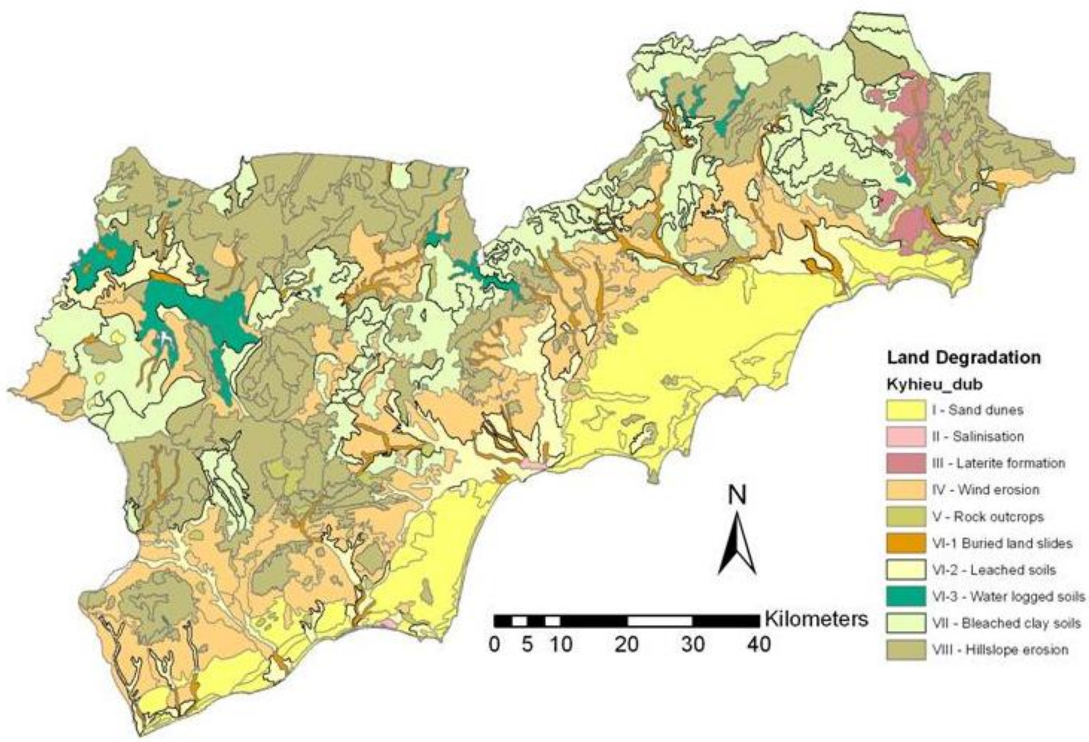


Figure 13 Land degradation in the Binh Thuan Province

A further assessment of the desertification processes in the two northeastern districts of Binh Thuan points to the following causes:

- ✓ **Location**. The topographical characteristics of the region create a micro-climate of localised arid and semi-arid areas. This localised situation is intensified by the long dry period of 9 months a year. The highly contrasting topography with sloping surfaces foster soil erosion and degradation processes during the rainy season.
- ✓ **Climate**. The special climatic condition with long sunshine duration, strong winds and an extended dry priod is favourable for desertification. On average, there are 5 to 6 dry months a year with rainfall below 5mm/month and 3 to 4 months with rainfall below 1mm/month. According to the hydrothermal coefficient of Xelianinov and the rainfall coefficient, the coastal area of Northeastern Binh Thuan province is classified as semi-desert and savannah.
- ✓ **Hydrology**. Surface runoff in the area is very low. In many places, there is little surface runoff. Most of the streams and rivers are seasonal. The water holding capacity is very low and the ability to recharge the groundwater is limited.
- ✓ **Soil**. The soil is poor in nutrients and its binding capacity is low. The soil water holding capacity is also low. Together with hot temperatures and high evaporation rates, the area is prone to desertification. Laterisation and salinisation are taking place at fast rates, and in turn increase drought and desertification. These processes all affect soil suitability and land use, particularly in the worst affected parts of the province.

In addition to desertification, other natural hazards and processes lead to soil degradation in the Binh Thuan Province (Figure 13). These are related to extreme rainfall events and include soil erosion, land slides, and leached and waterlogged soils. Their occurrence is associated with the hills and mountains in the west of the province.

4.3 Conclusions

Analysis of agricultural drought in the Binh Thuan Province supports the following conclusions:

- The climate in the province is characterized by high evapotranspiration (1350 mm) and abundant sunshine (2500 – 2800 hours per year). Of notice is the most variable onset of the wet season.
- Areas that are more sensitive to drought were identified. The data contribute to a classification of two climatic regimes in Binh Thuan: humid in the Western part of the province and semi-arid in the East. The areas most sensitive to drought are located in the North-Eastern part of the province. They coincide with the Bac Binh an Tuy Phong districts
- Most of the climatic variation concerns the onset and therefore the duration of the rainy season. The start of the rainy season is expected to delay further during the decades to come.
- During the past 30 years the total amount of rain in Binh Thuan changed from year to year. However predictions on the evolution of these parameters in the future are unreliable.
- Increases in agricultural biomass and yields were documented both on clay soils (Ferralsols, Acrisols) and sandy soils (Arenosols) during the past 30 years (1980 – 2009). Clay and silt containing soils are more productive than sandy soils since they are more resilient to drought.
- Areas in the humid mountains are particularly vulnerable to erosion. In the neighbourhood of water reservoirs this may pose a problem. On these soils, erosion can be mitigated by aforestation.

- Different types of soil degradation are described: sand dune formation, salinisation, laterisation, wind erosion, water erosion, rock outcrops;

4.4 References used for this chapter

Gobin, A., Pham Ha, H., Le Thi Thu, H., Le Trinh, H., Hens, L., Pham Quang, V. (in preparation). Natural hazards and resources management in the Binh Thuan Province, Vietnam. Environmental Science and Policy.

Gobin, A., Pham Ha, L., Le Thi Thu, H., Le trinh, H., Hens, L., Pham Quang, V., 2012. Land use and desertification in the Binh Thuan Province. Poster presented at the project workshop held at Belspo Brussels on 15 March 2012.

Le Thi Thu, H., Gobin, A., Huong, P.T.T., 2012. Indicators of environmentally sensitive areas (ESA) to desertification in the Binh Thuan province, Vietnam. In preparation.

Nguyen Thanh, B., Dondeyne, S., Raes, D., 2012. Agro-climatic characteristics of binh thuan province, south east Vietnam. Report of the mission of Binh Thanh Nguyen to Leuven during March – May 2012.

5 Desertification and Land Use Cover Change Detection (WP2.3)

5.1 Methodology

Three different methodologies were used for land cover change detection: (1) spatial and statistics analysis; (2) hard classification of 1990 and 2002 landsat images; and, (3) multiple resolution and multiple sensor remote sensing imagery.

Two land use maps (2005, 2010) were obtained through the Institute of Geography from VAST, and further processed in a godatabase which allowed for overlay analysis. The results were compared with statistics from the National Statistical Yearbook.

In a first stage, a pair of cloud-free Landsat images was selected to classify the study area: December 30, 1990 (Landsat-5 TM) and January 05, 2002 (Landsat-7 ETM+). A supervised training with maximum likelihood classification was based on ground truthed ROIs within the province, classified according to 7 classes (Table 8). At the time of processing, existing land use maps were not available. In addition the entire province was not processed leaving out the most eastern district which happens to be worst affected by desertification and drought.

Table 8 Classes discerned when classifying the land cover of the entire province.

Land cover class	Acronym	Description
Built-up	BUP	Urban or rural build-up - industrial – transportation – cities – towns -villages
Forest-Plantation	FPO	Natural forest - reforested land - mixed forest – orchards - groves
Dunes and sandbank	DSB	Dune roving - sandbank
Crop land	CLD	All arable land (not limited to land under crops) – rain-fed crop fields and bare fields
Highland and Bush	HIB	High lands or hills with vegetation – wild lands with spare vegetation – unused land
Water bodies	WAT	Permanent open water – lakes – reservoirs – streams - bays and estuaries
Lowland	WET	Irrigated cropland - paddy field - water ponds - flooded lands.

In a second stage, Land Use Cover Change detection was accomplished using multiple resolution and multiple sensor remote sensing imagery. The 2005 land cover map was reclassified to six land covers which can easily be delineated by their temporal NDVI profile, i.e. agriculture, forest, marginal land (dunes), paddy fields, urban area and water. Area fractions were derived from the rescaled reference land use map to contain per coarse pixel the percentage of each 2005 land cover class.

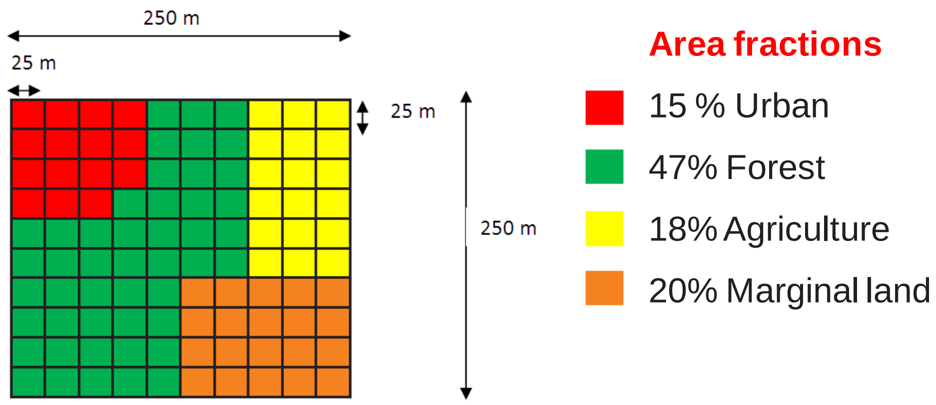


Figure 14 Example of area fractions applied to the land cover map

For every 5 year interval from 1989 to 2010 LANDSAT TM registrations in the dry season were downloaded (May to October) from the http://glovis.usgs.gov/ server and subsequently merged into one composite per year. The low availability of images due to clouds, discrepancies between Landsat sensors and the fast changing phenology hinder the development of a consistent time series of hard classified images. For a coastal subregion where high quality images were available, the land cover changes were analysed for dunes, forest, agriculture and urban areas over the period 1989-2010 with a five year interval.

NDVI-composites (S10) of the SPOT-Vegetation sensor for the years 2000, 2005 and 2010 were used for sub-pixel classification. 18 NDVI images covering both the wet and dry season were geographically transformed, resampled and temporally smoothed using the VITO model GLIMPSE. Sub-pixel classification, using a neural network approach, was carried out using the 2005 land cover map as reference data. The information was subsequently extended to the 2000, 2005 and 2010 10-day NDVI time series by means of a neural network resulting in a series of estimated area fraction images. The multi-layer-perceptrons network is trained by establishing a relation between NDVI temporal profiles and associated reference area fractions. A backpropagation algorithm is applied to compute the weights of the activation functions. The activation function for hidden layer and output layer is respectively a tangent sigmoid and log sigmoid function. The number of SPOT-VGT input images (18) and output estimated area fractions (6) determines the number of input and output nodes. The number of hidden nodes was set to 4.

5.2 Results

Past land use practices such as deforestation in the 70s and inherently poor soil quality have resulted in desertification near the coast. Based on **statistics and spatial analysis** of existing maps, land cover changes during the past decade show an increase in agricultural land of 10%, with 44 % of the total land managed by farmers in 2010 (Figure 15). The area for rice cultivation has declined with 7%; the production hasn't owing to an increase in irrigation. Forests occupy almost 48% of the total area but have declined with 6%. Urban and rural settlements account for 3.5% of the total land and have increased with 3%. Water and aquaculture (1%) have declined with 5%. Marginal land accounts for nearly 4% of the province and declined with 17%.

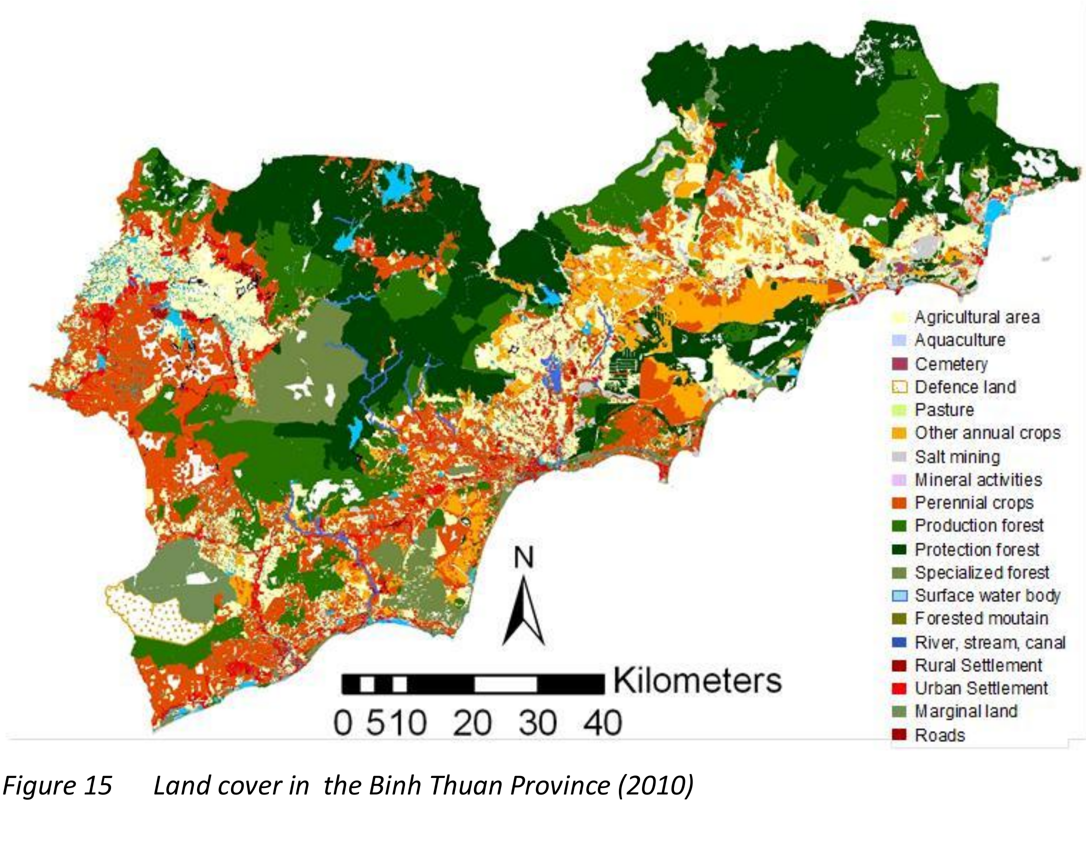


Figure 15 Land cover in the Binh Thuan Province (2010)

Based on classification of **LANDSAT 1990 and 2002 images**, the major changes during the 1990-2002 period were found in natural forests including planted forest, irrigated land and paddy fields; and vegetation re-growth, shrubs, hill's vegetation (Figure 16, Table 9). The areas of water bodies and built-up area increased significantly. From 1990 to 2002, the BUP, HIB, WAT and WET areas increased with respectively 0.7% (44.3 km²), 3.8% (233.6 km²), 1.1% (67.1 km²) and 5.6% (341.2 km²) while FPO, DSB and CLD decreased with 9.3% (562 km²), 0.5% (31.5 km²) and 1.5% (92.2 km²). Although the extent of wetlands may change from year to year due to varying precipitation and temperature, the variation in wetland area is likely due to classification errors and varying soil humidity levels.

Table 9 Area and percentage of each land cover class resulting from the classified images (6070 km²) for 1990 and 2002.

Land cover class	Acronym	1990		2002	
		Area (km²)	Rate (%)	Area (km²)	Rate (%)
Built-up	BUP	60.8	1.0	105.1	1.7
Forest-Plantation	FPO	1818.1	30.0	1255.4	20.7
Dunes - sandbank	DSB	141.9	2.3	110.4	1.8
Crop land	CLD	1332.2	21.9	1240.0	20.4
Highland and Bush	HIB	2407.0	39.7	2640.6	43.5
Water bodies	WAT	13.4	0.2	80.5	1.3
Lowland	WET	296.6	4.9	637.8	10.5
Total		6070	100	6076	100

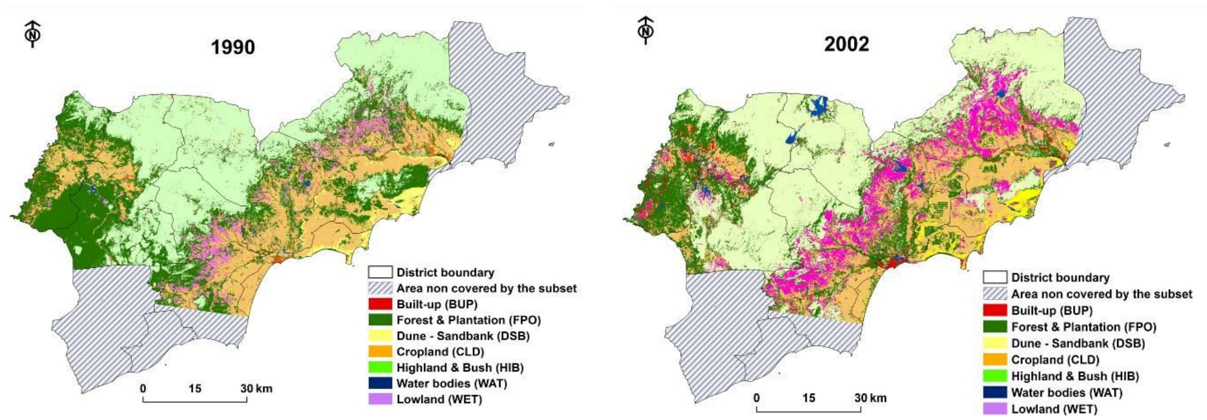


Figure 16 Land use and land cover maps (1990 and 2002) resulting from the integration of supervised classification and visual interpretation of a Landsat-5 TM (December 30, 1990) and Landsat-7 ETM+ (January 05, 2002) image.

The results of change detection showed that during 1990-2002, 3759 km² (62% of the area) were unchanged while changes occurred in 2311 km² of the land (38%) (Table 10). The unchanged areas were mainly composed of HIB (34%), CLD (12.7%) FPO (11%) and WET class (2.2%). The highest change rates between the 1990-2002 period occurred in forest (49%), followed by cropland (24%) and highland bush (14%). Minor changes occurred in wetland (7%), dunes (2.7%) and artificial built-up area (1.7%). The change in closed canopy forest was mainly due to conversion into open canopy bush (21%), rain-fed cropland (12%) and irrigated agricultural land (14%). The change in cropland was mainly due to conversion to forest (13%) and irrigated land (5%); 1.2% was converted to dunes. Highland bush was converted to forest (9%) and irrigated land (2.5%). Interesting is the observation that dunes were converted to cropland and forest.

Table 10 Area (km²) and percentage of change in each lulc class and annual rate of change between 1990 and 2002

Change class		Districts and city affected by changes						Total area (km²)	Change rate (%)	
From	To	Bac Binh	Duc Linh	Ham Thuan Bac	Ham Thuan Nam	Phan Thiet	Tanh Linh			
FPO	HIB	91.3	46.6	40.6	76.4	0.5	237.5	492.8	21.1	49.1
	WET	136.2	8.1	75.6	82.7	2.0	20.1	324.6	13.9	
	CLD	98.3	34.8	57.7	30.3	2.4	58.4	282.0	12.1	
	BUP	4.5	15.6	3.6	2.0	1.5	6.1	33.4	1.4	
	WAT	2.3	2.7	4.6	0.8	0.2	3.9	14.4	0.6	
CLD	FPO	57.6	55.9	89.7	36.4	30.5	35.1	305.2	13.1	24.1
	WET	36.3	7.5	36.1	29.7	1.3	9.6	120.5	5.2	
	HIB	9.7	7.1	16.1	5.0	0.6	8.3	46.8	2.0	
	BUP	9.2	12.6	7.2	2.6	2.7	9.4	43.7	1.9	
	DSB	9.7	0	8.4	0.3	10.3	0.0	28.7	1.2	
	WAT	2.3	3.0	3.7	0.5	1.2	6.2	17.0	0.7	
HIB	FPO	70.2	11.7	55.3	27.1	2.0	44.0	210.3	9.0	14.4
	WET	30.9	0.1	18.0	5.4	0	3.2	57.7	2.5	
	CLD	25.0	0.3	5.9	1.3	1.1	4.1	37.7	1.6	
	WAT	3.4	1.4	16.7	0.3	1.5	6.7	30.0	1.3	
WET	CLD	30.4	0.6	19.2	33.7	0.9	1.3	86.1	3.7	7.0
	FPO	8.9	2.8	8.5	10.2	0.2	2.8	33.5	1.4	
	HIB	6.9	0.4	6.5	13.2	0.1	6.2	33.3	1.4	
	BUP	2.5	0.5	0.9	1.4	0.1	0.4	5.8	0.2	
	WAT	1.9	0.7	1.6	0.6	0.2	0.4	5.5	0.2	
DSB	CLD	29.7	0.2	5.8	1.7	13.2	0.2	50.7	2.2	2.7
	FPO	4.7	0.8	2.4	0.5	3.6	0.4	12.4	0.5	
BUP	FPO	7.8	6.4	6.7	3.2	1.2	1.1	26.4	1.1	1.7
	CLD	4.2	0.7	3.5	2.0	0.8	1.3	12.5	0.5	
Total (km²)		683.9	220.5	494.5	367.0	78.1	466.8	2310.9	99.0	99.0

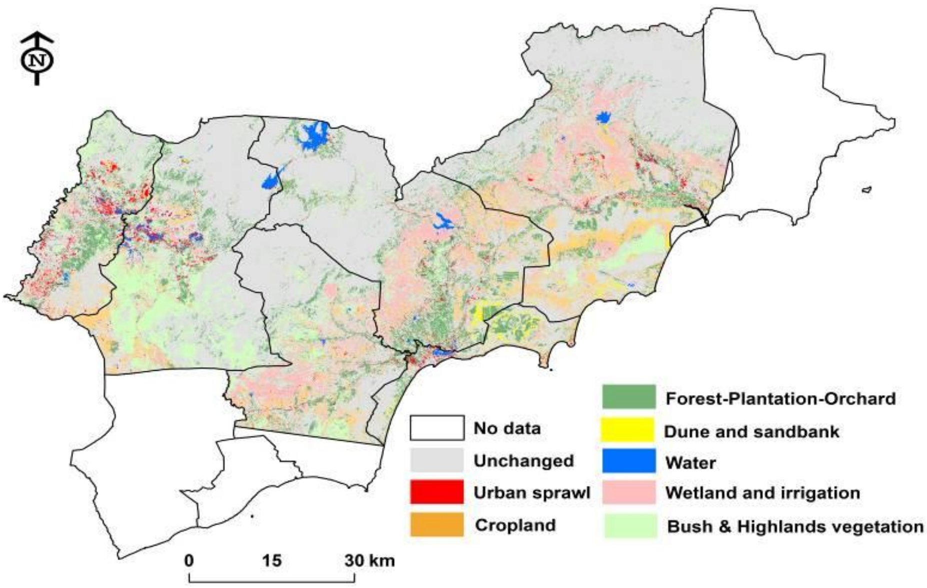


Figure 17 Change detection map for the studied districts (spatial extends of converted classes are highlighted).

The combination of **multi-temporal and multi-sensor images** using both hard classification of LANDSAT images and neural network methodology applied on SPOT-VGT images allowed to detect land cover changes and in particular dry and wet season agricultural activities in the Binh Thuan Province of Vietnam.

In four coastal communities we focused on desertification and in particular on dune dynamics using hard classification of LANDSAT images. Land cover changes during 1989-2010 showed that dunes have stabilised in the area (Figure 19, Figure 20). Between 1989 and 2010 the dunes decreased with 0.67% in line with the previous findings resulting from the classification of the 1990 and 2002 images. The forest in the four communities has increased with 28.6% owing due to increased revegetation efforts of dunes and villages to protect houses and roads from sand storms (Figure 19). The latter provides for the false impression that artificial surfaces have declined with 14% in the four communities. Agriculture has declined between 1989 and 2010 with around 7% owing due to dune encroachment and afforestation. In addition there are exchanges of agricultural land between rainfed cultivation an irrigated cultivation including paddy. These dynamics can only be detected using multi-temporal low resolution analysis.

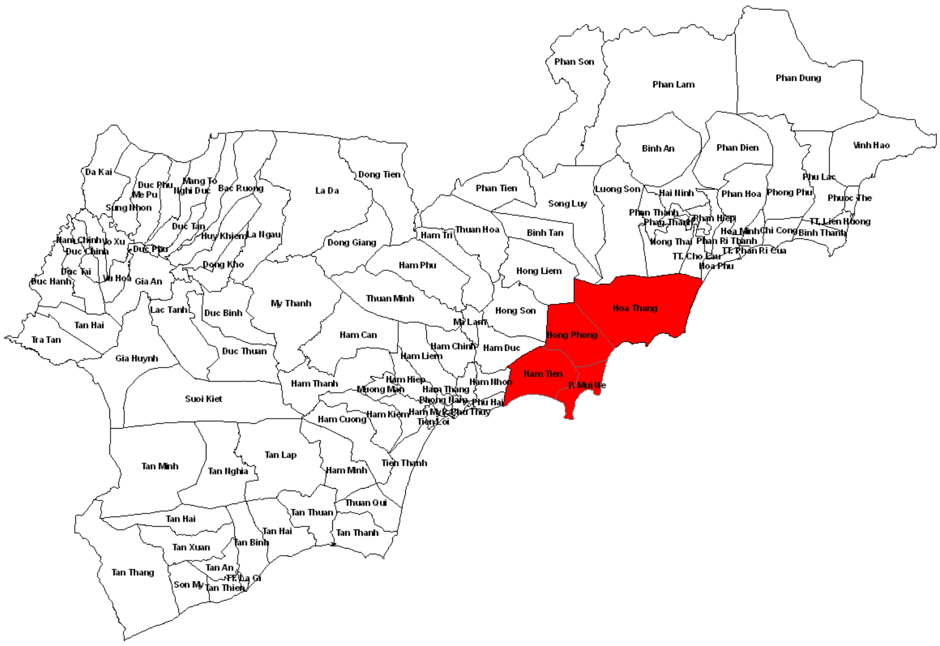


Figure 18 Location of the communities of Ham Tien, Hoa Thang, Hong Phong and P. Mui Ne in the Binh Thuan Province.

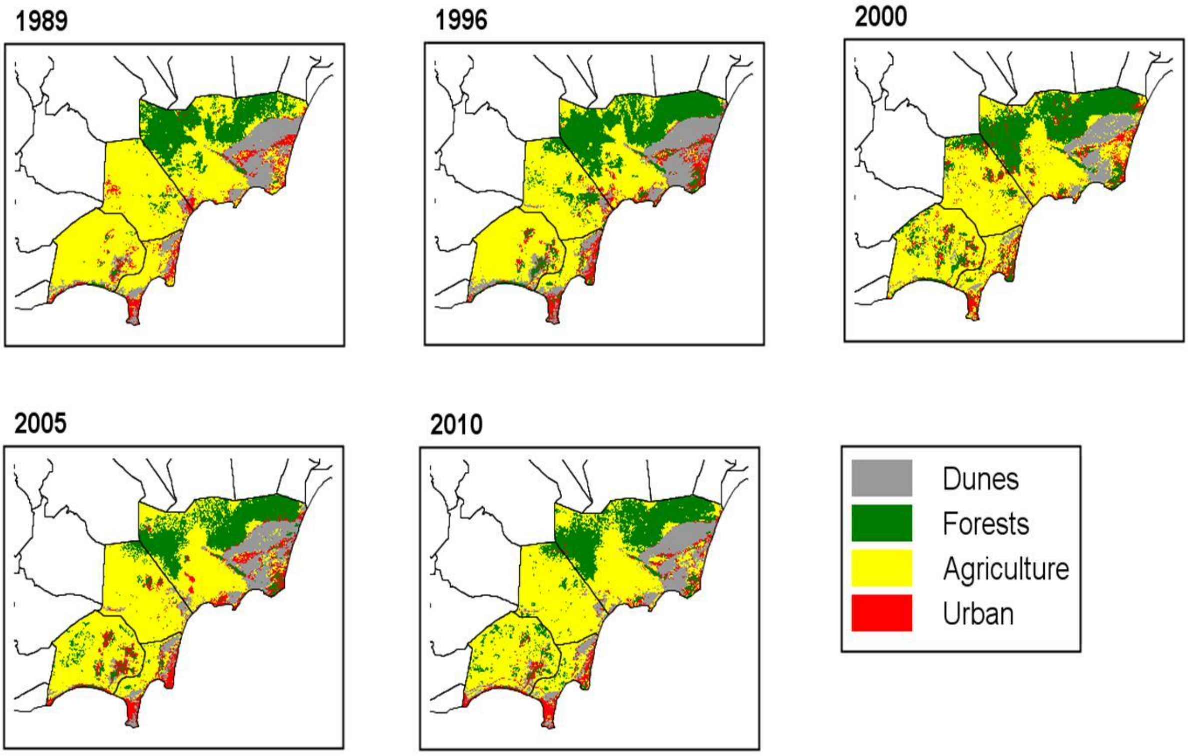


Figure 19 Land cover changes in the communities of Ham Tien, Hoa Thang, Hong Phong and P. Mui Ne in the Binh Thuan Province (red in Figure 18); according to hard classified LANDSAT images.

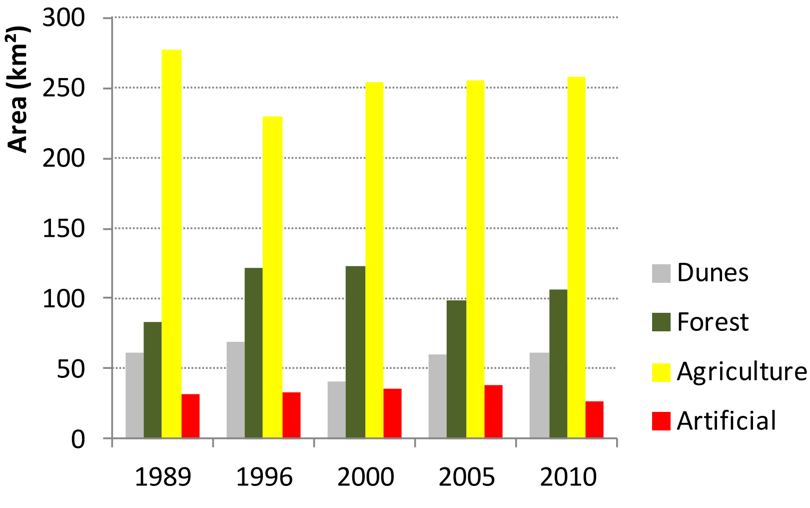


Figure 20 Land cover changes in 4 coastal communities based on LANDSAT processing

Forests cover nearly half of the Binh Thuan Province (49.5%) in 2010 (Figure 21); agriculture covers 39.5% of the area. The increase of agriculture at the expense of forests is observed in the entire province during the 2000-2010 period (Figure 22). Interesting is a decline in paddy fields with 9.5%, following the severe droughts from 2005 onwards when water availability for irrigation declined. Water bodies have increased with 3% owing due to dam construction in the forested and humid northern area of the province and due to aquaculture in the plains. Settlement areas comprise nearly 4% of the area in 2010, and have increased with nearly 17% in 10 years. Bare land (marginal land) covers only 1% of the province and includes sand dunes and rock outcrops. Bare or marginal land covers only 8.5% of the total degraded land in the province and shows that the pressure on land is high in the province.

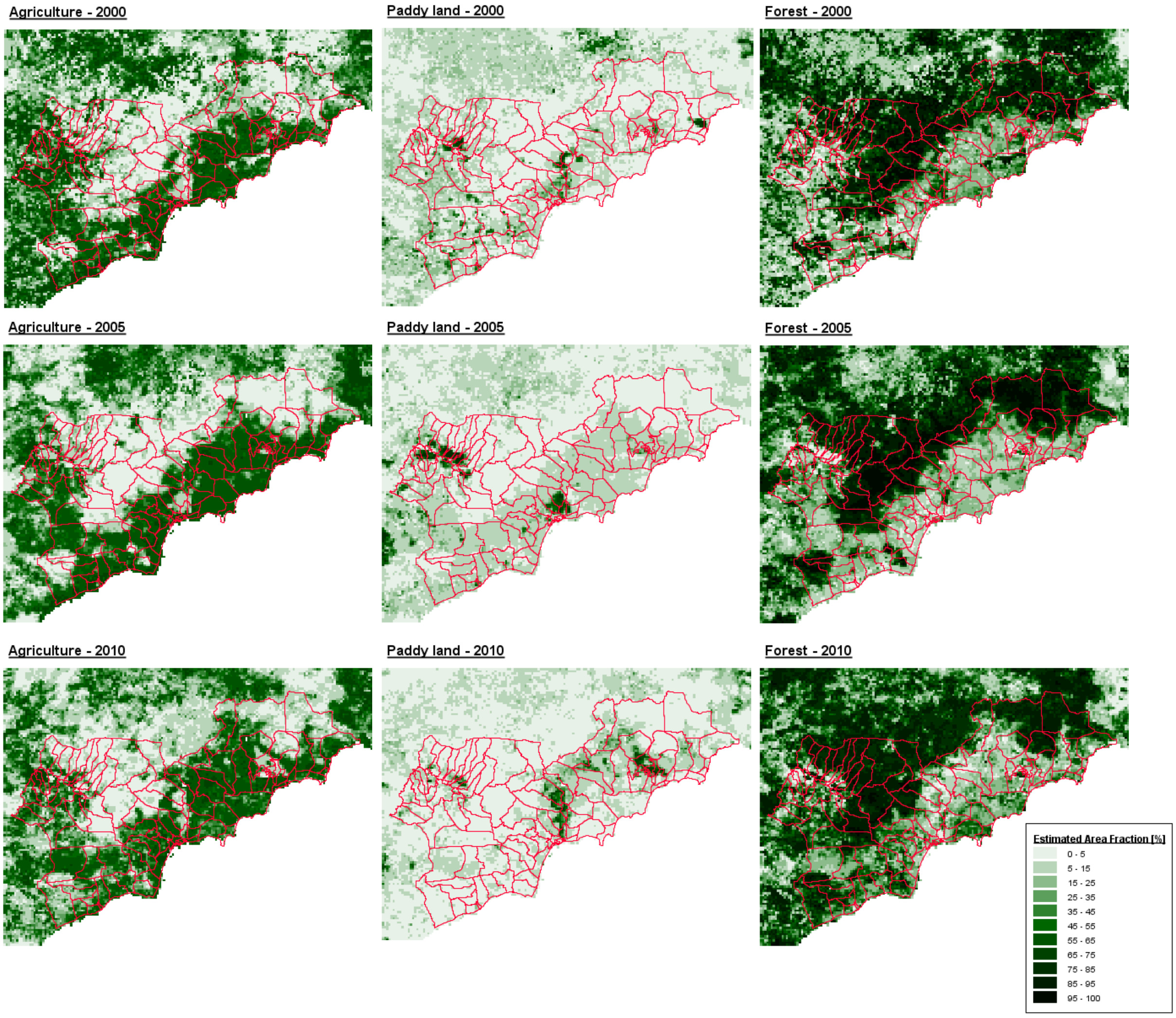


Figure 21 Estimated area fractions for agriculture, paddy fields and forest in the Binh Thuan Province

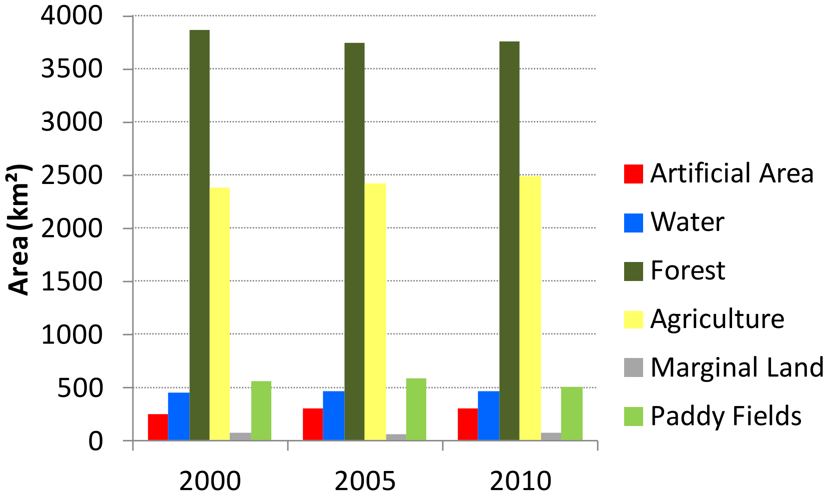


Figure 22 Land cover changes in Binh Thuan Province based on SPOT-VGT processing

5.3 Conclusions

The land cover and land use analysis (1990-2002-2005-2010) using remote sensing, statistical data and GIS maps leads to the following conclusions:

- Half of the province (47-49.5% in 2010) is covered by forest. The forest cover declines by 3% during the period 2005-2010;
- Almost 20% of the land (19%) is used to grow perennial crops. The agricultural land increases by 10% during the period 2005-2010;
- Settlements occupy larger surfaces over the years and occupy 3.5-4%% of the land in 2010. They have increased with nearly 17% during the last 10 years;
- Water and aquaculture (5-6% of the area) have increased with 1-3% owing due to dam construction and the rise in aquaculture; and,
- Marginal land (1%) includes bare soil such as sand dunes and rock outcrops.The overall area has increased with 4%, mainly due to deforestation in the hills while the sand dune areas seem to have stabilised due to revegetation programmes.

5.4 References used for this chapter

Gobin, A., Pham Ha, L., Le Thi Thu, H., Le trinh, H., Hens, L., Pham Quang, V., 2012. Land use and desertification in the Binh Thuan Province. Poster presented at the project workshop held at Belspo Brussels on 15 March 2012.

Gobin, A., Pham, H., Le Thi Thu, H., Le Trinh, H., Hens, L., Pham Quang, V. (in preparation). Natural hazards and resources management in the Binh Thuan Province, Vietnam. Environmental Science and Policy.

Hountondji, Y., de Longueville, F., Ozer, P., 2012. Land cover dynamics (1990-2002) in Binh Thuan province, Southern Central Vietnam. International Journal of Asian Social Science, 2(3): 336-349. http://hdl.handle.net/2268/116012

Van Hoolst, R., Gobin, A., Eerens, H., Bertels, L., 2012. Land cover changes in the Binh Thuan Province using multi-temporal & multi-sensor images. Poster presented at the project workshop held at Belspo Brussels on 15 March 2012.

6 Societal impacts of desertification (WP3)

6.1 Methodology

6.1.1 Primary data

This chapter deepens the socio-economic effects of drought in Binh Tuan. The results are based on the analysis of official statistical data, family and authorities questionnaires. Cause-effect relationships are assessed using a Leopold matrix that was established using a Delphi approach, involving 23 Vietnamese experts. The following socio-economic techniques were used:

- Semi-strucutred interviews with government officials, scientists, farmers and the water board of the Binh Thuan Province;
- Household (208) and decision makers questionnaires (208);
- Community group questionnaires administered to the community council (29);
- Expert assessment of causes and effects of drought using a Delphi approach; and,
- Leopold matrix to analyse cause-effect relationships of drought.

6.1.2 Other methods

The above primary data and analysis was put in a larger context by linking the findings to available data sets, using the following methods:

- Literature survey and data analysis of the previous WPs to analyse the interaction between bio-physical and socio-economic factors in the province and in particular in its two most Northern districts;
- Statistical analysis of the data on water availability, agricultural production shifts, income, expenditure, poverty and immigration;
- Spatial analysis of the geo-database established resulted in further analysis of causes and effects. GIS mediated thematic maps were generated on agricultural production shifts and interpretations were sought for land use changes.

6.2 Results

The overall picture of the Binh Thuan Province, and its most Northern districts shows an area with subtle signs of a changing climate. Among these signs, the delay in the onset of the rainy season is probably the most significant. We focused on three socio-economic impacts: water availability, crop changes in agriculture, income (and related aspects as poverty and expenditure), and migration.

The majority of households (66%) relies on tap water for household use. Dams and reservoirs supply the cities, major villages and coastal areas with drinking water and hydro-electricity, and the plains with water for irrigation. Groundwater in the coastal areas is at risk of becoming saline.

The gradual changes in climate allow local farmers to adapt to the new situation e.g. by growing less water demanding crops such as dragon fruit (Figure 23). The area planted with dragon fruit more than doubled in the Binh Thuan Province from 5,799 ha to 13,404 ha, while the production almost tripled from 96,806 to 299,302 tonnes during the period 2005 - 2010.

The availability of irrigation water is more influential than drought on the cultivated area and its production (Figure 24); the area increased from 84,568 ha to 107,207 ha. The rice production increased from 333,408 tonnes in 2005 to 535,411 tonnes in 2010. During the 2005-2010 period, the area and yield of rice increased due to the increasing availability of irrigation systems in the Binh Thuan province. Water availability for irrigation results in three rice crops per year.

Water melon and sesame are declining in area, whereas rainfed cassava is on the increase and mainly grown on sandy soils. Maize is after rice the most important staple crop.

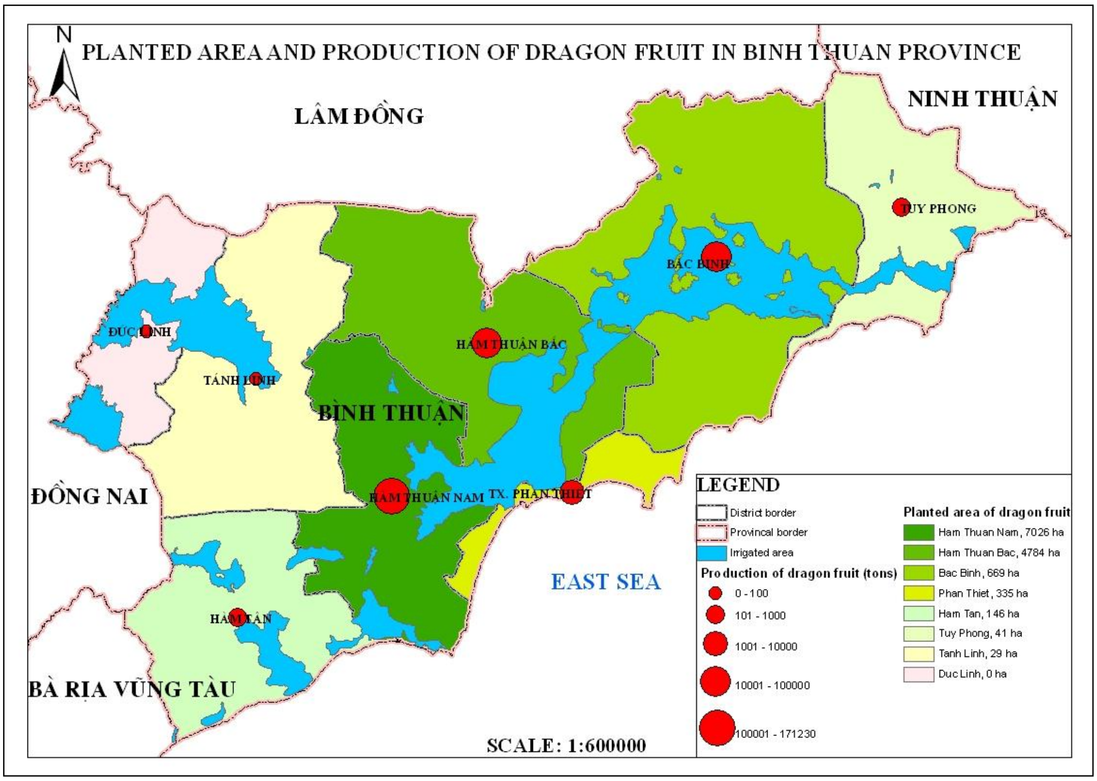


Figure 23 Irrigated area, dragon fruit area and production in Binh Thuan province (2010)

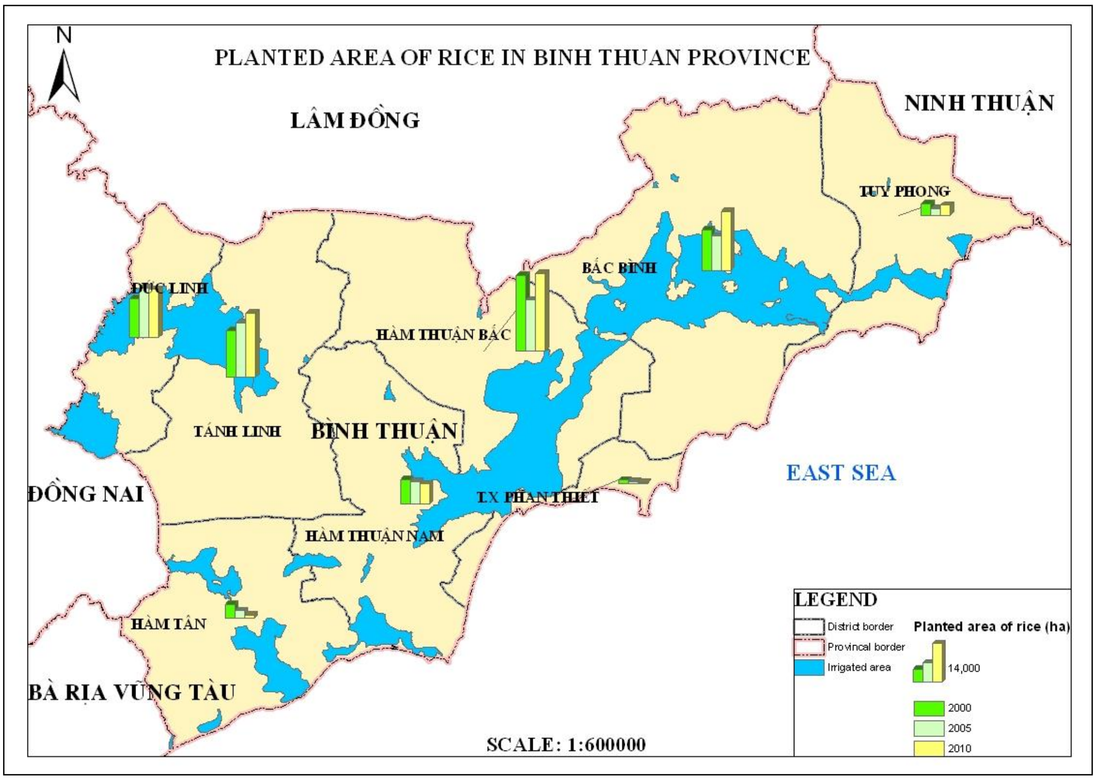


Figure 24 Irrigated area and rice production in Binh Thuan province during 2005-2010

The slowly progressing character of increasing drought episodes allows establishing management options for an adaptation to drought. The socio-economic impacts of drought in the affected north-eastern districts of the Binh Thuan province showed that as a result of these slowly progressing adaptations, no negative impacts of drought on income, expenditure, and poverty were found.

The self reported average annual income per household is higher that the official statistics and doubled in 2.5 years time while the 2011 inflation rate is 18%. Around 58% of the interviewed households obtain their income from agriculture (crops, husbandry, aquaculture; Figure 25). Poor is the household that has an average income/person/month: below 500.00 VND (18€) per year in the cities or below 400.000 VND (14€) in the rural areas. On average, 12% of the households in the communes of the worst affected districts are poor; this figure is significantly below the country's average of 19%. The majority of expenses goes to food and energy.

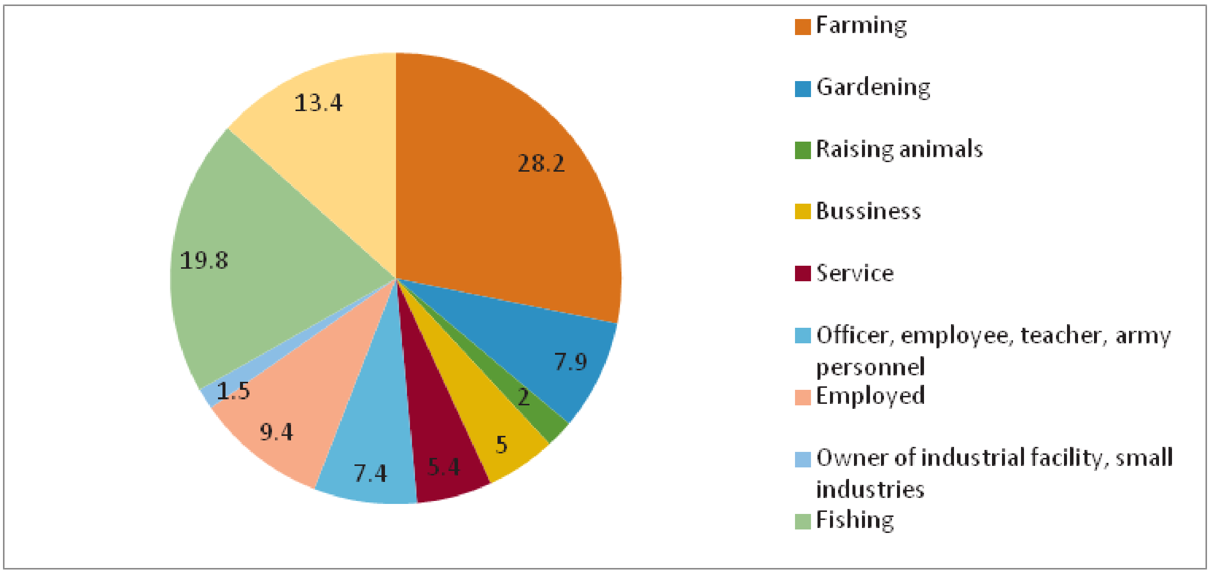


Figure 25 Self reported source of main income in 2010

Migration in the Binh Thuan Province points to urbanisation and rural outmigration. Urbanisation in Binh Thuan, Bac Binh and Tuy Phong is not more important than in Vietnam as a whole. A minor rural outmigration of on average 800 persons per year in the Bac Binh district reflects mainly young persons who prefer to work in industry in major cities. In general, the data for Binh Thuan do not provide evidence for climate induced migration. The migration phenomena are explained by economic reasons such as the attraction by industry, tourism, or other service sectors. In particular in Bac Binh and in Thuy Phong, tourism in the coastal area develops fast.

Indicators of of cause and effect were selected on the basis of all project reports and literature review. The Delphi method was used to select sustainability indicators of cause and effect for identification of the impacts of desertification. According to the panel of 23 experts, 27 cause and 22 effect indicators were of particular importance to desertification and drought in the Binh Thuan Province (**Error! Reference source not found.**). Land use planning, surface water availability and number of dry days score the highest as indicators of cause. Water supply for agriculture, water supply for household use and rice cultivation followed by income from agriculture are rated as the most important indicators of effect.

6.3 Conclusions

The results show that:

- 27 cause an 22 effect indicators were identified that according to the panel of experts, were of particular importance to drought in Binh Thuan. Land use planning, surface water, and dry periods were the most important drought related causes of social-economic effects in the province. They mainly impacted agricultural production, water supply both for agriculture and for households, and rice production.
- Water availability for agriculture mainly depends on irrigation that is collected by dams; 10% of the agricultural land is currently irrigated leaving the majority of agricultural land rainfed;
- Over 50% of the households depend on tap water for drinking and personal hygiene. Most vulnerable to drought are the families that use well water (over 40%) and rain water (less than 5%). Developments in agriculture are driven by the availability of irrigation water.
- Local communities adapt to drier conditions by selecting new crops: areas and production of less water demanding crops such as dragon fruit increase. New crops, that are drought tolerant, such as jatropha and sterculia, are introduced. The area where rice is grown depends on the availability of irrigation water. It decreases when no water is available; it increases as soon as new dams provide water all over the year.
- The families report an average yearly income of 110.328.078 VND (4,000€). Significant variations exist according to location and source of income. Income levels are higher in the coastal area (aquaculture, tourism) and among cattle breeders. There are no indications that income is negatively affected by increasing drought.
- Households in the surveyed area report to spend on average 52.865.263 VND a year. Most money goes to basic food and investments in properties. Expenditures are characterized by significant variations according to communes and type of expenditure. No indications were collected of influence of drought on expenditure.
- Overall 12% of the households in the study area are classified as poor. By commune, this figure varies between 31 and 0 %. There is no indication that poverty is associated with drought.
- The population in the study area shows a modest growth. Moreover there is a rural outmigration that is below the Vietnamese average.

These results are discussed in a context of resilience, uncertainties and future directions of research. In conclusion, the farmers manage to adapt to the slowly progressing drought stress in the province by investing in irrigation and by selecting their crops in line with the changing environmental conditions. Alternative options to traditional farming including new crops, aquaculture and tourism, have a minor role in the transition processes. The relatively high income in the area allows investments, increases resilience and seems to counteract outmigration.

6.4 References used for this chapter

Pham, Ha Linh, Gobin, A., Hens, L., Le Trinh, H., 2012. 6 Societal impacts of desertification. Report of WP3.

Le Trinh H., A. Gobin, L. Hens. Selection of sustainability indicators of cause and effect for identification of the impacts of desertification for Binh Thuan province, Vietnam. Submitted to the journal of Ecological Indicators (http://www.journals.elsevier.com/ecological-indicators/)

Le Trinh H., A. Gobin, L. Hens. Uncovering causes and effects of desertification using a Leopold matrix in Binh Thuan Province, Vietnam. Submitted to Human Ecology http://www.hunter.cuny.edu/humaneco/human-ecology-an-interdisciplinary-journal

7 Adaptation and mitigation strategies and plans (WP4)

7.1 Methodology

Expert panels were organised to establish a Leopold matrix and perform the AHP ranking.

To contribute to an evidence based drought policy in Binh Thuan, the following methods were used:

- A synthesis of the 3 climate change scenario's handled by the Vietnamese authorities (MONRE);
- The analytical hierarchy process (AHP) allows to weight and prioritize causes and effects of drought;
- Risk assessment of the bio-physical and social-economic aspects of drought allows to identify both the natural and human sensitive and vulnerable aspects;
- Cost-benefit analysis allows to put decisions on mitigation projects in a monetary and sustainability context;
- A Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis is used to analyse the status and the future trends of the responses to drought under the 3 scenario's and their impacts on decision makers and other stakeholders;
- Best practices for adaptation measures, were identified in a context of the UNCCD and UNFCCC recommendations;
- The important elements for drought policies emerging from this research were summarized in a context of terms of reference (ToR) for a strategic environmental assessment (SEA);
- Conclusions and recommendations were cross-checked during 4 workshops in Hanoi and Brussels.

7.2 Results

Combined effects of desertification and human activity may cause increased degradation of natural resources including vegetation. Drought and intense heat may contribute to poverty in rural areas without access to water resources. The most vulnerable are farmers without access to irrigation and the rural poor.

A risk assessment analysis using a combined Delphi, Leopold Matrix and Analytical Hierarchical Process involving 23 experts elicited land use planning, surface water availability and number of dry days as overall important causes (Table 11). In particular the relationship surface water resources for agriculture, irrigation and water supply for agriculture, aquaculture and shrimp cultivation, rainfall and agriculture, rainfall and rice cultivation, surface water resources for household use, and population density and household water supply as most important cause-effect relationships. Water availability for rural income generating activities such as irrigation, rice production and shrimp cultivation are at the core of the perceived problems.

Current **mitigation** efforts to combat desertification include sand dune stabilisation through revegetation and the construction of dams for water supply to the worst affected areas. Drought mitigation efforts include land, water and soil resources management such that salinisation, laterite formation and erosion are avoided. Only coarse inventories of current water resources are known, their use or potential to bridge the dry season is less well known. Salt intrusion is reported in coastal areas, but the extend of the problem is unknown.

Table 11 Risk assessment for climate change and desertification in the Binh Thuan province

EFFECTS / CAUSES		*Agricultural activities*														*Water supply*		*Income*		*Expenditure*		*Migration*	
		Cultivated area							Raising animals														
		Rice	Vegetable	Sweet potatoes	Cotton	Dragon fruit	Cassava	Maize	Buffaloes	Cattle	Goats	Shrimp aquaculture	Fresh water fish aquaculture	Rising sheep	Mode of production	Agriculture	Eating	Agriculture	Industry	Health	Food	In migration	Out migration
Physical	Geographical and natural position of the territory	3.9	3.9	3.0	4.6	4.8	2.4	2.7	2.3	2.2	2.8	4.0	3.2	3.7	4.4	6.5	5.3	4.7	3.8	3.6	2.6	4.5	4.6
	Geology	2.0	1.9	1.8	2.1	2.2	1.8	1.6	0.9	0.9	0.7	1.9	1.2	1.0	2.5	3.7	3.4	1.8	2.1	1.2	0.5	1.9	1.9
	Soil characteristics	5.8	5.5	4.9	5.3	5.1	4.3	4.5	1.0	1.1	1.5	1.5	1.1	1.2	4.8	4.0	2.2	3.6	1.2	0.9	0.4	1.3	1.5
	Land use/ land cover	5.4	5.3	4.7	5.5	5.3	4.4	4.8	4.3	4.4	4.5	3.2	2.8	4.4	5.1	4.1	2.2	4.6	2.0	1.4	1.1	2.3	2.4
	Topography	5.8	4.5	4.5	4.7	4.9	3.9	3.4	2.3	2.8	2.8	4.1	4.0	3.5	5.4	6.2	4.9	3.5	2.6	1.9	1.0	2.4	3.0
	Rainfall	6.8	5.9	4.9	5.1	5.3	4.5	4.7	2.9	2.7	2.7	4.7	4.0	3.1	5.7	7.1	6.0	4.9	2.3	3.3	2.5	2.2	1.9
	Water resources – Surface water	6.6	4.9	4.1	4.5	4.7	2.8	3.8	3.9	3.6	2.8	6.3	6.3	3.1	5.7	7.6	6.8	5.4	4.1	4.2	3.7	3.6	3.4
	Water resources – Ground water	2.0	2.1	2.3	3.0	3.0	1.3	1.3	1.3	1.2	1.2	3.2	2.2	2.2	3.4	3.8	6.4	2.7	3.2	3.2	3.1	2.3	1.9
	Sunshine duration	5.4	5.0	4.5	5.6	5.6	3.7	4.4	1.7	2.1	2.2	2.6	1.8	2.8	3.2	4.7	3.7	3.8	1.5	4.0	2.6	1.3	1.4
	Period of sunny, dry days	6.2	6.3	5.0	5.2	5.4	4.4	5.2	4.6	4.3	4.3	3.8	3.6	4.5	4.1	6.7	5.8	5.3	2.7	4.7	4.2	2.2	2.4
	Temperature	5.2	5.4	4.6	5.2	5.3	3.8	4.2	4.7	4.6	4.1	4.8	4.5	4.8	4.3	5.1	4.0	3.5	2.3	4.4	3.4	1.8	1.6
	Humidity	5.2	5.3	4.3	4.3	5.1	3.7	4.1	2.7	2.6	2.3	2.1	2.3	3.4	3.6	4.5	3.3	3.1	1.8	4.1	1.9	1.0	0.9
	Wind/wind direction	1.7	1.9	1.4	1.1	1.3	1.1	1.5	1.3	1.3	1.1	0.8	0.6	1.3	2.4	1.6	1.1	1.2	0.7	2.8	0.6	0.3	0.3
	Wind speed	3.3	2.7	1.7	2.7	3.2	2.0	3.4	1.0	0.9	0.8	0.7	0.5	1.0	2.4	1.7	1.2	1.9	0.9	2.1	1.0	0.7	0.6
	Hazard/risk	4.1	4.0	3.9	3.2	3.7	3.6	3.1	2.7	2.6	2.6	4.2	3.8	2.3	4.5	3.8	3.8	4.4	2.7	3.2	2.9	3.4	3.8
Socio-economic	Population density	3.6	3.2	1.9	2.2	2.2	2.2	2.2	2.5	2.7	2.8	2.1	2.5	1.9	3.9	4.7	6.8	4.4	3.1	4.1	3.1	5.1	5.4
	Social awareness	2.6	2.6	2.1	2.5	2.8	2.8	2.7	2.1	2.2	2.2	3.3	2.8	2.5	5.7	2.7	3.4	3.7	3.7	4.0	3.6	3.2	3.4
	Land use planning	6.0	5.5	5.1	5.0	5.2	4.9	5.1	4.5	4.5	4.4	5.0	4.7	4.1	6.6	6.0	4.8	5.5	3.5	1.9	1.3	5.1	4.6

CAUSES	EFFECTS	Agricultural activities														Water supply		Income		Expenditure		Migration	
		Cultivated area							Raising animals														
		Rice	Vegetable	Sweet potatoes	Cotton	Dragon fruit	Cassava	Maize	Buffaloes	Cattle	Goats	Shrimp aquaculture	Fresh water fish aquaculture	Rising sheep	Mode of production	Agriculture	Eating	Agriculture	Industry	Health	Food	In migration	Out migration
	Forestry	3.1	2.1	1.7	1.6	1.6	2.7	2.5	1.3	1.2	1.9	1.9	1.2	1.5	3.3	4.5	3.9	3.6	2.7	1.9	1.2	2.6	2.0
	Conversion of forest	2.3	1.6	1.4	1.3	1.4	2.1	1.9	1.3	1.3	1.6	0.9	0.8	1.0	3.9	3.1	2.7	2.2	2.1	1.9	1.2	1.9	1.4
	Titanium mining	1.4	1.4	1.5	0.9	1.0	0.7	0.7	0.6	0.8	1.1	2.6	2.4	1.2	3.8	2.3	2.7	2.0	5.2	2.5	1.8	2.9	2.5
	Aquaculture	3.6	1.9	1.6	1.4	1.3	0.9	0.9	0.7	0.7	1.1	7.1	6.5	0.8	4.5	3.6	2.6	4.9	2.1	2.8	2.7	2.4	2.2
	Irrigation	6.5	4.9	3.3	3.8	3.5	2.7	3.3	1.4	1.3	1.5	4.2	4.3	1.4	6.4	7.4	6.1	6.2	2.3	2.3	1.4	2.2	2.2
	Hydroelectricity/reservoir	4.7	3.9	2.5	3.0	2.8	2.0	2.3	1.4	1.5	1.6	3.1	3.6	1.4	5.3	6.6	4.8	4.4	3.6	2.0	1.3	3.0	4.4
	Immigrant-resettlement from developing projects	2.8	2.6	2.3	1.6	1.8	2.2	2.3	2.2	2.3	2.3	1.6	2.3	1.5	5.2	4.6	5.2	3.6	1.8	3.5	2.8	5.3	5.3
Biological/ Ecological	Dunes	2.1	2.7	3.2	2.8	2.8	2.1	1.7	1.3	1.3	1.5	2.6	2.6	1.7	3.8	3.2	2.8	2.7	1.6	2.5	1.6	1.3	1.4
	Forest	2.2	1.9	1.7	1.8	1.8	1.7	1.5	2.6	2.5	3.0	1.1	1.2	2.1	5.5	5.2	4.7	3.3	1.9	3.1	1.3	1.9	1.5

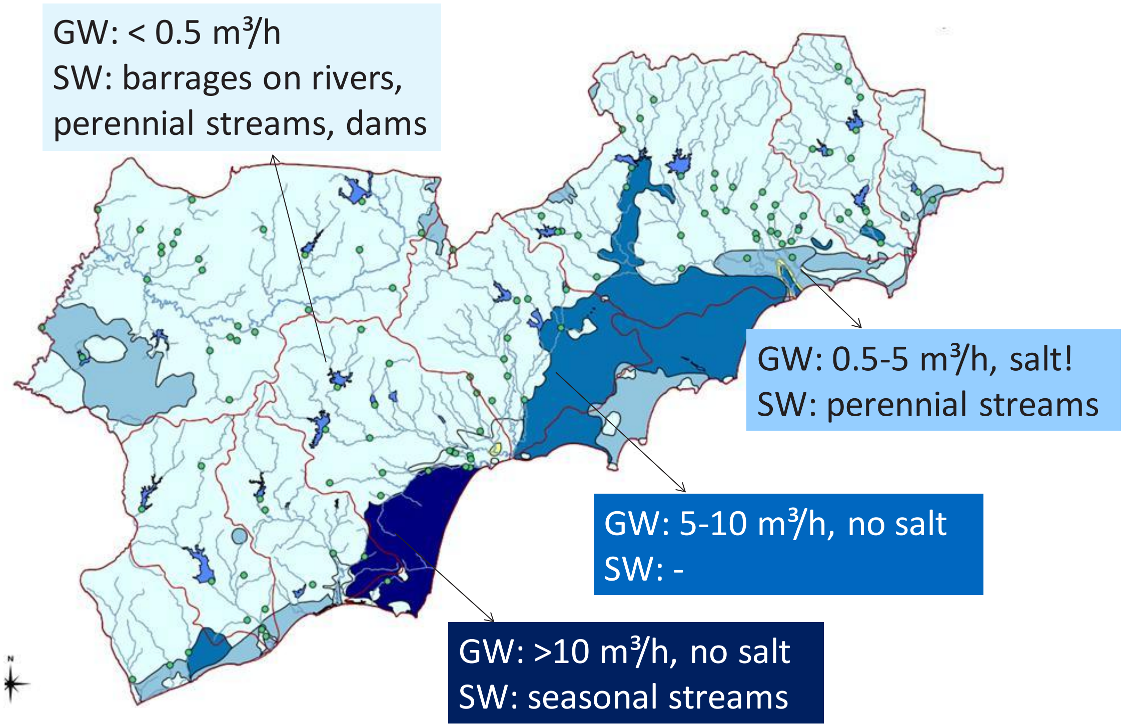


Figure 26 Surface Water (SW) and groundwater (GW) resources in the Binh Thuan Province

Current **adaptation** options concentrate on the following items:

- ✓ Bridging the dry season with the available fresh water resources remains a major challenge in the rural areas;
- ✓ Less water demanding opportunity crops such as dragon fruit are increasingly grown near rivers and streams;
- ✓ A shift to drought tolerant crops such as cassava and cashew occurs on sandy soils; and,
- ✓ The sand dunes offer opportunities for tourism.

7.3 Conclusions

The results of the previous WP's were complemented with a risk assessment and a ranking (AHP) of causes and effects of drought in Binh Thuan, best practices to deal with drought, a cost-benefit of selected policy options, and a SWOT analysis of the local situation.

- The results of the AHP methods allow to weight and prioritise aspects of causes and effects. Water supply, immigrant-resettlement and forest conversion were considered as the most important causes of drought. Water resources for households, agriculture, and aquaculture, agriculture practices (especially those applied in the production of rice), and socio-economic activities were considered as the most important effects. Current adaptation policy options include the installation of irrigation dams. Increased irrigation leads to increased agricultural production and enables the population to bridge the dry season. On the other hand, irrigation dams limit the availability of suspended particles and contribute to river bank and coastal erosion. An active agricultural policy to cultivate less water demanding crops more efficient use of the irrigation water and rational water use in the households, tourism and other industrial sectors are part of the adaptation measures. A combined SWOT and risk assessment analysis was carried out to uncover strengths, weaknesses, opportunities and threats (SWOT analysis) of strategic adaptation policies to desertification for the major sectors, i.e. agriculture, forestry, aquaculture and fisheries, water and natural resources, industry, and land use planning. This allowed to advocate an integrated and comprehensive drought policy (including strategic management of water resources, proper land use, protection of in particular the forests and dunes, and maintenance of the current income trends), its instruments (ecosystem conservation and water management plans, increasing the resilience of the agriculture, monitoring, and specific interventions as insurance systems), and the main stakeholders/target groups (farmers, poor, administration).

- A marginal cost-benefit analysis shows that the construction of dams shows a most beneficial ratio when the increased agricultural production us taken into account. It remains however difficult to allocate reliable costs related to the mitigation of river banks and coastal erosion.
- An outline for SEA provides a basic framework to assess future development projects on their environmental and social merits. The SEA specifically includes the results that emerged from this study.
- An analysis of three scenarios (low-mid-high) shows that for the Binh Thuan province between 5.42 and 10.8 % of the population (mid: 60,964.09 people) will be affected, and between 2.55 and 5.00% of the land (mid: 19,063.52 ha) will be damaged mainly as a result of sea level rise. This will result in an estimated 4.2 to 10.0 % decrease of the GDP (mid: 963,953.02 million).

The combination of the bio-physical and socio-economic data with the results of the analyses in WP4 is new for Vietnam and Binh Thuan. This type of policy support is highly appreciated. An integrated approach to natural resources use and management is essential to combat environmental hazards such as desertification. To this extent the Vietnamese government has installed effective policies that include action programs on reforestation to combat desertification and erosion, on improved water resources for household use and irrigation, on agriculture and animal husbandry, and on coastal zone management. The carrying capacity of these systems, however, is not known and further monitoring and research is needed to elicit the limits of the current options.

7.4 References used for this chapter

Le Trinh H., A. Gobin, L. Hens. Application of the analytical hierarchy process to propose and prioritise solutions – a case study in the province of Binh Thuan, Vietnam. Submitted to the Journal of Environmental Management http://www.journals.elsevier.com/journal-of-environmental-management.

Le Trinh H., A. Gobin, L. Hens. Risk assessment for desertification and climate change – a case study in Binh Thuan province, Vietnam. Accepted for publication in the Journal of Human and Ecological Risk Assessment http://www.tandf.co.uk/journals/titles/10807039.asp

Le Trinh H., A. Gobin, L. Hens. Mitigation and adaptation options to desertification in the Binh Thuan Province of Vietnam. Report of WP4.

Gobin, A., Pham, H., Le Thi Thu, H., Le Trinh, H., Hens, L., Pham Quang, V. (in preparation). Natural hazards and resources management in the Binh Thuan Province, Vietnam. Environmental Science and Policy.

Gobin, A., Le Trinh, H., Pham Ha, L., Hens, L.. Land use and desertification in the Binh Thuan Province of South-Eastern Vietnam: mitigation and adaptation options now and under climate change. Selected for presentation at the European Geophysical Union General Assembly 2012, at Vienna.

8 Project Conclusions

The climate in Binh Thuan is characterised by an average 1130-1340 mm of rainfall a year and a high evaporation of 1350 mm, which points to a dry climate. Moreover, drought in Binh Thuan is characterised by a significant variation in the onset of the rainy season and in the time period the rain comes. When these parameters are introduced in the IPCC climate models, a progressing drought characterized by an average temperature increase of 1.6°C by the middle of this century has to be expected.

Historical hydrological data show that in Binh Thuan the total amount of rainwater does not change. However, the length of the dry season (and consequently this of the wet/rainy season) varies considerably. This affects the flow of water in the rivers and the replenishing of the groundwater layers.

The hydrological regime also contributes to soil degradation. Areas with a high rainfall intensity (e.g. in the Bao Lac and Xyan Loc communes) are prone to erosion. In the coastal area the sand dunes are subject to movements (Bac Binh and Tuy Phong districts). The clay soils, bordering the ancient river banks, dry out, become arid and hard owing to laterite formation. This results in four types of soil degradation: sand dune formation in the Central-Eastern part, salinisation of soils in the areas bordering the sand dunes, wind and water erosion on clay soils, laterite formation, and erosion with rock outcropping in the mountains.

The human activities in Binh Thuan are determined by the ecosystems: a sandy coastal area in the East (13% of the land) a central agricultural belt (20%) and mountains in the West (47 %).

The changing bio-physical characteristics affect agriculture. Farmers move to drought stress resistant crops as dragon fruit in the non-irrigated areas, while water demanding crops as paddy rice, are increasing in the irrigated parts of the province.

There are no indications of shortage of surface and groundwater availability for the households, although the drinking water reserves are at risk of depletion (surface water) and salinisation (coastal groundwater).

The main policy response to drought in Binh Tuan is building dams to collect irrigation water. Currently in Bac Binh and in Tuy Phong 17800 ha of the land is irrigated and more dams are planned. On the short term, irrigation increases the income of the farmers which contributes their resilience, keeps poverty to low levels and prevents out-migration of young adults. On the other hand, the dam policy contributes to coastal erosion and changes the river banks.

Binh Thuan is in need of a more comprehensive drought policy that takes into account the negative effects of dam construction, the risks related to drinking water availability, waste water management and the protection of the ecosystems. A main target should be rational water use. This policy should be driven by managerial (planning for specific issues, SEA), technical (advanced irrigation), economic (water fees), monitoring and training instruments. It should address the main stakeholders (farmers, households, tourism) in the province. This integrated policy should be evidence based and use the results of risk analysis, priorities in causes and effects of drought, cost benefit approaches and best available technologies.

Drought policy in Binh Thuan is in need of research support. Most of the research these days is analytical and descriptive. More attention should go to the bio-physical and socio-economic mechanisms that drive the drought induced changes. Moreover applied research e.g. on how to implement rational water use and integrated water management in the province should be undertaken. A proposal along these lines should be submitted in line with the BTC activities and complementary funding by Belspo (Bilateral agreement). In Vietnam, the same project should be submitted to the Binh Thuan People’s Committee and the Ministry of Planning and Investment.

9 Products and services

9.1 Work package reports and presentations

- WP1: Summary report 101 pp.; full report (in Vietnamese) 278 pp.; powerpoint presentations; geo-atlas with 24 thematic maps; relational database.
- WP2.1: summary reports; full report; powerpoint presentations.
- WP2.2: report including maps 54 pp., powerpoint presentations**.**
- WP3: Report 84 pp., including thematic maps; powerpoint presentations.
- WP4: Report; 86 pp, SEA concept note; powerpoint presentations.
- WP5: Report; powerpoint presentations.

9.2 Publications

9.2.1 Journal papers published or accepted for publication

- Hountondji Y, de Longueville F., Ozer P. (2012). Land cover dynamics (1990-2002) in Binh Thuan province, Southern Central Vietnam. International Journal of Asian Social Science, 2(3): 336-349. http://hdl.handle.net/2268/116012 (related to WP2)
- Le Trinh H., A. Gobin, L. Hens. Risk assessment for desertification and climate change – a case study in Binh Thuan province, Vietnam. Accepted for publication in the Journal of Human and Ecological Risk Assessment http://www.tandf.co.uk/journals/titles/10807039.asp (related to WP4)

9.2.2 Journal papers submitted or in preparation

- Gobin, A., H. Nguyen Trong, V. Pham Quang, H. Pham Thi Thanh. Heavy rainfall distribution during ENSO cycles and the impact on flooding and paddy rice cultivation. Submitted to Natural Hazards and Earth System Sciences (related to WP1)
- Gobin, A., Pham, H., Le Thi Thu, H., Le Trinh, H., Hens, L., Pham Quang, V. (in preparation). Natural hazards and resources management in the Binh Thuan Province, Vietnam. Environmental Science and Policy.
- Ozer P. (in preparation). Disparition du village de pêcheurs de Phan Thiet (Vietnam): reflexions sur les representations des risques climatiques en milieu côtier, GEO-ECO-TROP (related to WP2)
- Le Trinh H., A. Gobin, L. Hens. Selection of sustainability indicators of cause and effect for identification of the impacts of desertification for Binh Thuan province, Vietnam. Submitted to the journal of Ecological Indicators (http://www.journals.elsevier.com/ecological-indicators/) (related to WP3)
- Le Trinh H., A. Gobin, L. Hens. Uncovering causes and effects of desertification using a Leopold matrix in Binh Thuan Province, Vietnam. Submitted to Human Ecology http://www.hunter.cuny.edu/humaneco/human-ecology-an-interdisciplinary-journal (related to WP3)
- Gobin, A., Le Trinh H., Pham Ha, L., L. Hens, Le Thi Thu, H., Pham Quang, V.. Land use and land cover changes and socio-economic activities related to climate change and desertification in Binh Thuan province, Vietnam. In preparation – Environmental Science and Policy or Land Use Policy (related to WP3)
- Le Trinh H., A. Gobin, L. Hens. Application of analytic hierarchy process to propose and prioritise solutions – a case study in the province of Binh Thuan, Vietnam. Submitted to the

Journal of Environmental Management http://www.journals.elsevier.com/journal-of-environmental-management/ (related to WP4).

9.2.3 International conference proceedings

- Doutreloup, S., Erpicum, M., Fettweis, X., & Ozer, P. (2011). Analysis of the past (1970-1999) and future (2046-2065 and 2081-2100) evolutions of precipitation and temperature, in the Province of Binh Thuan, South East Vietnam, based on IPCC models. Proceedings of the 1st International Conference on Energy, Environment and Climate Change, August 26-27 2011, Ho Chi Minh City, Vietnam. Available at http://hdl.handle.net/2268/96759 (related to WP2)
- Hountondji, Y., & Ozer, P. (2011). Land use and land cover change analysis 1990-2002 in Binh Thuan Province, south central Vietnam. Proceedings of the 1st International Conference on Energy, Environment and Climate Change, August 26-27 2011, Ho Chi Minh City, Vietnam. Available at http://hdl.handle.net/2268/97731 (related to WP2)
- Ozer P. (2012). Non, le village de pêcheurs de Phan Thiet (Vietnam) n'a pas été victime du changement climatique, selected for presentation at the Colloque international Géomatique et gestion des risques naturels, 6-8 mars 2012, Oujda, Maroc. (related to WP2)
- Gobin, A., Le Trinh, H., Pham Ha, L., Hens, L.. Land use and desertification in the Binh Thuan Province of South-Eastern Vietnam: mitigation and adaptation options now and under climate change. Selected for presentation at the European Geophysical Union General Assembly 2012, at Vienna. (Related to WP3 and WP4)

9.2.4 Press articles

- VITO annual report
- VITO vision on major project findings
- VITO vision on project workshop

9.3 Workshop presentations by project team members

- Hanoi: March 2011 workshop; all work packages were presented.
- Hanoi: November 2011 workshop; all work packages were presented.
- Brussels: March 2012 workshop; all work packages were presented.

10 Project Management

10.1 Project team

WP1 and coordination in Vietnam

Dr. Pham Quang Vinh
hientuanphuong@yahoo.com

WP2

Section1: Dr. Pierre Ozer
pozer@ulg.ac.be

Section2: Prof.Dr.ir. Dirk Raes
Dirk.Raes@ees.kuleuven.be
Withdrawn from the project in November 2011
Tasks completed by Dr.ir. Anne Gobin

WP3 and coordination in Belgium

Prof.Dr. Luc Hens
Luchens51@gmail.com
Dr.ir. Anne Gobin
anne.gobin@vito.be

WP4

Prof.Dr. Luc Hens
Luchens51@gmail.com
Dr.ir. Anne Gobin
anne.gobin@vito.be

10.2 Management

10.2.1 Timing

The Belgian section of the project started on 1st April 2010 and was planned to last until March 31st 2012. Two events influenced the project coordination:

- The Vietnamese section of the project started on January 1st 2010 and ended by December 2011. This resulted in an overlapping phase of 1.5 year and a two sided declination of 6 months in total. This only caused minor problems in the synchronisation of the WP's. To some extent this was even an advantage as WP1 (on which the other WP's relied) started 3 months before WP 2-4.
- By June 2010, after signing the contract, the VUB decided to transfer the project to VITO. The administrative procedure lasted until August 2011.
- During this period no expenses could be made on the VUB part of the project. Also an agreement between VUB and KUL that was requested by Leuven University was not realized.

This was a major cause of the withdrawal of the project by the Leuven group (Prof. D. Raes) in November 2011.

- These delays in the execution of the project resulted in a request to extend the project period until May 31st 2012 and revision of the budget allocated to VUB. This request was kindly agreed upon by BELSPO.
- The ULg group of Prof. P. Ozer executed its part of the research in line with the previous schemes.

10.2.2 Management meetings

Three types of management meetings allowed coordinating the project:

- International: Vietnamese-Belgian meetings on the project progress and the management of the project were hold both in Hanoi and in Belgium at each occasion the promoter visited the project. During the whole time span of the project 5 such meetings were organized in Hanoi and one in Brussels.
- National: during the active period of the project (1/4/10-30/6/10 and 1/9/11-31/5/11) 4 meetings were organized with the Belgian partners in the project.
- Internal: in particular after the transfer of the project to VITO, the project execution was most intense. This necessitated regular meetings in Mol and Berchem among the VITO participants.

These different types of meetings mainly targeted to information exchanges and project planning, proved to be most useful and necessary to steer the interrelations between the working packages.

10.2.3 Workshops

- Scoping workshop and kick-off conference: on July 21st a scoping workshop was organized at the Institute of Geography (VAST) in Hanoi. The main aim of these activities was to present the project both to or scientific and a stakeholder audience, during the starting phase of the research. Comments contributed to the fine tuning, planning and execution of the field work. 30 participants contributed to these activities.
- Mid-term workshop: in March 2011, the Institute of Geography organized a mid-term evaluation of the first year results of the project. In the workshop mainly participated professors and researchers of VAST. The workshop was most necessary in adjusting the Belgian delays with the Vietnamese progress. The workshop noticed the participation of 15 interested partners.
- Concluding conferences: both in Hanoi (November 21st 2011) and in Brussels (March 15th 2012) conferences were organized to announce the results of the project. The Hanoi workshop organized at the Institute of Geography attracted some 45 participants, while 50 people assisted in the workshop organized in the BELSPO meeting rooms in Brussels. Both workshops allowed collecting comments from the scientific community and the other stakeholders. This information proved to be most useful in drafting the discussions of the different work packages. Most comments were related to further research and policy issues. The workshops equally contributed to the dissemination of the results.

10.2.4 Exchange activities

- During the first project year a group of 6 Vietnamese researchers of VAST that were involved in the project visited Belgium for a 10 days period. The mission allowed to realize contacts with research departments in areas related to climate change, drought and remote sensing.
- During the second project year (May-July 2011) two Vietnamese researchers visited Belgium for 3 months each. Ms. Pham Ha Linh, worked at VITO on aspects related to WP3. She was directed by Dr.ir. Anne Gobin. Mr. Nguyen Thanh Binh worked at the department for Earth

and Environmental Sciences of KUL, guided by Dr. Stefaan Dondeyne. He worked on the agro-climatic aspects that are part of WP2.

- Belgian visitors to Binh Thuan included Anne Gobin (November 2011, May 2012), Pierre Ozer (March, 2011) and Luc Hens (July 2010 and July 2011). At each occasion the Vietnamese partner kindly organized all necessary contacts in Binh Thuan. These visits proved to be most necessary to collect data, but also to become acquainted with the study area.
- During the project period the Belgian promoter visited Vietnam 5 times. At each occasion both a contents (workshop reporting, field visit) and a managerial (status review, coordination, planning) component was foreseen. The Vietnamese project promoters visited Belgium twice: once at the occasion of the mission of the Vietnamese delegation; a second time at the occasion of the scientific concluding workshop in Belgium.

10.3 Coherence between project proposal and results

10.3.1 Content and scientific value

On WP1, 3 and 4 all targets proposed were reached.

On **WP1**, this concerns the contents of a most complete report, an atlas on drought issues and a GIS database. The surveys on hydrology, fauna and flora, soil degradation, land use and land use changes, and drought sensitive areas were executed by the Institute of Geography. The results were integrated in the WP1 report.

On **WP2**, the climate analysis based on both historical and projected data was carried out very well by the ULg. The statistics were brought in line with the field observations. Land use/cover change detection was analysed by VITO and ULg. The contribution on agro-climatology, that was allocated to KULeuven, was initially limited to the results of the stay of Mr Nguyen Than Binh at the department of Earth and Environmental Sciences in Leuven. Further efforts by VITO were subsequently undertaken to include a comprehensive analysis of meteorological data. These findings were augmented with a soil suitability for agriculture (irrigation) and land degradation analysis.

On **WP3** this concerns the full report including a description of the bio-physical and the socio-economic status in Binh Thuan, an identification of the main causes and effects in the province and an in depth analysis of these main socio-economic drivers and effects. The discussion highlights among others aspects of resilience of the population, drought policy and implications for further research. WP3 invested significant energy in establishing socio-economic indicators and indexes to monitor drought and its policy responses. In particular the changes in agricultural crops were studied.

WP4 used a combination of methods that provide evidence based materials to establish a drought policy for Binh Thuan. This approach was innovative and resulted in recommendations for a sound adaptation and mitigation policy. Also an outline for a strategic environmental assessment, including the points of sensitivity demonstrated by this project, was one of the outputs of WP4.

10.3.2 Scientific spin-off

As shown in the sections 5.5 and 5.6 of this report, currently 4 proceedings reports and 9 papers are in different stages of the publication process (accepted, submitted, in preparation). This is most significant for a two years project. This result is mainly related to the interdisciplinary originality of the project, and the relative undercooled scientific attention that was given to the study area this far. Also the workshops resulted in cross links and optimization of the scientific use of the results. The workshop in Brussels resulted in a link between the WP3 data and on Ph.D. work at the ULg. A main aspect concerned the scarce socio-economic (e.g. on income and expenses) data on the area, a relative unknown impact of extreme weather events including drought on both the environment and socio-economics of the area, and a further exploration of adaptation options in terms of natural resources management.

10.3.3 Societal spin-off

- **Policy**: an important target group of the results of this project are policy makers in Vietnam. The National competent Ministries (MONRE, MOSTE, MARD, MPI) were involved in establishing the main project, lines and items. They followed up the project in the workshops, to which a number of them actively contributed by lectures and discussions. As an outspoken target of the project was related to drought policy implications in Binh Thuan, the provincial authorities were a main stakeholder. They most cooperatively provided data and arranged appointments for the field work; they participated in the workshops, and expressed their special interest in the way the project provided multiple and complex evidence based policy data. They equally expressed their interest in tangible outputs as the data base and the atlas. Their basic attitude was driven by the fact that they most welcomed scientific and evidence driven support for their mainly experience based policy.
- **Local Authorities**: a similar attitude was encountered at the level of the district authorities: cooperative at the stage of data gathering and interest in the feedback of the results. BTC recently focuses at Binh Thuan with a project on impacts of climate changes of urbanization. As shown e.g. by the discussion at the Brussels conference, the results will be of direct use for them.
- **Research**: the results will directly benefit the VAST Institute of Geography, of which different departments were actually involved in the project trough the workshop and performing parts of the project. Also the Vietnam National University and in particular the faculty for environmental sciences contributed to the project. During the project period Luc Hens contributed to an international conference an international cooperation with Vietnam in the area of Marine Sciences and received as the only Belgian thus far, a golden medal of VAST in recognition of outstanding lifetime scientific collaboration performance.
- **NGOs**: during the project contacts with WWF (Hanoi) and other organizations were maintained in relation with their work on drought in Vietnam.