

# **Environmental Indicators For Tropical Areas**

## **A Methodology Applied to Forest, Water and Soil Degradation in Thai Nguyen Province, Vietnam**

**Yannick Glemarec**

Technical Editor: Pierre Brabant  
Unit 140 "ESPACE" of IRD

A research undertaken within the framework of project STD3 - CT94-0310 of the European Union (DG XII) and coordinated by l'Institut de recherche pour le développement, France





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Photo on cover page: G. Bourgeon

Contacts : Yannick Glemarec,  
Email : [yannick.glemarec@undp.org](mailto:yannick.glemarec@undp.org)  
Pierre Brabant, ,  
Email: [Pierre.Brabant@bondy.ird.fr](mailto:Pierre.Brabant@bondy.ird.fr)  
Centre IRD de l'Île de France  
32, avenue H. Varagnat F 93143 Bondy Cedex. France  
<http://www.bondy.ird.fr/carto>

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## ABBREVIATIONS

BOD	Biological Oxygen Demand
CERPAD	National Centre for Rural Planning and Development
COD	Chemical Oxygen Demand
DANIDA	Danish International Development Assistance
DOSTE	Department of Science, Technology and Environment (Vietnam)
EC	European Commission
EIS	Environmental Information System
EQI	Environmental Quality Index
ESRI	Environmental System Research Institute
FAO	Food and Agriculture Organisation
FIPI	Forest Inventory and Planning Institute
GIS	Geographical Information System
HDI	Human Development Index
HMS	Hydro-Meteorological Service (Vietnam)
IG	Institute of Geography, Vietnam
IRD	Institut de recherche pour le développement (former ORSTOM)
IUCN	International union for the Conservation of Nature
LQI	Land Quality Index
MOSTE	Ministry of Science, Technology and Environment (Vietnam)
STRESS	Pressure, State, Response model
UNDP	United Nations Development Programme
USLE	Universal Soil Loss Equation
WATSAN	Water and Sanitation
WHO	World Health Organisation
WRI	World Resource Institute
WSS	Water Supply and Sanitation
UNICEF	United Nations Children's Fund
UNDP	United Nations Development Programme



# INTRODUCTION

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This book is about environmental indicators, and the positive contributions such indicators can make to policy development and decision making processes in tropical areas.

Research into environmental indicators for tropical areas is still nascent. The development of environmental indicators designed to meet the unique requirements of tropical areas is often constrained by a limited quality and availability of data. In many tropical areas, complete and reliable field measurements are lacking, and bureaucratic restrictions frequently prevent full access to the limited information that does exist. Consequently, there remains much scepticism of the actual contribution that environmental indicators can make to support policy decision-making in such a context. Using the analytical and communication functions of a database managed by a Geographical Information System (GIS), this study explores a number of methodologies to construct environmental indicators - using only available published information and data - that are sufficiently robust to support policy decision-making in tropical areas.

The preparation of this book was made possible by an EC funded research programme (STD3 - CT94 - 0310) to improve policy formulation and decision-making for the sustainable development of the Vietnamese uplands. The EC research programme ('the Programme') was co-ordinated by the French Institute of Research for Development (IRD, formerly ORSTOM). The fieldwork was carried out in partnership with the Institute of Geography (IG) of Vietnam. A GIS database was created for the three pilot provinces of Thai Nguyen, Bac Kan and Lam Dong. These provinces typify the conditions that characterise the Uplands, which account for 75 per cent of Vietnam's surface area.

A specific objective of the research was to use the GIS database to develop an Environmental Information System for the preservation and sustainable development of the uplands' natural resources. As part of that objective, the purpose of this study - and of this volume - is to define indicators that allow environmental information to be analysed and readily communicated to local decision makers. The analysis of the results given in the final chapter demonstrate the decision-making support potential of environmental indicators and do not constitute an exhaustive exploitation of the data gathered by the Programme. With its emphasis on practical results, however, this book should be of interest not only to those engaged in designing tools to support environmental decision-making, but also to development practitioners working towards the sustainable management of tropical uplands, particularly in Vietnam.

The book consists of four main sections, plus comprehensive Appendices. Chapter 1 examines the principal tools used to establish Environmental Information Systems and to construct environmental indicators. Chapter 2 describes the experimental approach adopted by the Programme, and the main environmental challenges in the pilot province of Thai Nguyen. It also establishes the rationale for the selection of a pressure indicator, a state indicator and a response indicator to describe each of the four major environmental degradation mechanisms in the Uplands - deforestation and loss of biodiversity; soil erosion; water shortage; and water pollution. Chapter 3 describes the methodologies adopted to aggregate the various Pressure-State-Response indicators. And Chapter 4 uses these indicators to analyse and briefly examine the state of the environment in Thai Nguyen Province and assess the effectiveness of existing environmental policies.

Tropical Uplands display an apparent abundance of natural resources (land, water, forest, pastures, wild fauna, minerals, etc). However, would-be developers realise quickly, when soils have died and crops have failed as a result of inadequate land management practices, that their fertility was largely illusory and that tropical uplands are often a highly complex and fragile ecosystem. A key challenge for the sustainable development of tropical uplands is to manage their natural resources efficiently - in a way that meets the needs of growing populations, while minimising negative impacts on the whole ecosystem.

An assessment of past development efforts in tropical uplands shows that sustainable development is easier to aspire to than it is to realise. By and large, decision makers have a good understanding of the principal mechanisms of environmental degradation such as soil erosion, deforestation, biodiversity loss

or air and water pollution. However, they are generally unaware of the dynamic linkages between these mechanisms and the potential impact of various development policies on each of them.

The establishment of an Environmental Information System is essential for sustainable development and management of the complex tropical upland ecosystem. The tremendous advances in information and communication technologies and, notably, the development of desktop geographic information systems, provide unprecedented opportunities to develop cost effective geographical and environmental information systems to support policy decision-making.

The spatial cartographic visualisation functions of a GIS database allow it to easily communicate substantial amounts of environmental data to policy decision makers. Cartography is one of the oldest and most effective instruments for analysis and communication of geographical information. It is easier to communicate complex information visually with maps than by tables or lists, as maps make full use of the natural capacity to make spatial distinctions of colours, forms and relations. GIS are also outstanding integrating and organising tools, because they require users to choose and share the most critical data in their specialisation within a common database. GIS are, therefore, invaluable tools to promote and strengthen integrated decision-making.

However, even a perfectly designed and developed GIS can be difficult to consult and fully utilise. The complexity of computer-assisted data processing limits direct access and manipulation by policy decision makers. And the large amounts of available information can often serve to divert, rather than contribute to, decision-making processes. In the absence of complementary communication tools, GIS do not meet the information needs of strategic decision-making, which requires highly aggregated and interpreted statistical data. Furthermore, the data will have to be communicated to the decision makers using flexible tools that are adapted to the complexity of a particular decision-making process, and to allow a close dialogue between the decision maker and the analyst. One option in developing this dialogue is to integrate aggregated environmental indicators with the capacities of a GIS.

The environmental indicators developed in this study aim to satisfy this key requirement - communicating information on complex ecological and socio-economic interactions in a directly accessible manner to policy decision-makers. These indicators were developed on an experimental basis for the pilot province of Thai Nguyen in Vietnam only. But they were selected so that they could also be readily transposed to other upland provinces and, potentially, to the whole midland and highland zone of Vietnam and beyond.

The Thai Nguyen case study proves the value of environmental indicators for the sustainable development of tropical uplands. It demonstrates their enormous utility as information tools for increasing decision makers' awareness and understanding of the fragile balances in an ecosystem that is often perceived - incorrectly - to be highly fertile and under exploited. It also provides pointers for follow-up methodological work to strengthen the relevance of environmental indicators to policy decision making in tropical areas.

# **I ENVIRONMENTAL INFORMATION SYSTEMS**

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*Environmental policy, if it is to be effective, must be properly informed. And to be properly informed, a system for collecting relevant environmental data, analysing them and presenting them to decision makers must be in place. On the face of it, this is a Herculean task - the quantity of data, the areal extent and range of environments, the logistics of data capture, and the translation of raw data into usable information, have combined historically to limit the capacity of those charged with formulating environmental policy to make decisions based on a complete picture of the situation being analysed.*

*The tremendous advances in technology over recent years have not only provided new techniques for data collection, but - crucially - offer vastly improved methods for processing, aggregating and presenting the data as user-friendly information. The technological development of Geographical and Environmental Information Systems (GIS/EIS) is key to this, and has provided unprecedented opportunities to integrate a wide range of data within a single structure. That, in turn, allows the production of enhanced indicators which feed into, and inform, the decision making process.*

*This chapter examines the nature of the decision making process and describes how environmental indicators contribute to expanding and enhancing the information available to that process. It looks also at the way that they are used and at their limitations.*

## 1.1 OBJECTIVES OF ENVIRONMENTAL INFORMATION SYSTEMS

In Rio de Janeiro in 1992, the United Nations Conference for Environment and Development (CNUED) stressed the need to incorporate environmental concerns in all decision-making processes as a means to promote sustainable development. Chapters 8 (*Integration of Decision-making Processes for Environment and Development*) and 40 (*Information for Decision-making of Agenda 21*)<sup>1</sup> recommend the establishment of information systems to integrate development and environment decision-making processes. The following reviews the specific objectives of integrated environmental information systems as well as the tools available to develop them.

### 1.1.1 Objectives and Users of Environmental Information System

The main objective of an Environmental Information System (EIS) is to provide to decision makers the set of information necessary to enable them to make the best and most timely decisions at the best quality/price ratio (K. McCLOY, 1995). The specific objectives and end users of an EIS will vary according to the type of decision that is required. The data collected by the EIS, and their degree of transformation, will thus have to be adapted to these various objectives and users.

Decision-making can be likened to a cycle in which problems are identified, and where policies are formulated, put into practice, evaluated and re-adjusted in order to improve the situation. This decision-making cycle is represented in Figure 1.

*Problem Identification:* Information is generated by scientists or by the direct users of natural resources based on observation, data collection and analysis of a given situation. The objective at this stage of the Decision Making Cycle is frequently to identify the extent of the problem(s) and their origins in order to bring them to the attention of local decision makers. The Environmental Information System must be capable of providing a good description of the state of the environment.

*Policy Development:* Decision-makers and their technical advisors will formulate policy on the basis of the data collected and the severity of the identified problems. Environmental problems often have complex causes, and decision-makers are thus generally faced with a number of alternative solutions for policy development. The objective of this phase of the Decision-Making Cycle is to select «the best» possible solution taking into account the existence of various selection criteria and priorities.

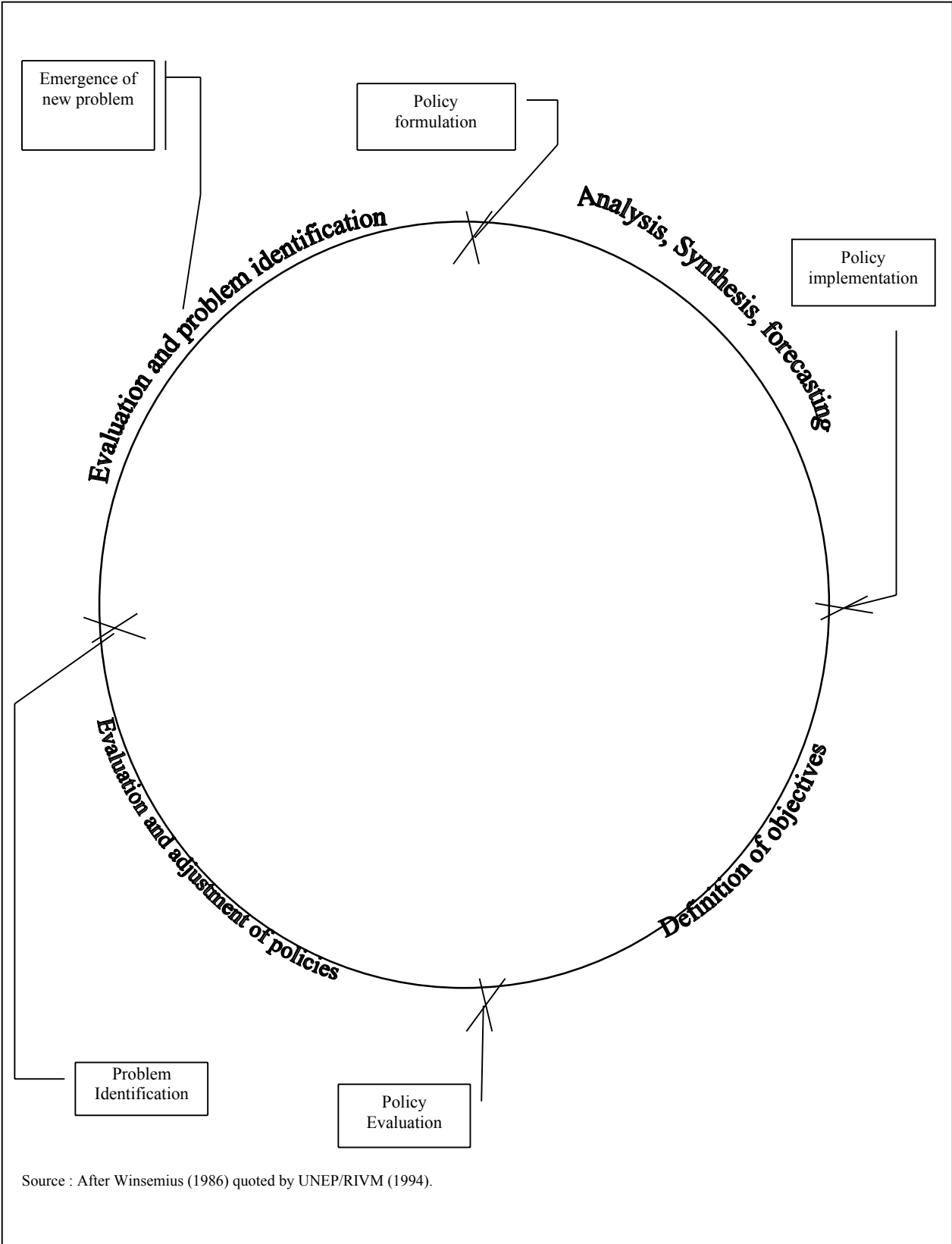
*Putting Policies to Work:* The E I S should allow government authorities, as well as economic agents, to verify to what extent the policies developed, such environmental protection legislation is respected by all partners.

*Evaluation of Policies:* The objective of this stage of the Decision-Making Cycle is to evaluate the effectiveness of the policies that are put into place so that they can be re-adjusted, if need be, to better address the issues. An Environmental Information System must enable evaluation of the environmental, economic and social impacts of the devised policies.

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<sup>1</sup> Agenda 21 consolidates all the contributions made by preparatory working groups to UNCED. The Conference approved the document, which is being used as reference material for the formulation of a number of national development strategies.

Figure 1 : The Decision-Making Cycle

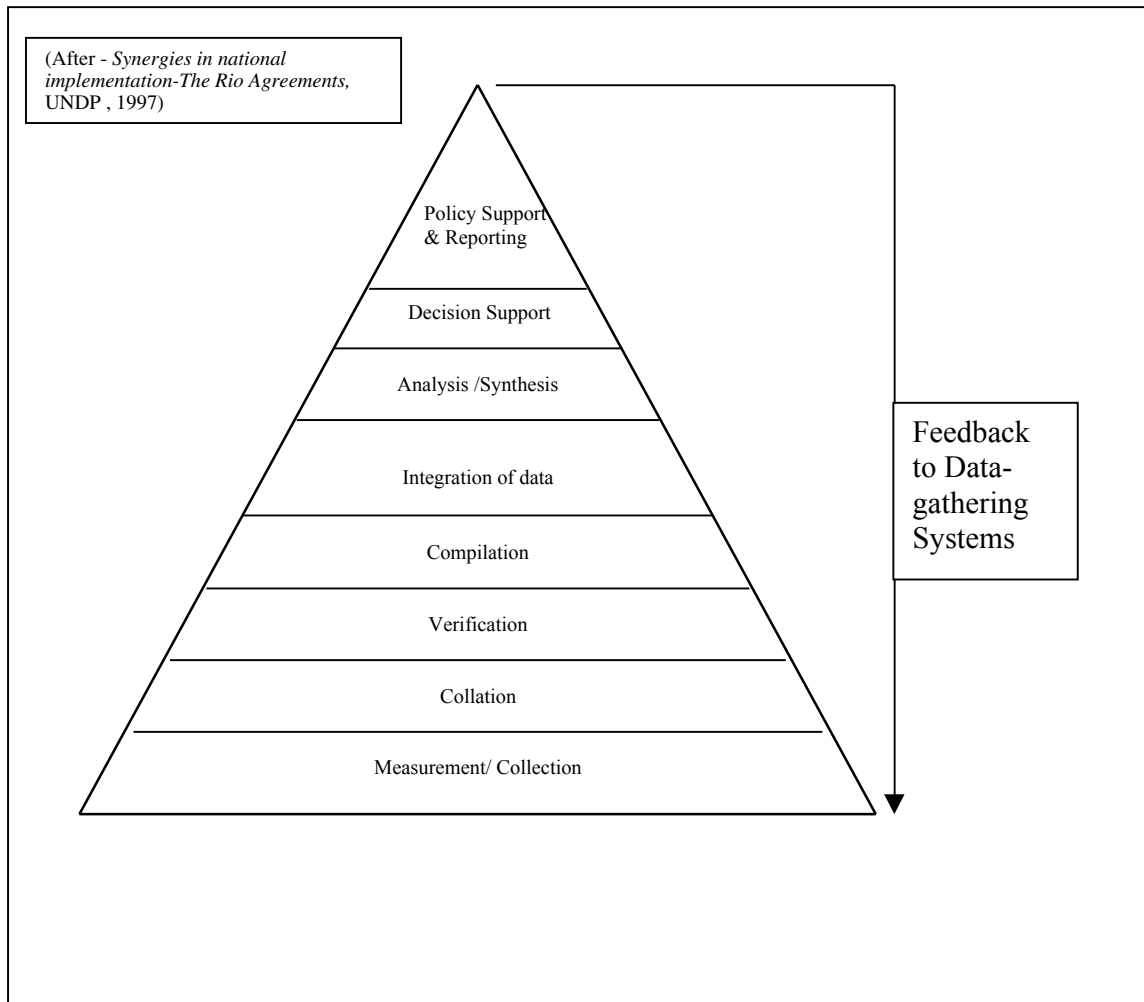


Source : After Winsemius (1986) quoted by UNEP/RIVM (1994).

### 1.1.2 Steps and tools for establishing an Environmental Information System

The transformation of environmental data into information that is appropriate for decision-making can be thought of as an information pyramid, as shown in Figure 2. The collected raw data are checked, compiled, integrated, analysed and synthesized at each level of this pyramid until they can be directly assimilated by policy decision makers in negotiating and formulating development strategies.

**Figure 2 : The information pyramid**



The data are defined as nominal or ordinal raw observations of an object or a location. Although the raw data can sometimes be used directly as sources of information, they generally require preliminary manipulation to be usable. The radiance of a surface is an example of raw data that must initially be translated into various types of land occupation to be easily understandable and to be considered as information. While a land cover map can be used directly by certain environmental managers, it may have to be integrated into other primary information - such as the soil's susceptibility to erosion, or suitability for a given use - if the information it provides is to be of value to the decision-making process. And, again, this processed information may have to be re-processed to be useful to decision-makers.

Three major levels in the information pyramid stand out in the establishment of an effective EIS which can respond to the varying needs of different groups of users: (i) collection and structuring of the data covering all the fields of sustainable development; (ii) development of tools for analyses of the data; and (iii) development of communication tools which can translate complex environmental data into an easy-to-understand format for decision makers.

### 1.1.2.1 Collection and structuring of environmental data

The construction of an exhaustive source of data provides the foundation of an EIS. The scope of environmental information spans a vast array of scientific information, statistical measurements and other quantitative and qualitative data. This information may be biophysical, socio-economic or political in character. A conceptual framework for the representation of the environment is therefore required in order to structure the collection of information and to facilitate its analyses.

In 1979, Friend and Rapport introduced a conceptual framework called STRESS. It was popularized by the OECD (1993) and is currently used by a majority of multilateral organisations involved in sustainable development.

Figure 3 published by the United Nations Environment Programme (UNEP - 1995) represents this concept. Human activities exert pressure on the environment and modify its state (the use of natural resources, the discharge of waste, etc.). These changes in state can have an impact on the essential functions of the environment and, consequently, may generate social reactions and responses that address perceived negative effects.

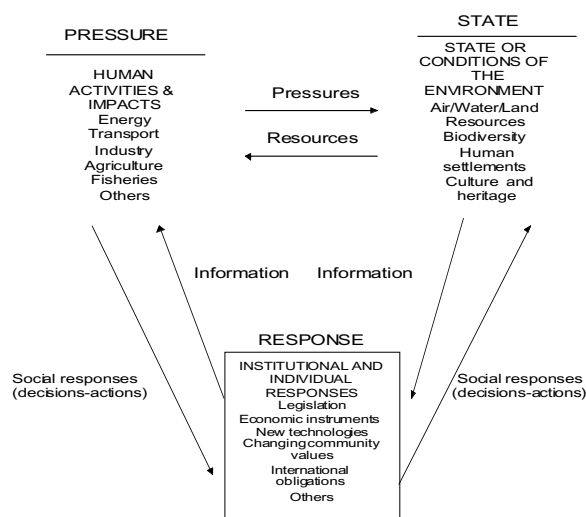
**Figure 3 : Pressure - State - Response model (STRESS)**  
Source : PNUE (1995)

This concept of Pressure-State-Response is utilised by almost all environment impact assessment models (Swart, Bakkes, Niessen, Rotmans, de Vries and Weterings, 1995). It owes a large part of its popularity to the fact that it can be used both at national and international levels, and even at the level of a single undertaking. An integrated information system for the environment therefore, will aim to collect data relating to all of these three subsystems: Pressure-State-Response.

Because of the quality and diversity of information required, it has proven difficult to create such a database. Chapter 40 of Agenda 21 underlines the need for improving the collection, the storage and the diffusion of environmental information to the different users:

*“Information within many countries is not adequately managed, because of shortages of financial resources and trained manpower, lack of awareness of the value and availability of such information and other immediate or pressing problems, especially in developing countries. Even where information is available, it may not be easily accessible, either because of the lack of technology for effective access or because of associated costs especially for information held outside the country and available commercially”.*

Table 1 provides an assessment of data collection for various sectors at the international level. The most studied sectors - and, therefore, those with the most data available - are agriculture (B+), energy (B) and public health (B). It is not surprising that most major efforts to collect information have focussed on these three sectors. Agriculture and energy have immediate effects on economic growth. Similarly, public health is a strong political mobilisation factor all over the world.



**Table 1 - Report Card on the quality and availability of global environmental information for decision-makers**

Sector	Quality of info.	Main environmental information gaps
Climate change	D	Lack sufficient data on average ocean temperature, average atmospheric temperature, sea level changes, pack ice thinning, flow of nitrogen oxides, socio-economic impacts of various climate change scenarios.
Ozone	C	Lack adequate measures of ultraviolet radiation, measures of tropospheric ozone, understanding of chemical behaviour of CFCs and other ozone-depleting chemicals, as well as their alternatives.
Biodiversity	D	Lack adequate inventory and monitoring of existing species and habitats, measures of ecosystem health, measures of threatened and endangered species, economic values of species.
Tropical forests	C	Lack periodic measures of tropical forest area and types and rates of deforestation, measures of non-timber forest products, understanding of role of forests in stabilization of global climate.
Energy	B	Lack measures of renewable energy sources, greenhouse gas emissions.
Human health	B	Lack measures, in many developing countries, of mortality associated with environmental conditions, sanitation, human nutrition.
Lands and soils	D	Lack measures of land degradation, soil erosion, land use and cover, urbanisation, identification of fragile soils, effectiveness of remedial measures.
Freshwater and oceans	C-	Lack measures of groundwater and groundwater pollution, water use, water pollution, sediment flows, coastal ocean quality, chronic sources of pollution from land-based sources, inventory and living resources.
Air quality	D	Lack measures of urban air quality, indoor air quality, transboundary flows and acid deposition.
Agriculture	B+	Lack measures of conservation of soils, water, wildlife, comprehensive understanding and monitoring of effects of intensive use of pesticides and chemical fertilisers.
Toxins and hazardous wastes	D	Lack measures of amounts generated, transported, treated, disposed, cleaned up, and of contamination, understanding of absorptive capacity of natural systems.

From "The Challenge of Sustainability" (Kumar, Manning, Murck, 1993), after J.T Mathews (1991), "Moving Towards Eco-Development: Developing Environmental Information for Decision-Makers".

The least studied sectors - those that have a paucity of data – are biodiversity conservation (D) and soil conservation (D), which are recent global concerns.

The development of computer-assisted information management technologies has allowed a more complete collection of the environmental information described above, along with a rapid increase in its dissemination. In addition indirect methods for data collection such as remote sensing are increasingly being used.

Remote sensing has become a crucial tool in the collection of information and, generally, in the study of the natural environment. Remote sensing is a scientific discipline which covers the entire range of techniques used for observation, analysis, interpretation and management of the environment. It involves measurements and images obtained using airborne, spatial, terrestrial or maritime platforms. As the name suggests, it assumes the acquisition of information remotely, without direct contact with the detected object (F. Bonn, G. Rochon, 1992).

The analysis of images obtained by remote sensing was initially performed visually by the interpretation of aerial photographs (photo-interpretation) for the needs of a wide variety of disciplines. With the introduction of digital images, computer-aided image processing technologies were developed. Their progress closely followed rapid developments in data processing in terms of both hardware and software (F. Bonn, G. Rochon, 1992).

The European Space Agency, Brazil, Canada, the United States, France, India and Japan have launched a large number of remote sensing satellites. The applications of satellites vary considerably according to the characteristics of their sensors. The three satellite systems most commonly used are Landsat (Land satellite, E.U.), SPOT (Système Probatoire d'Observation de la Terre, France) and NOAA/AVHRR (National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer, E.U.). Table 2 presents a comparison of the principal characteristics of the different sensors available on these three systems in the 1990s.

**Table 2 - Principal characteristics of the Landsat, SPOT and NOAA/AVHRR Satellite Sensor**

	Landsat MSS	Landsat RBV	Landsat 4-5 TM	SPOT 1-2 HRV	NOAA/AVHRR
Spectral bands (µm)	0,5 to 0,6 MSS4 0,6 to 0,7 MSS5 0,7 to 0,8 MSS6 0,8 to 1,1 MSS7 10,5 to 12,4 MSS8 (Landsat 3)	0,5 to 0,75	0,45 to 0,52 TM1 0,52 to 0,60 TM2 0,63 to 0,69 TM3 0,76 to 0,90 TM4 1,55 to 1,75 TM5 10,4 to 12,5 TM6 2,10 to 2,35 TM7	0,50 to 0,59 XS1 0,61 to 0,69 XS2 0,79 to 0,90 XS3  0,51 to 0,73 (P)	0,55 to 0,68 0,73 to 1,1 3,55 to 3,95 10,5 to 11,5 11,5 to 12,5
Resolution	80m 240 m IR thermal	40m	30m	20m (XS) 10m (P)	1100 m
Sensor Swathe Width	185 km	185 km	185 km	2 x 60 km orientable +/- 400 km	2700 km
Cycle	18 days	18 days	16 days	26 days	Daily

(After F. Bonn, G. Rochon, 1992, and K. McCloy, 1995).

High ground resolution allows SPOT to create images whose limits in spatial resolution and geometric precision are equivalent to air photographs, even for smaller scale observations. Cartographic products developed from SPOT images can meet average and larger scale cartographic standards (scales higher than approximately 1:50,000). Landsat images, meanwhile, have a lower resolution (40-80 metres) and are used for smaller scale cartographic products (typically, scales lower than 1:50,000). But their sensing swathe width (185 km) makes them more economical for cartographic work extending over a large area.

NOAA/AVHRR satellites permit frequent observations of large parts of the world. They are particularly suited to the study of highly variable phenomena on a very small scale. Their importance is expected to increase in the future because of growing global environmental concerns, such as climate change. Significantly, data recorded by these satellites permit reasonably precise measurement of surface - particularly ocean - temperatures.

The complementarity of these different sensors means that it is not unusual for a geographical project to use a combination of different satellite images. For instance, a project to evaluate agricultural production based on a geographical database at 1:50,000 may use Landsat and SPOT images as the basis for land use maps, while NOAA/AVHRR images are used to monitor harvests. Remote sensing technologies have experienced a very rapid development, and satellite images with a ground resolution of less than 5 metres are commercially available.

The advance in the dissemination of information mirrors the growth of the Internet - in 1969, the Internet connected just four computers, while in June 1998 it was made up of more than 140 million users. And today, there are many hundreds of millions more. That massive growth has been accompanied by an exponential increase in the amount of basic environmental data that is now accessible on the Internet.

But the sheer quantity of information - which is, of course, the strength of the Internet - also restricts the exchange of information. An online search of key words such as "land quality indicators" or "sustainable land management" using the main search engines (Infoseek, Lycos or Yahoo, for example) would produce almost a million positive hits. Only a very small proportion of these results, however, are likely to be relevant. Fortunately, several organisations have taken the initiative to create basic catalogues of

data that are available on the Internet. Table 3 provides a list of four sites offering such services for land quality indicators.

**Table 3 - Four Environmental Information Resource Internet Sites**

<b>Name</b>	<b>URL</b>	<b>Compiler</b>	<b>Contents</b>
Compendium of Sustainable Development Indicator Initiatives and Publications	<a href="http://iisd1.iisd.ca/measure/compendium.htm">iisd1.iisd.ca/measure/compendium.htm</a>	International institute for Sustainable Development, Environment Canada, and World Bank	Comprehensive review of initiatives undertaken to elaborate sustainable development indicators in Canada and worldwide
Consortium for International Earth Science Information Network (CIESIN)	<a href="http://www.ciesin.org/">www.ciesin.org/</a>	Consortium for International Earth Science Information Network (CIESEN)	Inventory of publications about land quality indicators
LQI News	<a href="http://www.esd.worldbank.org">www.esd.worldbank.org</a>	International working group on Land Quality Indicators (World Bank, FAO, UNDP, UNEP)	Information on initiatives carried out to develop land quality indicators
World Resources Institute (WRI)	<a href="http://www.wri.org/wri/index.html">www.wri.org/wri/index.html</a>	World Resources Institute	Abstracts of studies carried out by WRI in the area of environmental indicators

Also, most national environmental agencies maintain databases and support reference centres connected to global networks. For soil conservation, several international agencies also play a critical role in information exchange. Table 4 lists four of these institutions.

**Table 4 - Soil Institutions with a global information sharing mandate**

<b>Institutions</b>	<b>Mandate</b>
International Soil and Reference Information Center. Wageningen, The Netherlands.	Fonded in 1966, ISRIC is a centre for documentation, research and training focussing on the world's soils, with emphasis on the resources of developing countries. ISRIC collects, generates and transfers information on soils, and participates in global Programmes such as SOTER and WOCAT.
International Board for Soil Research and Management. Bangkok, Thailand.	Fonded in 1983, IBSRAM promotes and assists research on soils and land.
World Association of Soil and Water Conservation, Ankeny, U.S.A.	Fonded in 1983, WASWC includes about 700 members. It sponsors workshops, publishes a quarterly newsletter, edits proceedings, and implements the global Programme WOCAT ( <i>World Overview of Conservation Approaches and Technologies</i> ). Launched in 1992, this Programme aims at compiling and evaluating existing soil and water conservation technologies and approaches; and makes this information available in the form of handbooks, reports, maps, databases, and expert systems.
International Soil Conservation Organisation.	Founded in 1983, ISCO organises international conferences of scientists, environmentalists from NGOs and governmental organisations, development experts, and others; to promote conservation, management and sustainable use of natural resources. ISCO is based wherever the next conference is to be held.

(After International Soil Conservation Organisation (1996))

Progress made in information technologies are contributing to solving the current technological constraints in accessing and sharing environmental information. Nevertheless, further data collection efforts - at both national and international levels - are required to improve the quality of information currently available in environmental databases.

### 1.1.2.2 Information Analysis

Although improvements in the collection and storage of information should be a priority in the creation of Environmental Information Systems, much of the current demand for information could be met by better analysis of the existing data (Kumar, Manning, Murck, 1993). The fact that only 5 per cent of the data recorded by the Landsat satellites is currently analysed (Environment Canada, 1992, quoted by Kumar, Manning, Murck, 1993) underlines this need.

As with data collection and storage, the development of computerized data-processing technologies has opened new horizons for information analysis (Kumar, Manning, Murck, 1993). Two new tools in particular - geographical information systems (GIS) and numerical modelling - facilitate the analysis of information.

#### *a. The Geographical Information Systems (GIS)*

GIS has been variously defined. The following definition is one of the most widely accepted “a geographical information system unifies the techniques and methods of spatially referenced information, of their vectoral or matrix coding, their organisation in databases as well as the various processing treatments and procedures required for their utilisation. The purpose of a geographical information system is to provide planners and managers with the information necessary to support decision-making” (Caloz, 1990, in F. Bonn and G. Rochon, 1992).

The core of a GIS consists of a relational database<sup>2</sup>. Each piece of information is separately recorded in the database, and spatially referenced. This allows the representation of various information subjects (soil, roads, etc.) in the form of individual and independent thematic maps, or layers. These layers can be analysed and printed separately, or can be aggregated according to need. This concept of layers is fundamental to an understanding of the logical organisation of a GIS - it is the core around which the entire system is organised. Figure 4 shows the main thematic layers of a GIS database on natural resource management. Given the increasing importance of GIS in the management of the environment and the paramount role GIS plays in this study, a brief description of their principal functions is required. F. De Blomac (1994) notes that to attempt to describe the functions of a GIS is not easy. There are a number of reasons for this. First, the GIS handles spatial data that, by their nature, have very rich information content, with complex relations that make many spatial analyses and applications possible. Second, the GIS operates where several science and technological disciplines converge: geodesy, topography, cartography, data processing, geography (in its broadest sense) and other disciplines calling upon spatially referenced data. Some authors use the term *geomatic* to refer to this wide range of disciplines.

Despite such broad applicability, the principal GIS functions are identified as follows.

***Data Integration, Structuring and Protection*** One of the major problems facing environmental management is the diversity of formats and scales used for the collection, storage and communication of environmental data. These data may take the form of maps at various scales, of photographs, of statistical tables, and of narrative reports. Such diversity has often proved to be a major constraint upon the integration of these data into the decision-making processes (FAO, 1995). But GIS makes it possible to integrate graphic and non-graphic data simply and coherently, thereby facilitating their processing and analysis. A second major problem is the loss of information as a result of inadequate archiving. By centralising information, GIS allows information to be digitally duplicated at will, while protecting it from loss, degradation or theft (G. Korte, 1992).

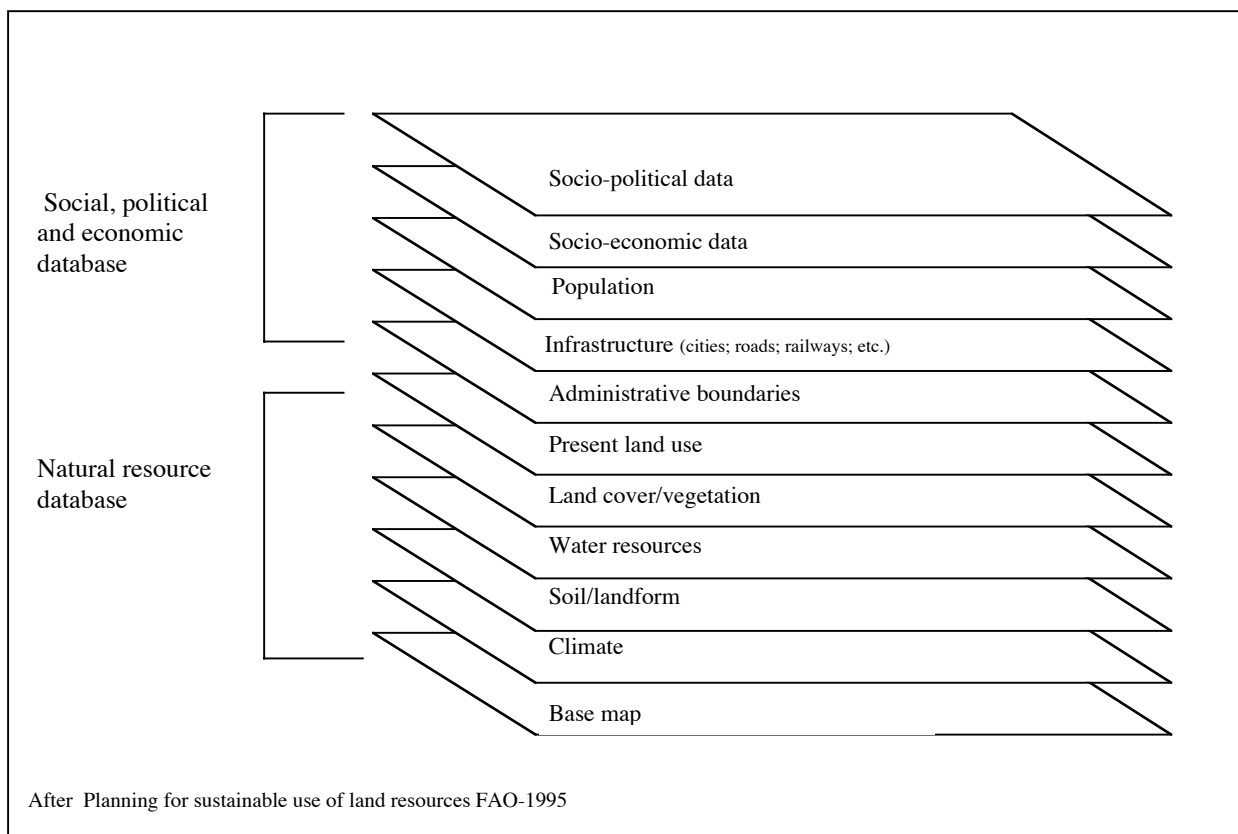
***Easy update of the data*** Although substantial progress has been achieved in recent years, the process of manually updating maps remains expensive and constraining. In comparison to the techniques of traditional cartography, GIS allows maps to be rapidly updated whenever new data becomes available. The GIS thus produces in maps to a much higher quality (G. Korte, 1992).

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<sup>2</sup> A relational database registers data in a collection of tables, each containing data on a given topic. These tables contain a common field through which they can be interconnected. Hence, it is possible to merge the data of several tables together. This information management approach is extremely efficient as data need to be entered only once, hence reducing data storage requirements, and can be easily updated and searched.

**Data Analysis** GIS offers numerous tools for analysis of the spatial attributes of information. Spatial analysis illustrates relations of proximity, inclusion and juxtaposition; and is used to identify and quantify spaces that present particular combinations of values that can then be translated into constraints (F. De Blomac et al., 1994). The following main categories of spatial analysis are useful in GIS:

**Figure 4 : Main thematic layers of a GIS database for natural resource management**



1. Analysis by thematic combination Whenever it is necessary to evaluate a combination of factors which are described in several layers and associated with entities of disparate forms, an overlay function is used. These are at the heart of all multi-criteria evaluations. A good example is the quantification of the environmental impact on the construction of roads, which must incorporate information as diverse as land slope, land occupation, biological diversity and the vulnerability of terrain to erosion.
2. Proximity Analysis This allows the user to determine zones of proximity in relation to a given phenomena. This method may be used, for instance, to determine zones of exclusion around protected areas.
3. Geographical network analysis This is a tool that allows the analysis and calculation of the shortest path - for example, the optimisation of routes or the installation of urban services sites.

*Graphic Representation and Consultation:* Cartography is one of the oldest and most effective mechanisms for analysis and communication of geographical information. It is easier to communicate complex information visually with maps than by tables or lists, as maps make full use of a person's natural capacity to make spatial distinctions of colours, forms and relations (ESRI, 1996).

#### *b. Numerical Modelling*

Numerical modelling is the second major tool for data analysis. GIS and numerical models are generally used in close association. There are two main types of modelling: interpretation and simulation.

Interpretation models are used to extrapolate a second series of parameters based on a first series of parameters at a particular time. For environmental management, this technique has proved to be particularly useful in the interpretation of and translation of satellite images into patterns of land cover. This, of course, reduces the requirement for traditional methods of data collection on the ground.

Simulation models are based on the actual state of a series of parameters at a given moment in time. Simulation models are used to produce a prognosis of future development using algorithms that estimate the changes that will occur by postulating certain anticipated conditions. A simulation model of plant growth, for example, may use measurements of the index of surface of leaves (ISF) as a starting point, and build sub-models of vegetation growth to estimate the ISF at a particular time in the future. The raw data required for these sub-models of vegetation growth would include soil type, slope, cultivation methods, and climatic conditions.

The sustainable management of natural resources requires a long-term impact assessment of decisions made that affect these resources. The simulation model is an invaluable tool for this type of analysis. The use of this technique requires the creation of databases that are spatially referenced for all the parameters relevant to natural resource management. The model acts at each step of the information cycle - at the data collection level as well as at the level of interpretation, or data analysis. This generally takes place in association with, or as a component of, a GIS.

It is not the purpose of this study to present a detailed review of the main advances made in modelling. But two key milestones in environmental modelling deserve mention. Until very recently, most modelling was used to solve a specific problem - acid rain, contamination of aquifers, soil erosion, and so on. The RAINS model of acid rain simulation offers perhaps the best known example of this approach. This model, represented in Figure 5, was used successfully during negotiations for trans-boundary air pollution in Europe (Hettelingh and Al, 1992, as quoted by R. Swart, J Bakkes et al, 1995).

Following the Rio Conference, several initiatives were introduced in an attempt to model the interactions between development and environment. Figure 6 illustrates the general concept of the integrated model TARGET. This model analyses, on a small scale, the interactions between socio-economic and biophysical processes, and assesses their impact on the ecosystem and on the population. The various components of the model are organised in line with the Pressure-State-Response concept. TARGET may be thought of as a two-dimensional matrix, whose columns describe the chain of causality for a given object while the lines denote linkages between various pressures, states and impacts.

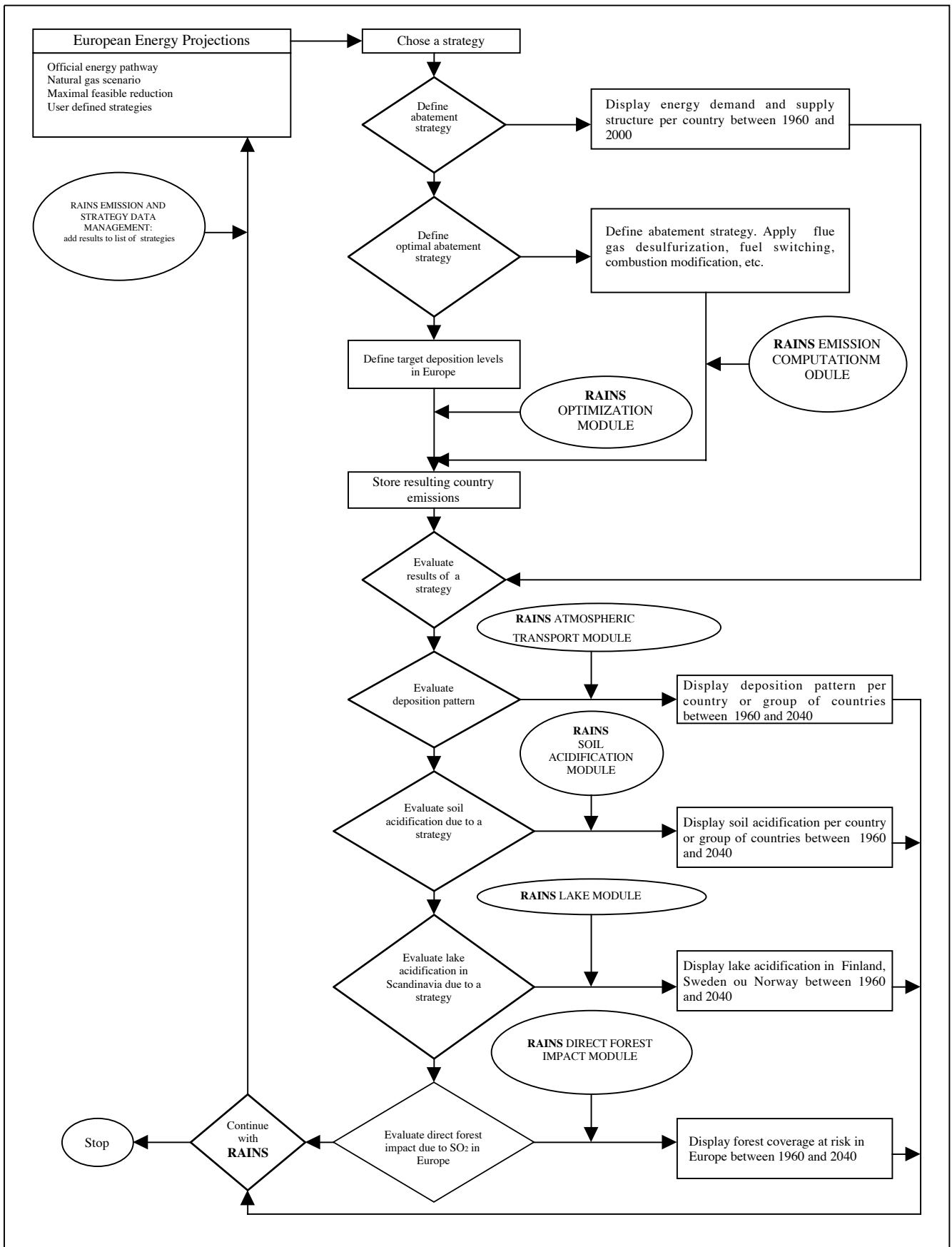
#### 1.1.2.3 Communication of Information to Decision Makers

##### *a. Constraints of integrating environmental data in the decision-making process*

Despite recent progress in information technologies, UNEP notes an important limitation on the role of Environmental Information Systems in decision-making for sustainable development (Guide to Information Management in the Context of the Convention on Biological Diversity, 1996):

*"It has become clear that the major obstacles to increased use of information in decision-making are organizational, not technological in nature, meaning that investments in information technology alone will not provide a solution. We know the causes of many key environmental challenges and we know how to collect and analyse data about them. We also know how to build information systems to manage*

Figure 5 : The RAINS-model of acidification (Hettelingh, 1990) from L. Swart, J. Bakker *et al*,



*the data we collect and, for example, summarize information on the status and distribution of biological resources. Such systems have been implemented in many parts of the world.*

*Scientific information is only one factor affecting the way in which decisions on biodiversity are made, and is not always the most significant. Other means include political judgement, legal and financial necessity, personal or group bias, and commercial or international pressure».*

The importance of this last point - the fact that decision-making processes are not based solely on scientific logic, but on political, financial and legal objectives - was discussed at length by Lucien Sfez (*Critique of the Decision*, 1992). Highlighting the extent to which most decision-making systems rest on the traditional hypothesis of the process occurring over three stages (preparation-decision-execution), Sfez goes on to stress that *«by following these stages of the most traditional decision-making process, one assumes a principle of coherence, a principle which will be isolated of the diversity of the actions, of their frequent irrationality, the tangles of motives to which the players are subjected... if there are players».*

A decision is the result of a complex process that is spread out over time (Sfez, 1992). It is often impossible to specify the exact moment at which a decision is made - if, indeed, there is a decision maker - or to identify the person who made the decision, even where there are authorised decision makers involved. It is more accurate, therefore, to think more in terms of a decision-making process, than of a decision (H. G Zoller, H. Beguin, 1992). The word 'process' suggests a sequence of two or more key activities. Broadly, this means that the decision is a result of negotiations taking place over time, and that it involves a group of actors whose values and interests are not necessarily convergent and whose members are not equal in influence. These intricacies are underlined by Zoller and Beguin (1992): *«the more players there are, the more complex is the collective process and the more difficult it is to appreciate from the outside as the processes of arbitration between the parties in question are seldom public «.*

Most Environmental Information Systems aim - erroneously - to reduce the complexity of the decision-making processes to a simple problem, compressed in a given and short moment in time. The logic for this approach assumes that the presentation of a report synthesizing irrefutable scientific facts and rational alternatives will generate, once presented to the appropriate body, an appropriate decision.

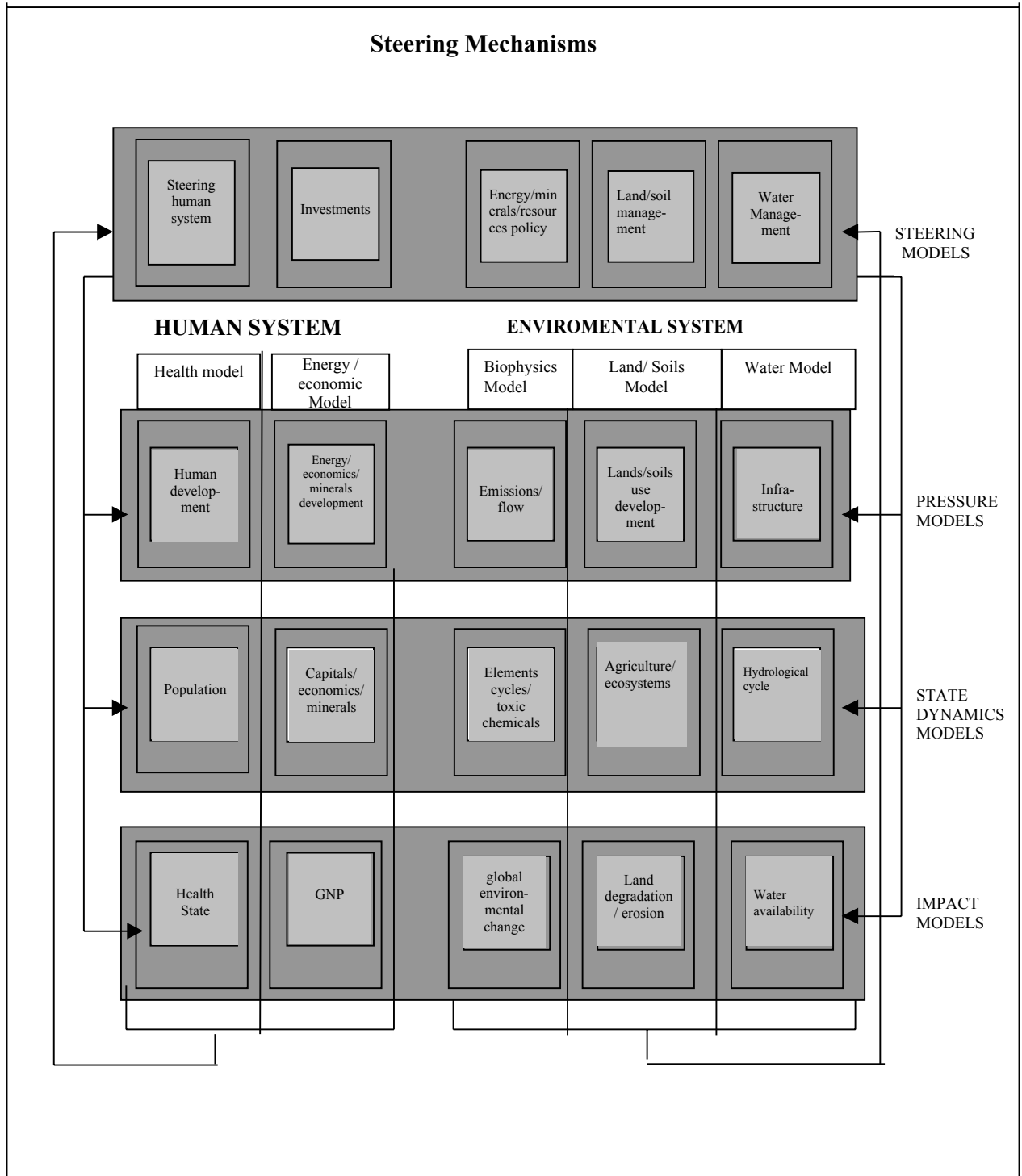
This simple linear diagram is only met in rare and extreme cases (Sfez, 1992). Information is often used to justify a predetermined decision and not to lead the way to a decision itself. Indeed, it is sometimes manipulated to suggest a strategy that is predetermined by the decision maker, or by others (K. McCloy, 1995). It is often difficult to gain a full understanding of the decision-making processes. But a major step to integrating environmental concerns into them would be, first, to recognize their complexity and, second, to develop flexible tools adapted to that reality.

A first condition for the better integration of a set of factors into decision-making will be the establishment of a dialogue between the analyst and the decision-maker (Sfez, 1992). The fact that decisions are the result of a complex process will require the development of tools permitting a constant exchange of feedback and counter-feedback between the analyst and the decision-maker. The development of simulation models or other analytical research instruments facilitates through the development of several scenarios, the establishment of such dialogue.

This possibility of interaction between the decision-maker and the analyst however is not always exploited, and the scenarios generated by these instruments are often presented to the decision-makers as absolute predictions. Such an approach will lead decision-makers to lose any interest in these support tools whenever their predictions proven not to be strictly exact.

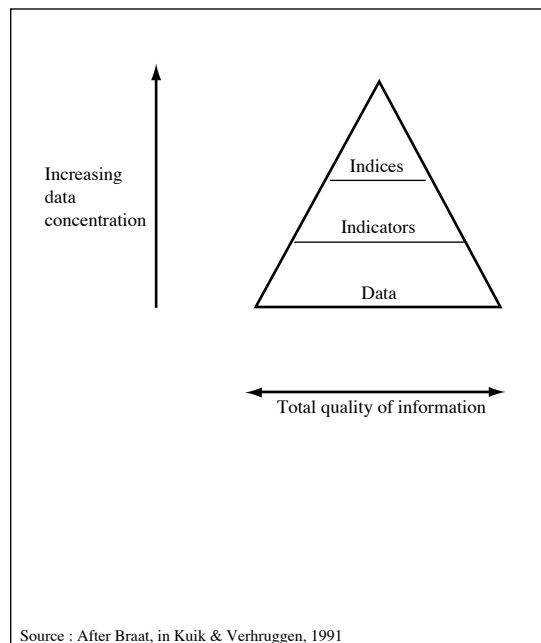
A second condition will be to adapt information products to the various types of decision-making. (K. McCloy, 1995) identifies three distinctive types of decision-making.

**Figure 6 : TARGETS - Integrated Model of Sustainable Development - After Rothmans et al. (1994), quoted by L.Swart, J.Bakker *et al.*, 1995**



- *Strategic planning.* This aims to define the long-term objectives of a policy or an organisation and the mobilisation of resources required to achieve these goals. Decision-making for strategic planning will generally be based on very aggregated statistical data. These data could be presented in the form of tables or of maps.
- *Programming.* The purpose of programming is to translate the strategic objectives and plans into programs which can be carried out by specific units or sections of an organisation in accordance with available resources and future needs. Decision-makings with regards to programming are based on rigorous simulation models and exhaustive databases.
- *Operational control.* The purpose is the management of personnel and other resources engaged in the implementation of programs delegated to the operational level or unit in the organisational hierarchy. It is concerned with management of the organisation on a day-to-day basis. The decision-making at this level will normally be based on extremely precise but generally simple data like quantities of a given element.

**Figure 7 : Indicators and Indices in the Information Pyramid**



GIS, even when perfectly designed and developed, are difficult to consult and fully to utilise (Darracq, Brabant, Nguyen Tran Cau, Le Duc Can, 1995). The complexity of their data-processing tools limits access and manipulation by decision-makers. Furthermore, the absolute mass of information available can often divert more than contribute to decision-making procedures. Possible conflicts and the hierarchical relationship among different sets of data is seldom apparent. In the absence of complementary tools to facilitate communication of information to decision-makers, GIS appear to be unsuitable to support strategic decision-making, which is based on highly aggregated statistical data.

In the absence of a full understanding by political decision-makers of the functions of GIS, funds are often inadequate for their update, reducing their utility gradually. This fact limits many GIS project in practice to the production of atlases and other cartographic products. Special communication tools targeted towards decision-makers will have to be developed to allow a full use of the results of numerical modelling and GIS for strategic decision-making.

*b. Tools for the Communication of Information for decision-makers*

A first step in the development of such communication tools involves the interpretation and the aggregation of environmental data. The EIS has often been criticised for creating data-rich but information-poor tools; of limited relevance to decision-makers (USEPA, 1995). The language of the engineer is not necessarily that of the decision-maker. While raw scientific and statistical data constitute real information for the scientists who identify and define problems, that same data will only be usable to decision makers after it has been analysed and aggregated.

All too often, environmental reports are presented as long tables of statistics and physico-chemical data analysis, perhaps with limited interpretation of the results or discussion of the trends that they suggest. Chapter 40 of Agenda 21 underlines the need «*for transforming existing information into forms more useful for the decision-making process and more adapted to the needs of the various groups of users*». This is also emphasised by Kumar, Manning and Murck (1993), «*A data set only becomes information when it is accessible and understandable*».

One of the principal mechanisms for interpretation and aggregation is the development of environmental indicators and indices. The purpose of indicators and indices is to simplify, synthesize and interpret a mass of data to make them directly understandable by decision-makers. This point can be highlighted in

a second representation of the information pyramid, shown in Figure 7. Here, the primary data gathered form the base of the information pyramid and are gradually converted into indicators and indices. The aggregation and communication functions of indicators and indices supplement the visualisation inherent in the cartographic approach. Thus, environmental indicators and indices can be used either independently, or in close association with a GIS to communicate environmental data which are accurate in their quantitative and qualitative content, but can also be easily understood and used by non-scientific or non-environmental decision-makers.

The development, the potential and the limits of environmental indicators and indices are examined in depth in the following chapter.

## **1.2. INDICATORS OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT**

### **1.2.1 The impact of statistical bias in macro-economic indicators on environmental management**

The word «indicator» comes from the Latin verb «indicare» which means to reveal, to let know, to estimate or to place a value on (Hammond and al, 1995). Some highly aggregated indicators, such as gross national product (GNP), aim to simplify and to present a large number of statistical, scientific or economic data in a manner directly accessible to the public. Other simple indicators with only one parameter - the hour hand of a clock, or the mercury of a barometer, for example - make it possible to provide an immediate reading of a phenomenon or of a trend that is otherwise not easily perceptible.

Indicators influence all fields of human activity. A fall in the Standard and Poor's Stock Average or a slow down in GNP growth immediately affects the investment decisions of institutions, of private companies and private individuals. Indicators are intellectual representations whose objective is to represent as accurately as possible a certain reality. Like any intellectual representation, the construction of an aggregate indicator is seldom free from bias. In practice, though, bias may have long term, negative consequences.

As early as 1966, a proposal presented to the Commission of National Accounting in France by Bertrand de Fontenelle stressed the «statistical prejudices» associated with the development of national accounting and macro-economic indicators, and their negative consequences on environmental protection and social welfare (Bertrand de Fontenelle, 1996):

*« In principle, National Accounting takes into consideration only those transactions subject to payment: National Accounting retains as goods and services only activities which are exchanged on the market or which are suitable to be exchanged there. This has led to three logical consequences:*

- a. *Services rendered purely on a pro-bono (non-monetary value) basis do not appear in positive flows;*
- b. *Harmful effects which are produced are not reflected as negative flows;*
- c. *Depletion of natural resources appears only in disposal costs «.*

This logic results in a general discrediting of any investments made for public interest - such as school buildings, playgrounds and libraries - and in neglecting the services produced by the environment and the costs associated with its degradation. These paradoxes, highlighted by B. de Fontenelle and other «pioneers», led to increasingly widespread awareness of statistical prejudices inherent in traditional macro-economic information systems. They gave rise to two principal types of initiatives to better incorporate environmental dimensions in public policies:

- (i) Establishment of expanded national accounting systems in order to incorporate social and environmental considerations;
- (ii) Preparation of environmental indicators and, more recently, of indicators of sustainable development.

Although environmental indicators are the focus of this study, Appendix 3 contains the key approaches of environmental accounting, which are particularly important for producing indicators of sustainable development.

## 1.2.2 Key initiatives in constructing environmental and sustainable development indicators

A number of initiatives were introduced to develop environmental indicators in response to a very strong increase in awareness by people in Europe and North America at the very beginning of the 1970's (Harvard University, 1996). Wayne Ott (1978) summarized a large amount of this work in 1978 in his study entitled « *Environmental Index* », which lists the principal indices for water and air quality and describes several techniques of aggregation.

Curiously, following Ott's study, a discernible lack of interest towards environmental indicators became evident and very little research was published on this subject over the following decade (Harvard University, 1996). It is only at the end of the 80's that the Government of Canada re-introduced research in this field (Bakkes and al., 1994). In 1987, the Government of the Netherlands, too, began similar work. During an economic summit meeting of the G-7 held in Paris the same year, the seven most industrialized countries requested the OECD to develop environmental indicators.

Awareness of the strong interactions between environment and development reached new heights at the time of the Rio Conference. Chapters 8 and 40 of Agenda 21 recommend the use of environmental indicators as key tools with which to integrate the environment into the decision-making processes.

After UNCED, there was an increase in the number of initiatives to develop environmental indicators or, more ambitiously, sustainable development indicators. Table 5, developed by Bakkes et al. (1994) lists the initiatives introduced by eight governments and multilateral organisations, and demonstrates the wide range of existing approaches used in developing these indicators. This diversity is a result partly of the large number of situations and objectives to which these indicators are applied.

**Table 5 - Comparison of Environment indicator Methodologies**

Agency and Year	Number of Indicators	Type of Indicators	Special Unit	Temporal unit
OECD (1991)	25	Expert	National	Annual, at best
UNECE (1985)	25 (9 categories)	Expert	National	Not clear
UNEP (1984)	70 (15 categories)	Expert	National	Not clear
The Netherlands (1984)	15	Expert	National	Annual, at best
Canada (1991)	43 (18 categories)	Expert	National	Annual
Denmark (1991)	25 (4 categories)	Expert	National	Annual
IUCN (1991)	65 (5 categories)	Expert	Not clear	Not clear
Norway (1992)	34 (9 categories)	Expert	Varied	Annual, at best

Sources: OECD, 1991 a; UNECE, 1985; UNEP, 1984; Vos et al 1986 (Dutch); Environment Canada, 1991; Danish Miljøministeriat 1992; IUCN, 1991; Norwegian Central Bureau of Statistics, 1992, cités par Bakkes et al. (1994).

As a second illustration, a bibliographical study by the World Bank (J. Dumanski, S. Gameda, C. Pieri, 1998), identified no less than 101 individual research projects attempting to define land quality indicators. In April 1995, the United Nations Department for the Coordination of Policies and Sustainable Development (UNDCPSD) initiated a «Work Programme on Sustainable Development Indicators» with the objective to harmonize these various initiatives. This work Programme which is still on going, has three principal objectives:

1. To develop a set of descriptive indicators to evaluate progress towards sustainable development. Each country can select indicators which will correspond best to the conditions of its sustainable development, as well as their activities and priorities.
2. To regularly evaluate and adjust the menu of sustainable development indicators.
3. To continue the elaboration of highly aggregated sustainable development indicators to facilitate decision-making processes.

In August 1996, UNDCPSD published a first series of sustainable development indicators and methodological guidelines for their aggregation. This document was given to all U.N. Member States to help them to incorporate sustainable development into their decision-making. The list of sustainable development indicators proposed by DCPDDNU is given in Appendix IV. This menu of indicators is to be regularly revised based on feedback received from Member States.

### **1.2.3 The role of indicators incorporating the environment into the decision making process**

The objective of research undertaken in the 1990's with regard to environmental indicators differs significantly from research undertaken during the 1970's. Initially conceived to contribute to problem identification, environmental indicators today aim largely to contribute to decision-making and to the development of strategy.

Chapter 1.1.1 compared the decision-making process to a cycle through which problems are identified; and policies are formulated, implemented, evaluated and adjusted in order to improve the existing situation. Each family of indicators has a different role to play in each of these four stages in the cycle (M. Cheatle, 1995):

Problem Identification: At this stage, indicators can help to represent the situation, to define the problems, to identify priority issues, and to sensitise decision makers and the wider public. These indicators - or «descriptives» - are generally very simple, consisting of just one parameter. The number of faecal coliforms, for example, is generally used as a simple indicator to measure the organic pollution in water.

Policy Development: In this stage, the indicators can help to formulate policies and strategies which address the problems identified by the Problem Identification phase. However, a series of simple descriptive indicators can seldom provide all the information necessary to support decision-making. The problems often have complex causes and a number of options to address them may exist.

Access to spatial analysis models, systems of multicriteria analysis or other instruments of analytical study will often be required to support decision-making. Indicators associated with these analytical systems are strongly aggregated to present the entire set of data analysed in a way that is directly accessible to decision makers. These highly aggregated indicators, or indices, are particularly useful in enabling the broader participation of the various groups involved in decision-making. The degree of aggregation of these indicators will depend on the unique requirements of the end-users.

Putting policies into Practice : In this stage, indicators can be useful in comparing the progress of the policies with pre-established quantitative objectives. These indicators must be descriptive and highly aggregated.

Evaluation of Policies: This stage aims to evaluate the effectiveness of policies, allowing adjustments to be made if necessary. Performance indicators are particularly useful here. These indicators must enable a comparison of results against original objectives. These indicators can either be descriptive or highly aggregated.

Indicators are developed based on a selection of a wide range of data to meet a specific objective. The development of an indicator will thus respond to criteria different from those used for the development of simple statistics. Although indicators are often presented in a numerical or graphic form, they differ from other statistical data insofar as that they form an integral part of a decision making process. An indicator designed for one given objective may be entirely inappropriate for another objective. However, once adopted, indicators guide the collection and presentation of data, making these tasks more efficient and allowing for more productive use of information.

### 1.2.4 Classification of Indicators

This brief examination of the main initiatives used to formulate environmental indicators and, more recently, sustainability indicators, shows that these terms designate instruments of a highly variable nature and complexity. For the purposes of this study, it is useful to adopt a classification system. UNEP (1994) proposes a classification of environmental indicators according to three criteria: (A) the objective; (B) the topic; and (C) its position in the chain of causality.

A. Classification by objective: Indicators can be classified according to their role and objective in the decision-making process, as a means to identify a problem or to support the formulation, monitoring and evaluation of policy.

B. Classification by topic: Indicators can be classified according to the topics or themes they describe. They may describe aspects of the environment, such as water or air for example, or more specific themes such as eutrophication and deforestation.

C. Classification by place in the chain of causality: Indicators can be classified according to the place they occupy in the chain of causality, by their description of direct or indirect pressures on the environment (pollution, deforestation, economic and population growth, etc), the state of the environment (soil erosion, water pollution, etc.) or responses suggested for particular environmental problems (programme of conservation of the lands and water, family planning, etc). This classification follows the conceptual framework 'STRESS' introduced by Friend and Rapport (1979).

### 1.2.5 Constructing environmental indicators

Four major approaches for the preparation and the presentation of environmental indicators suggest themselves: (i) indicators with only one parameter; (ii) profiles of environmental quality based on the juxtaposition of several single-parameter indicators; (iii) numerically aggregated indicators; and (iv) graphically aggregated indicators.

#### Insert 1: Definitions of environmental indicators

OECD uses the following definitions.

Indicator: A parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value.

Index: A set of aggregated or weighted parameters or indicators.

Parameter: A property that is measured or observed.

#### 1.2.5.1 Indicators with a single parameter

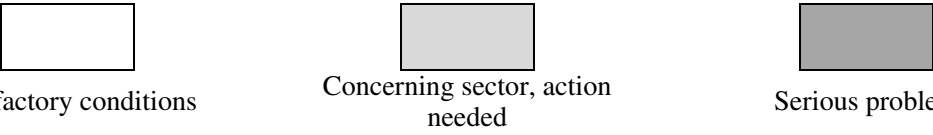
Simple indicators with a single parameter such as the biological oxygen demand (BOD) of a water body are in general easily measurable. Because of the absence of aggregation or other subjective statistical processing, their validity in representing an environmental process allows them to be internationally recognised.

The main disadvantage of simple indicators is that a preliminary analysis is often required for their interpretation. In this sense, they are of a limited use to policy decision makers. Many environmental monitoring programmes have faced this problem and, consequently, have failed to influence decision-making.

### 1.2.5.2 Profiles of environmental quality

Profiles of environmental quality constitute a first step in facilitating the analysis of information by presenting several simple indicators together in a logical way. They have been defined as « *a number of indicators presented together in order to represent environmental conditions (but not aggregated together)*... » (Ott, 1978). Figure 8 offers an example of the environmental quality profile used by Ott (1978).

**Figure 8 : Environmental quality profile for EPA Region 10 in 1976**

Component	Indicator	State	Trend
Water	River miles not meeting standards		Improving
	Severity of violation of standards		Improving
Air	Days of standards violations		Improving
	Severity of pollution in days in which standards are violated		Improving
Radiation	Near-term exposure		No change
Pesticides	Concentration in food, water and air		Improving
Solid wastes	Per cent of the population served by sanitary landfills		Improving
Noise	Number of persons exposed to unacceptable noise levels		Worsening
 <p>Satisfactory conditions      Concerning sector, action needed      Serious problem</p>			
Source: Ott, 1978			

In an index, the aggregation of individual indicators is performed by a mathematical formula; in an environmental profile, however, this aggregation is performed by the end-user. The Swedish Commission for Environmental Accounts is currently developing profiles that combine simple and aggregated indicators (Bakkes et al., 1994). Critics of environmental quality profiles assert that these also require - as with simple indicators - a relatively sophisticated knowledge from the end-users to be truly useful as an aid to decision-making.

### 1.2.5.3 Numerical indices (aggregated indicators)

Ott (1978) states that an environmental index is a mathematical function made up « *of two variables or more* ». The advantage of aggregating several simple indicators into a single index is to make a mass of specialized data immediately understandable to users. A simple index of air pollution, which is comprehensible to all, can directly raise the awareness of a population and policy decision-makers and promote the development of preventive policies. Table 6 shows the list of simple or aggregated environmental indicators proposed by the Organisation for Economic Cooperation and Development (1997)<sup>3</sup>. These indicators are listed in the STRESS model format.

<sup>3</sup> This table lists the core environmental indicators proposed by OECD. It includes « ideal » indicators (designated by a double asterisk), complementary indicators that qualify messages conveyed by the core indicators, and alternative indicators when core indicators cannot be measured.

**Table 6 - Summary of table OECD indicators by environmental component**

	<b>PRESSURE</b>		<b>STATE</b>		<b>RESPONSE</b>	
<b>Issues</b>	<b>Indicators of environmental pressures</b>		<b>Indicators of Environmental conditions</b>		<b>Indicators of societal responses</b>	
Climate change	<ul style="list-style-type: none"> <li>Index of greenhouse gas emissions</li> <li>CO2 emissions</li> </ul>	M S	<ul style="list-style-type: none"> <li>Atmospheric concentrations of greenhouse gases</li> <li>Global mean temperature</li> </ul>	S S	<ul style="list-style-type: none"> <li>Energy efficiency</li> <li>Energy intensity</li> <li>Economic and fiscal instruments</li> </ul>	M/L S M
Ozone layer depletion	<ul style="list-style-type: none"> <li>Index of apparent consumption of ozone depleting substances</li> <li>Apparent consumption of CFCs and halons</li> </ul>	M S/M	<ul style="list-style-type: none"> <li>Atmospheric concentrations of ozone depleting substances</li> <li>Ground level UV-B radiation</li> </ul>	S/M M	<ul style="list-style-type: none"> <li>CFC recovery rate</li> </ul>	M
Eutrophication	<ul style="list-style-type: none"> <li>Emissions of N and P in water and Soil (→ nutrient balance)</li> <li>N from fertilizer use and from livestock</li> <li>P from fertilizer use and from livestock</li> </ul>	L S S	<ul style="list-style-type: none"> <li>BOD/DO, concentration of N and P in inland waters and in marine waters</li> </ul>	S/M M/L	<ul style="list-style-type: none"> <li>% of population connected to biological and/or chemical sewage treatment plants</li> <li>% of population connected to sewage treatment plants</li> <li>User charges for waste water treatment</li> <li>Market share of phosphate-free detergents</li> </ul>	M/S S M S/M
Acidification	<ul style="list-style-type: none"> <li>Index of acidifying substances</li> <li>Emissions of NOx and SOx</li> </ul>	M/L S	<ul style="list-style-type: none"> <li>Exceedance of critical loads of pH in water and soil</li> <li>Concentrations in acid precipitation</li> </ul>	M/L S	<ul style="list-style-type: none"> <li>% of car fleet equipped with catalytic converters</li> <li>Capacity of SOx and NOx abatement equipment of stationary sources</li> </ul>	S/M M/L
Toxic contamination	<ul style="list-style-type: none"> <li>Emissions of heavy metals</li> <li>Emissions of organic compounds</li> <li>Consumption of pesticides</li> </ul>	M/L L S/M	<ul style="list-style-type: none"> <li>Concentration of heavy metals and organic compounds in env. Media and in living species</li> <li>Concentration of heavy metals in rivers</li> </ul>	L S/M	<ul style="list-style-type: none"> <li>Changes of toxic contents in products production and processes</li> <li>Market share of unleaded petrol</li> </ul>	L S
Urban environmental quality	<ul style="list-style-type: none"> <li>Urban air emissions: Sox, NOx, VOC</li> <li>Traffic density <ul style="list-style-type: none"> <li>-- urban</li> <li>-- national</li> </ul> </li> <li>Degree of urbanisation</li> </ul>	M/L M S S/M	<ul style="list-style-type: none"> <li>Population exposure to: <ul style="list-style-type: none"> <li>-- air pollution</li> <li>-- noise</li> </ul> </li> <li>Ambient water conditions in urban areas</li> </ul>	L M M/L	<ul style="list-style-type: none"> <li>Green space</li> <li>Economic, fiscal and regulatory instruments</li> <li>Water treatment and noise abatement expenditures</li> </ul>	M/L M S/M
Biodiversity/ landscape	<ul style="list-style-type: none"> <li>Habitat alteration and land conversion from natural state</li> </ul>	L	<ul style="list-style-type: none"> <li>Threatened or extinct species as a share of total species known</li> </ul>	S	<ul style="list-style-type: none"> <li>Protected areas as % national territory and by type of ecosystem</li> </ul>	S L
Waste	<ul style="list-style-type: none"> <li>Waste generation <ul style="list-style-type: none"> <li>-- municipal</li> <li>-- industrial</li> <li>-- nuclear</li> <li>-- hazardous</li> </ul> </li> </ul>	S S S S/M	Not applicable		<ul style="list-style-type: none"> <li>Waste minimisation</li> <li>Recycling rate</li> <li>Economic and fiscal instruments, expenditures</li> </ul>	L S/M M
Water resources	<ul style="list-style-type: none"> <li>Intensity of use of water resources</li> </ul>	S	<ul style="list-style-type: none"> <li>Frequency, duration and extent of water shortages</li> </ul>	M/L	<ul style="list-style-type: none"> <li>Water prices and user changes for sewage treatment</li> </ul>	M
Forest resources	<ul style="list-style-type: none"> <li>Actual harvest/productive capacity</li> </ul>	M	<ul style="list-style-type: none"> <li>Area, volume and structure of forests</li> </ul>	S/M	<ul style="list-style-type: none"> <li>Forest area management and protection</li> </ul>	M/L
Fish resources	<ul style="list-style-type: none"> <li>Fish catches</li> </ul>	S	<ul style="list-style-type: none"> <li>Size of spawning stocks</li> </ul>	M	<ul style="list-style-type: none"> <li>Regulation of stocks (Quotas)</li> </ul>	M
Soil degradation (desertification & erosion)	<ul style="list-style-type: none"> <li>Erosion risks: potential and actual land use for agriculture</li> <li>Change in land use</li> </ul>	L S	<ul style="list-style-type: none"> <li>Degree of top soil losses</li> </ul>	M/L	<ul style="list-style-type: none"> <li>Rehabilitated areas</li> </ul>	M/L
General indicators, not attributable to specific issues	<ul style="list-style-type: none"> <li>Population growth and density</li> <li>Growth of GDP</li> <li>Private final consumption expenditure</li> <li>Industrial production</li> <li>Structure of energy supply</li> <li>Road traffic volumes</li> <li>Stock of road vehicles</li> <li>Agricultural production</li> </ul>	S S S S S S S S	Not application		<ul style="list-style-type: none"> <li>Environmental expenditures</li> <li>Pollution control and abatement expenditures</li> <li>Public opinion</li> </ul>	M/L S/M S

Source: OECD (1997)

**Table 7- Biological, chemical and physical parameters used by selected authors to develop a water quality indicator in the United States**

Parameters	Horton	Brown and al.	Prati and al.	McDuffie and al.	Dinius	Dee and al.
<b>Chemical</b>						
D0	X	X	X	X	X	X
BOD <sub>5</sub>		X	X	X	X	X
COD			X	X		
Alkalinity	X				X	
Hardness					X	
Iron			X			
Manganese			X			
Ammonia			X			
Nitrites						
Nitrates		X	X			
Other Nitrogen				X		X
Phosphates				X		
Other Phosphates						X
Fluorides						
Chlorides	X	X	X		X	
Sulfates						
Oils and Grease						
Phenol						
ABS			X			
CCE	X		X			
Other			X	X		X
<b>Physical</b>						
Conductivity $\mu\text{S}/\text{cm}$ à 20 <sup>0</sup> C	X			X	X	
Temperature	X	X		X	X	X
PH	X	X	X		X	X
Suspended Solids			X			
Dissolved Solids						
Total Solids		X				
Turbidity						
Color					X	
Other						X
<b>Biological</b>						
Faecal Coliforms		X			X	
Total Coliforms	X			X	X	X
<b>Other</b>	X					

Horton: *Quality Index*; Brown et al.: *Water Quality Index*; Prati et al.: *Implicit Index of Pollution*; McDuffie and Haney: *River Pollution Index*; Dinius: *Social Accounting System*; Dee et al.: *Environmental Evaluation System*, cités par Ott. 1978.

The principal problem associated with the development of an index is the validity of the assumptions used in the selection and the weighting of its various parameters. Bakkes et al. (1994) note that obtaining a consensus on the assumptions made for the development of an index is essential. This point - which is crucial in this study - is also highlighted clearly in Table 7, developed by Ott in 1978. This represents the various combinations of indicators, identified by six authors in the United States, for the development

of a water quality index. The extreme diversity of these sets of parameters illustrates the uncertainties and subjectivity that characterise any effort to develop aggregated indicators.

Similarly, the Environment Quality Index (EQI) developed by Inhaber and a team at Canada Environment at the beginning of the 1970s illustrates the inherent problems in any weighting of various dimensions of the environment within the same index. The construction of the EQI was based on the aggregation of four sub-indices representing the major components of the environment identified by Inhaber (1976): (i) air quality; (ii) water quality; (iii) land quality; and (iv) miscellaneous (primarily insecticides and radioactive waste). Figure 9 shows the various sub-indices that make up the EQI. The equations of aggregation of the EQI and the sub-index for air quality are as follows:

#### Air Quality Index

$$I_{air} = \sqrt{0.2I_{SO_2}^2 + 0.1I_{SMP}^2 + 0.1I_{COH}^2 + 0.2I_{CO}^2 + 0.2I_{O_x}^2 + 0.2I_{NO_x}^2}$$

where

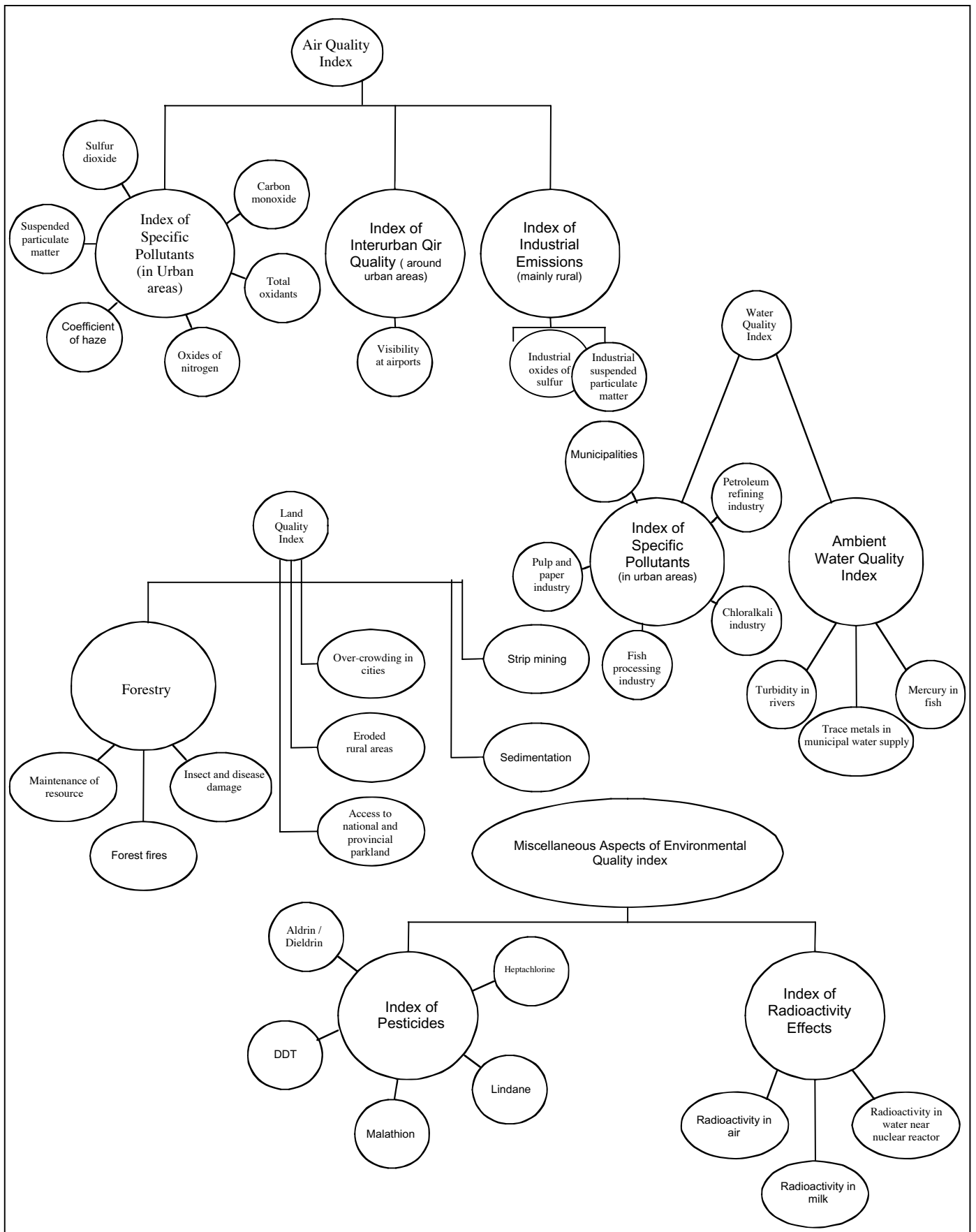
- $I_{SO_2}$  = Index for sulphur dioxide
- $I_{SMP}$  = Index for suspended particulate matter
- $I_{COH}$  = Index for coefficient of haze
- $I_{CO}$  = Index for carbon monoxide
- $I_{NO_x}$  = Index for oxides of nitrogen

#### Comprehensive Index of Environmental Quality

$$I_{EQI} = \sqrt{0.3I_{AIR}^2 + 0.3I_{WATER}^2 + 0.3I_{LAND}^2 + 0.1I_{MISCELLANEOUS}^2}$$

These equations reveal the point at which the selection and the weighting of individual indicators in the construction of a general environment index will influence the final result.

**Figure 9 : Inhaber's Quality of Environmental (IQE) Index**



### 1.2.5.4 Graphic Indices

A second method for aggregating simple or sectoral indicators is by graphic representation. Figure 10 illustrates one such representation - "the Environmental Diamonds". This approach was developed by Harvard University (1996) at the request of the Asian Development Bank. It is inspired by the "Development Diamonds" introduced by the World Bank in its "Report on Social Development Indicators" (1994). Based on the analysis of the principal components<sup>4</sup> of 33 environmental variables, Harvard University selected the following four major variables to represent environmental quality:

1. The quality of air in the urban environment, as defined by noise pollution and the concentration of suspended particles, SO<sub>2</sub> and lead;
2. The quality of water index, as defined by aggregating four indices: suspension of solid matter, the biological and chemical demand for oxygen, and the bacteriological count (E. Coli);
3. Soil quality, as defined by the rate of erosion and soil pollution caused by the use of agrochemical compounds and the discharge of solid and toxic waste;
4. The degradation of the terrestrial ecosystem measured by the percentage of forest cover, the rate of deforestation and the percentage of endangered vegetal and animal species.

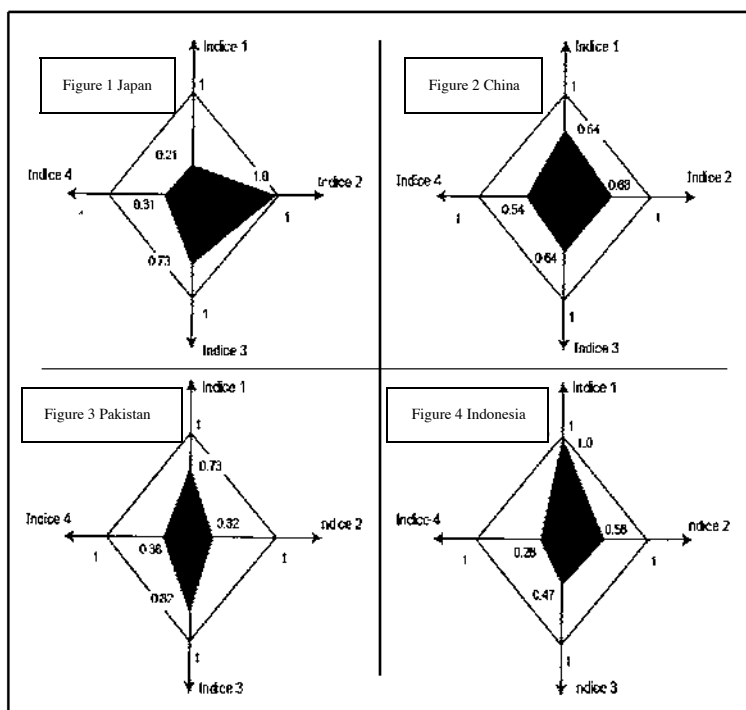
The state of these four major environmental components (air, water, soil and the ecosystem) is represented by Cartesian axes. The calculation of each index is based on a comparison between the present conditions of the component and the environmental standards accepted internationally or locally. The value of the index ranges from 0 to 1. These diamonds are designed to correspond to the commonly accepted notion of «big is beautiful». The broader the diamond, the better the condition. The narrower the diamond, the poorer the condition. For example in Figure 10 Japan has a good diamond and Pakistan has a poor diamond.

The principal objective of the Harvard's is to facilitate a comparison between the four major components of the environment and to avoid the problems inherent in the weighting of various aspects of environmental quality within the same index.

### 1.2.6 Indices of environmental functions

Two principal methodologies may be employed to calculate aggregate indicators for the environment: aggregation by environmental components (air, water, soil, forests); and aggregation by environmental functions (provision of natural resources, life support, waste assimilation, etc). Aggregating indicators by component allows more precise identification of environmental problems. Such indicators are generally easier to construct, but are more complex to interpret.

**Figure 10 : Environmental Diamonds**



<sup>4</sup> The principal component analysis is a mathematical reduction technique of the total number of data necessary to represent a multi-dimensional phenomenon. It allows the identification of the degree of correlation between different data and permits to select a limited set of data able to represent several highly correlated dimensions of the same phenomenon.

In actual fact, the main environmental components rarely evolve in the same direction and a comparative analysis of the respective impacts of their evolution requires a relatively thorough knowledge of environmental mechanisms. Thus objective of indices aggregated by environmental function is to reflect more simply the entirety of interactions between environmental components and their impact on the vital functions of the environment. Indices of environmental functions are therefore easier to understand by local decision makers. But they require substantial compromises to be made in the weighting of basic parameters, and need collection and analysis of much more information. For example, the EQI of Inhaber et al., and Harvard's Environmental Diamonds described above, are both aggregated by environmental components.

To put this discussion of the various available environmental indicators in perspective, a brief description of two set of indices by environmental functions developed by the World Resource Institute (WRI) and International Union for the Conservation of Nature (IUCN) is also of interest.

#### 1.2.6.1 The WRI's four indices model

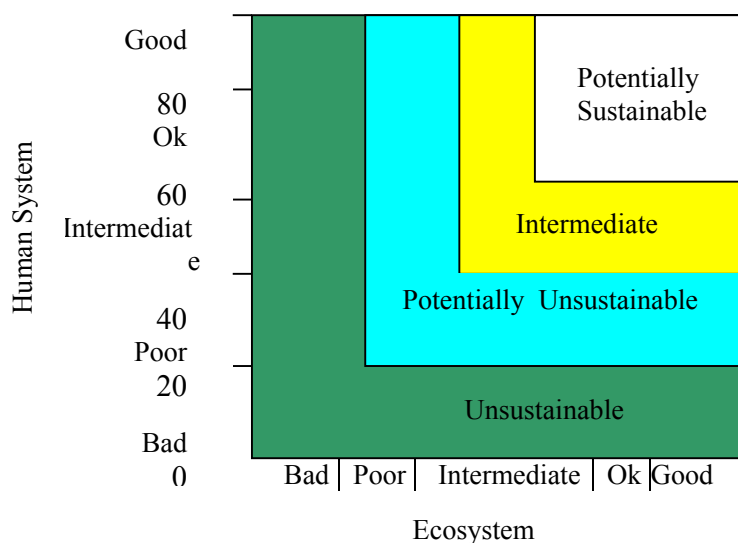
This model was introduced by the WRI, with the objective to simplify and to quantify the four main forms of interaction that exist between a population and the environment: (i) resource depletion; (ii) assimilation of domestic and industrial waste; (iii) production of vital services; and (iv) impact on public welfare.

WRI recommends that these four interactions can be represented by the development of four aggregated indices: (i) a resources depletion index; (ii) a pollution index; (iii) an ecosystem risk index; and (iv) an environmental impact on human welfare index. Table 8 presents several possible indicators to be used to constitute these four indices (WRI, 1995).

#### 1.2.6.2 The IUCN's sustainability barometer model

The IUCN/IDRC Programme for the follow-up and the evaluation of progress towards sustainable development (1995) suggests that several environmental indicators and socio-economic elements can be aggregated in a single graphic index - the Sustainability Barometer. This represents the entirety of the interactions between a population and the environment, and the sustainability of these interactions.

**Figure 11 : Barometer of Sustainability (Prescott-Allen 1990)**



The abscissa of the Barometer of Sustainability (Figure 11) is calculated by aggregating four thematic environmental indices similar to those suggested by the WRI: (i) index of natural areas, taken which measure the impact of the society on the ecosystem based on the percentage of natural areas in relation to constructed, cultivated, and managed areas; (ii) the index of the quality of the ecosystem, which measures the general quality of the air, water and soil, and the capacity of waste assimilation of the ecosystem; (iii) the index of biodiversity, which measures biological diversity; and (iv) the index of resource use which measures the use, of renewable and non-renewable resources.

The ordinate of this graph is based on the Human Development Index (HDI) which was developed by the United Nations Development Programme (UNDP, 1990 and following years). This Index aggregates statistical data such as literacy, life expectancy, the gross national product and other economic and social indicators to calculate for each country the opportunities offered to each individual to maximize their development capacities given the country's overall socio-economic condition. The objective of this index is to provide a measurement of a country's progress in development, but incorporating a more multi-sectoral view of development than the traditional use of only GNP per capita

IUCN notes that the choice of the indicators that make up the various environmental indices will depend initially on the conditions specific to each country or region.

## **1.2.7 Principal constraints in preparing environmental indicators**

### 1.2.7.1 Changes in the HDI construction methodology

The attention given to sustainable development and public concerns about the threats posed to the environment have led governments and multilateral institutions to re-examine the means at their disposal to estimate the importance of these threats, to oversee the state of environment and to evaluate the performance of their environmental policies. In this context, environmental indicators seem to be essential for their role as tools to promote and implement development policies. To translate this need for environmental indicators into reality however, remains a difficult task.

It has already been noted that efforts to define an environmental index face three principal stumbling blocks:

1. The absence of detailed information on certain components of the environment such as biodiversity or land conservation, even in countries which have at its disposal very sophisticated statistical apparatus;
2. Uncertainties and subjectivity associated with the selection and weighting of the indicators which constitute an environmental index;
3. Limited knowledge of the environment's absorption and regeneration capacity and, hence, of the environmental degradation thresholds.

An analysis of the methodological changes introduced in the construction of the Human Development Index (HDI) since its introduction in 1990 is useful in illustrating how these three constraints could impact the development of aggregated environmental indicators.

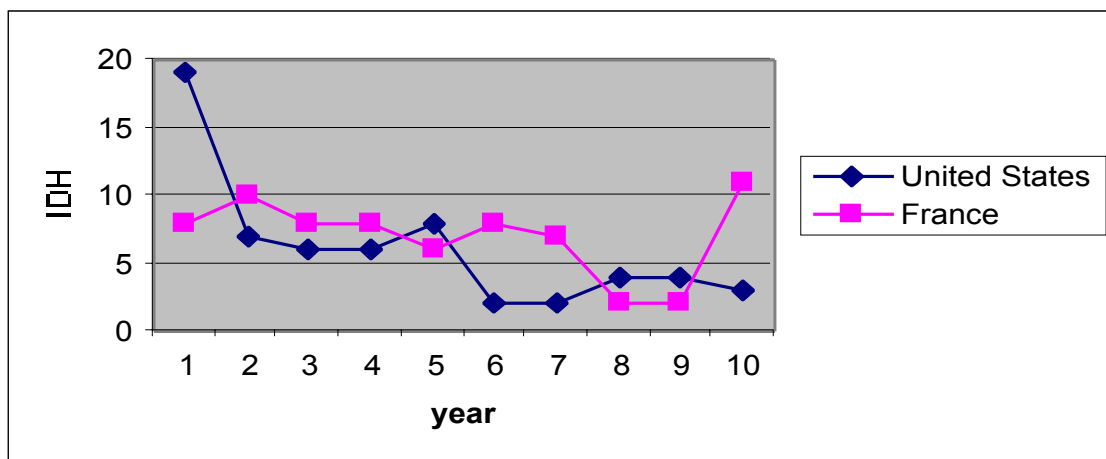
**Table 8 - Environmental indicators by function**

<b>Issues</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
<b>I. Source Indicators</b> 1. Agriculture a. Land quality b. Others  2. Forest  3. Marine Resources  4. Water  5. Sub-soil Assets a. Fossil Fuels b. Minerals	Value Added/Gross Output- Human induced soil degradation  Land use Changes, Inputs for EDP  Contaminants, Demand for Fish as Food  Intensity of use  Extraction rate(s) Extraction rate(s) Extraction rate(s)	Cropland as % of wealth Climatic classes & soil constraints  Area, distribut., vol. et value of forest  Stock of marine species  Accessibility to population (weighed % of total)  Sub-soil assets % wealth Proven reserves Proven reserves	Rural/Urban Terms of Trade  Input/Output ratio, main users, recyc.rates  % coverage Int'l Protocoles/Conv.  Water Efficiency measures  Material balances/NNP, Reverse energy subsidies, Input/Output ratio, main users, recyc.rates
<b>II. Sink or Pollution Indicators</b> 1. Climate Change a. Greenhouse Gases b. Stratospheric Ozone  2. Acidification  3. Eutrophication  4. Toxification	Emissions of CO <sub>2</sub> Apparente Consumption of CFC  Emissions of Sox, NOx  Use of Phosphates (P), Nitrates (N)  Generation of hazardous waste/load	Atmospheric Concentration of GHG and CFCs  PH and Concentrat. in SOx and NOx in precipitation  Biological Oxygen Demand, concentrat. in P et N in rivers  Concentrat. of lead, cadmium, etc. in rivers	Energy Efficiency of NNP % coverage Int'l Protocoles/Conv.  Expenditure on Pollution Abatement  % pop. With waste treatment  % Petrol unleaded
<b>III. Life Support Indicators</b> 1. Biodiversity  2. Oceans  3. Special Lands (e.g. wetlands)	Land Use Changes  Threatened, Extinct species % total	Habitat/NR	Protected areas as % threatened
<b>IV. Human Impact Indicators</b> 1. Health  2. Water Quality  3. Air Quality  4. Occupational Exposure, etc.  5. Food Security & Quality  6. Housing/Urban  7. Waste  8. Natural Disaster	Burden of disease (dailys/pers.)  Energy Demand  Population Density (persons/km2)  Generation of industrial, municipal waste	Life Expectancy at birth  Dissolved Oxygen, faecal coliform  Concentration of particulates, SO2, etc.  Accumulation to date  Flood	% NNP spent on Health, vaccination, etc.  Acces to safe water  % NNP spent on housing  Exp. on collect. & treatment, recyc. Rates

World Bank quoted by WRI-Environmental indicators (1995).

Figure 12 represents the variations in the HDI ranking of two countries - France and the United States - from 1990 to 1999. Table 9 gives the set of indicators selected to construct the HDI over this same time period.

**Figure 12 : Changes in HDI ranking of France and of the United States from 1990 to 1991**



The United States and France were ranked nineteenth and eighth respectively in the first publication of the Human Development Index in 1990. The second edition (1991), however, catapults the United States from nineteenth to seventh spot.

Two factors explain this spectacular improvement by the United States. The first factor was that in 1990, the literacy rate in the USA was estimated at 96%, placing it far behind most OECD countries. In 1991, this figure was adjusted, on the basis of more complete statistical data, to 99 %, which is the average of all other industrialized countries.

The second factor was that, the construction of the HDI was modified to include mean years of schooling as a second indicator for education. Since the United States has the longest mean years of schooling in the world (12.2 against 9.4 for France, for example), obtained the maximum score of 1 for the education indicator.

Then, in 1994, the United States and France again changed position. Although the choice of indicators did not change, the methods used to calculate the indicators were modified. The calculations used in the first four editions of the HDI were based on the relationship between the value of a given country and the maximum and minimal values attained by other countries (see the aggregation of the HDI in insert 2). But in 1994, theoretical thresholds became the basis for calculating maximum and minimum values for each indicator, replacing the previous use of the highest and lowest results achieved by all countries. Thus, the average years of schooling no longer varied from the 12.3 (the United States) to less than 0.1 (Burkina-Faso); but from 15 to 0 years. The resulting “grade“ of the United States for the education indicator was therefore reduced from 1.00 to 0.83. Although the United States still had the highest education value in the world, this high value indicators could no longer compensate for other relatively weak indicators, such as life expectancy, in comparison with the world’s other richest countries.

In 1995, the United States recorded second position in the HDI rankings, thanks to a change in the construction of the education index. The “ mean years of schooling” indicator was now replaced by «combined primary, secondary and tertiary gross enrolment ratio». With a score of 95 %, the United States ranked second in the world, with Canada achieving top spot.

In 1997, the United States’ ranking dropped to fourth position, while France, climbed to second position, the average life expectancy of its population having been re-valued from 77 to 78.7 years. In 1999, the

United States climbed to third place; with France falling to eleventh place, because of a further change in the calculation of income that gave increased weighting to GNP per capita.

**Table 9 - Modifications in the HDI construction methodology since its creation in 1990 showing how small changes in indicators can cause large changes in relative ranking of a country**

Year	Indicators used to construct the HDI	Rank USA	Rank France
1990	Life expectancy at birth Adult literacy rate GDP per capita [log (ppp\$)]	19	8
1991	Life expectancy at birth Adult literacy rate Mean years of schooling GDP per capita [ log (ppp\$) adjusted ]	7	10
1992	Life expectancy at birth Adult literacy rate Mean years of schooling GDP per capita [ log (ppp\$) adjusted ]	6	8
1993	Life expectancy at birth Adult literacy rate Mean years of schooling GDP per capita [ log (ppp\$) adjusted ]	6	8
1994	Life expectancy at birth Adult literacy rate Mean years of schooling GDP per capita [ log (ppp\$) adjusted ]	8	6
1995	Life expectancy at birth Adult literacy rate Combined primary, secondary and tertiary gross enrolment ratio GDP per capita [ log (ppp\$) adjusted ]	2	8
1996	Life expectancy at birth Adult literacy rate Combined primary, secondary and tertiary enrolment ratio GDP per capita [ log (ppp\$) adjusted ]	2	7
1997	Life expectancy at birth Adult literacy rate Combined primary, secondary and tertiary gross enrolment ratio GDP per capita [ log (ppp\$) adjusted ]	4	2
1998	Life expectancy at birth Adult literacy rate Combined primary, secondary and tertiary gross enrolment ratio GDP per capita [ log (ppp\$) adjusted ]	4	2
1999	Life expectancy at birth Adult literacy rate Combined primary, secondary and tertiary gross enrolment ratio GDP per capita [ $w(y) (\log y - \log y_{\min} / \log y_{\max} - \log y_{\min})$ ]	3	11

The HDI has benefited from comprehensive research since its inception that has acted to strengthen its relevance that is, to provide an even more transparent, bias-free and analytically sound measurement of human development throughout the world. A dedicated research unit has been established in the UNDP to update and, where necessary, to adjust the HDI construction methodology. However, the variations between the respective rankings of the United States and France over a 10 year period reveal the extent to which a new set of statistics, a change in the selection of indicators or a change in the construction methodology will influence the final value of a given index and its actual ability to support decision making.

### Insert 2 : Construction of the Human Development Index (HDI)

The equations of aggregation of the IDH have been varying considerably over the past ten years. We reproduce below the 1992 methodology.

The HDI includes three components: longevity, knowledge and income, which are combined in a three-step process to arrive at an « average » deprivation index. Longevity is measured by life expectancy at birth as the sole non-adjusted indicator. Knowledge is measured by two educational stock variables: adult literacy and mean years of schooling. The measure of educational level is adjusted by assigning a weight of two-thirds to literacy and one-third to mean years of schooling.

$$E = a_1 \text{ LITERACY} + a_2 \text{ YEARS OF SCHOOLING}$$

Where  $a_1 = 2/3$  and  $a_2 = 1/3$ .

For income, the IDH is based on the premise of diminishing returns from income for human development using an explicit formulation for the diminishing returns. A well-known and frequently used form is the Atkinson formulation for the utility of income:

$$W(y) = 1/(1-\epsilon) * y^{1-\epsilon}$$

Here,  $W(y)$  is here the utility or well-being derived from income, and the parameter measures the extent of diminishing returns. It is the elasticity of the marginal utility of income with respect to income. If  $\epsilon = 0$ , there are no diminishing returns. As  $\epsilon$  approaches 1, the equation becomes:

$$W(y) = \log y$$

The value of  $\epsilon$  rises slowly in the HDI as income rises. For this purpose, the full range of income is divided into multiples of the poverty line  $y^*$ . For all countries for which  $y < y^*$  - that is, the poor countries,  $\epsilon$  is set equal to 0. If  $y^* < y < (a+1)y^*$ , then  $\epsilon = a/(a+1)$ . So, the higher the income relative to the poverty level, the more sharply the diminishing returns affect the contribution of income to human development.

The HDI ranks countries relative to each other for a particular period. The maximum and minimum values that define the maximum distance to be travelled for each variable are specific to that year. To express this algebraically – with  $X_1$  as life expectancy,  $X_2$  as literacy and  $X_3$  as income - the contribution of each variable to the HDI can be written as  $Z_i$  where:

$$Z_{ijt} = [ X_{ijt} - \min_{ijt} ] / [ \max_{ijt} - \min_{ijt} ]$$

In this formula,  $j$  denotes a specific country and  $t$  the time period.

#### 1.2.7.2 Definition of environmental thresholds

A key question raised previously, needed to be able to calculate an environmental Index, is what are the maximum tolerable levels of environmental degradation? While the scientific community acquired a

reasonably sophisticated understanding of physical environmental degradation processes, little is still known about the degradation levels that must not be exceeded to maintain a comfortable level of life on earth, given the present state of technological development. This point can be illustrated through a short description of the methodological difficulties encountered to identify degradation thresholds for soil erosion and deforestation.

Although soil erosion is universally considered by the scientific community as a key indicator of land degradation, there is no consensus on a maximum acceptable value for this indicator in assessing the severity of degradation. The word «erosion» comes from the Latin verb *erodere*, meaning «to gnaw» (Roose, 1996). Despite the somewhat negative connotation of this word, erosion is a natural phenomenon that strips away the flesh of mountains but at the same time enriches the valleys and forms the rich plains that feed a large percentage of humanity. It is therefore not necessarily desirable to prevent all erosion, but rather to reduce erosion to an acceptable level.

An acceptable level of erosion was first defined as the balance between soil losses and soil formation through weathering of rocks. This can vary from 1 to 12 tons/ha/year according to climate, type of rock and soil depth (Roose, 1996). However, the productivity of the humiferous horizons (top soil), rich in biogenic elements, is generally far greater than that of alterites (deeper soil layers), which are more or less sterile. On the other hand humiferous horizons are the first to be affected by erosion. Therefore, to be able to reflect the importance of selective erosion of the nutrients and colloids which make soils fertile, the level of tolerance was defined as “*erosion that does not lead to any appreciable reduction in soil productivity*” (Roose, 1996). But this new definition also presented a number of difficulties. Roose (1996) states that “*in the case of some deep soils on loess, high soil losses on slopes entail only a small drop in soil productivity, but do lead to unacceptable damage downstream in terms of pollution of fresh water and siltation of dams*”.

As an alternative way to define the tolerance level of soil erosion, there are at least three aspects to be considered: (i) speed of soil rehabilitation; (ii) maintenance of soil productivity given equal inputs; and (iii) respect for the environment, in particular with regard to water quality and sedimentation (Stocking 1978, Mannering 1981, in Roose, 1996). Thus even a simple parameter such as erosion is not easy to define in terms of acceptable levels.

Development of a distinction of the maximum acceptable level for deforestation is no less challenging than for erosion. Does deforestation lead inexorably to soil erosion and environmental degradation? Tropical forests cover less than 7 per cent of the world area but shelter more than half of its terrestrial biodiversity (E.O. Wilson, 1988). Their extraordinary biological diversity notwithstanding, tropical forests are some of the most fragile habitats on earth. They develop on wet deserts: two thirds of the tropical forests are on very sandy ferrallitic soils and tropical podzols (P. Brabant, personal communication). Tropical podzols are among the least fertile soils, and are characterized by very strong acidity and low chemical fertility. Tropical forests can nevertheless thrive on these soils because of their dense and penetrating root systems which bring nutrients from lower horizons to the surface, and because of their continuous recycling of litter.

If forest clearing remains fairly - For example with localized openings of less than two hectares by slash and burn agriculture - the forest regenerates quickly and deforestation indeed encourages biodiversity through the introduction of opportunistic animal and vegetal species (FAO, 1994). But if deforestation occurs over larger size tracts, the short germination period of many tropical species will limit their capacity to migrate to other favourable sites. Monitoring of deforested areas suggests that in the case of large areas of deforestation, the complete regeneration of the tropical forest may take several centuries (E.O. Wilson, 1988). The impact of any deforestation will thus depend on land use, on the pedological substrata and on the extent of deforestation.

#### 1.2.7.3 Environmental indicators: a philosophy concealed ?

Even allowing for the complexity and the duration of the phenomena observed, the maximum thresholds of environmental pollution that may be selected often say more about an experts outlook than on the ecosystems that they are supposedly describing. In the absence of a «spontaneous revelation» of natural thresholds, the values that are determined will often depend heavily on our perceptions of human progress and accepted ethical and social values. To understand this concept, it is to consider that the existence of three main philosophical divides will affect the selection of environmental thresholds.

The first divide exists between a “growth-centric” and an “eco-centric” development model. In a study of future scenarios, the World Business Council for Sustainable Development (WBCSD,1987) emphasised the importance of the “ myths “ which govern our perceptions of environmental problems, and the solutions that we are likely to devise. Table 10 represents the four major myths as identified by the WBCSD.

It has been argued, as a defining concept that the contemporary world is dominated by the economic myth. Many essays on environment and sustainable development can be read almost as a revolt against the dominant economic myth and its limitations as the only vector of human progress. Environmental criticism therefore appears as an extension of the work of political economists, such as Robert Malthus, Karl Marx or Dennis Meadows (of the Rome Club), on the limits of growth. Jean-Marie Harribey (1998) offers the following definition of this development crisis:

*«The development crisis can be defined as the rupture between a process of capital goods accumulation and the entire process of regulation of social rapports and the relationship between man and an instrumentalised nature. It includes and goes beyond a crisis of capitalism. The latter is an interruption in the valorisation of capital related to a production crisis and the difficulty in generating added value, but without questioning adherence to the values of material progress».*

**Table 10 - Principal “Myths” Influencing Perceptions of the environment**

	<b>Hero</b>	<b>Religious</b>	<b>Democratic/ Scientific</b>	<b>Economic</b>
<b>Ideal</b>	Excellence	Goodness	Truth	Growth
<b>Behaviour</b>	Competition	Obedience	Reason	Maximising advantage
<b>Actors</b>	Heroes	Saints/ Prophets	Philosophers/ Scientists	Consumers/Busi ness
<b>Communication</b>	Stories	Scripture/Prayers	Logical arguments /Mathematics	Images/ Numbers

At the other end of the environmental debate is the following defining concept was published by The Economist (1998):

*«The notion of a growing number of people fighting over a fixed resource pie is a Malthusian bosh, as this newspaper has argued in the past. Human ingenuity, energised by sensible policies, creates resources faster than people use them; people learn to substitute sand (in the form of microchips) for sweat, and fuel cells for petrol engines».*

Taking as an example that the increase in agricultural productivity freed mankind from a shortage of arable land and that the multiplication of the needs and markets made it possible to avoid an interruption in the valorisation of capital; this second concept trusts technological development to compensate for shortages in raw materials. It also puts its faith in economic growth and technological progress to fight poverty and to solve associated environmental problems such as deforestation and land degradation.

Based on this second concept, and while recognizing the importance of protecting the environment, many nations are also opposed to the application of stricter international standards for protecting the environment. These nations particularly fear that these initiatives would, for short-term environmental gains, negatively affect their economic growth and the resolution of social problems, which they consider to be more pressing than environmental protection.

It is clear from the opposite views expressed above that assessments of the severity of environmental degradation will vary considerably depending on whether models of development are based on material progress, or on (arguably) slower economic growth to ensure that development is both sustainable and compassionate.

A second major divide can be discerned between a “deterministic” and an “evolutionary” concept of the environment. The deterministic concept of the environment rests on a vision of the universe in terms of repetitiveness, immutability and reversibility. Each physical environment corresponds to a maximum biotic capacity for mankind and an optimal management approach that must be respected.

The evolutionary concept of the environment defends a vision of the universe in terms of destruction-creation-complexification. It recognizes the right of mankind to recreate its environment and it takes a long-term perspective of mankind’s environment. For example, the concept of climax, popular among foresters, reflects a short-term perspective of the environment. However, the same site can give rise to various climaxes over time, which reflects a long-term perspective of the environment.

The third divide is found between a “ecocentric ” and an “ anthropocentric ” concept of the environment (Hatem, 1990). The ecocentric approach promotes the protection of all the components of an ecosystem for an ethical and non utilitarian reason. The environment has an intrinsic value that must be protected from the often harmful actions of human beings. It defends a systematic protection of nature and ecosystems.

The anthropocentric approach, on the other hand, places its emphasis on the search for human well-being. Its principal objective is to help humankind live; and to live well in its environment. Y. Veyret and P. Pech (1993) describe what they call the geographical approach to the environment: « *through nature, it is humankind who must be educated and protected, in particular when he plays the sorcerer's apprentice. By degrading the environment in which they live, human beings endanger their own existence. Nature is in this case the periphery and not the centre of a system*».

Our ignorance of the biotic capacity of the environment for the use of humankind for a given level of technological development and for a given level of comfort; and the subjectivity associated with sustainable development issues all combine to make the identification of environmental thresholds a particularly delicate task. Subsequent sections of this book contain a more thorough discussion of this problem.

### 1.3 CONCLUSIONS

It is important to stress again that most current initiatives in the field of environmental information focus on environmental data collection, to the detriment of data analysis and even more, to the detriment of data communication to decision makers. To support decision-making, environmental data has to be interpreted, simplified, synthesized and qualified. These data will have to be communicated to decision-makers using flexible tools adapted to the complexity of the decision-making processes, and allowing for a constant dialogue between the analyst and the decision-maker.

GIS are excellent analytical tools for the environmental manager. But in the absence of tools to facilitate communication of information to decision-makers, GIS will be remain unsuited to strategic decision-making. Strategic decision-making is based on very aggregated and strongly interpreted information. A key mechanism for such interpretation and aggregation is the development of Environmental Indicators and Indices.

Moreover it is clear that any aggregation methodology will have to be adapted to the unique requirements of the decision-makers. According to his position in the decision-making cycle, each actor will have specific needs as regards environmental information. But this notwithstanding, the same database should make it possible to develop different sets of environmental indicators for each objective and end-user in the decision-making cycle.

In applying indicators, it was shown that it is very important to remain mindful of the uncertainties and subjectivity that affect the selection and weighting of their various parameters. Critics of indices stress that this uncertainty and subjectivity are sufficient to deprive indices of scientific validity. Debates on the

respective merits of single-parameter indicators versus indices illustrate two traditionally opposing positions concerned with data processing to support decision-making. For some, data provided to decision-makers must be as complete as possible, despite the interpretation problems that such an approach may create. For others, the data must be as simple but as revealing as possible, despite the distortion which such simplification may cause.

It may be added however, that these two approaches are not mutually exclusive. Aggregated indicators and indices can more easily capture the attention of decision makers than raw physical, chemical or biological data. Because of their appeal, such indices make it possible to initiate a dialogue between decision-makers and analysts and to encourage a discussion on the raw data and the assumptions that allowed the construction of these aggregated indicators. 1998 Nobel Prize Laureate for Economy, A. Sen, elegantly expressed this point in his analysis of the impact of the Human Development Index (UNDP, 1999) on the formulation of development policies:

*“ By skilful use of the attracting power of the HDI, Mahbud got readers to take an involved interest in the large class of systematic tables and detailed critical analyses presented in the Human Development Report. The crude index spoke loud and clear and received intelligent attention and through that vehicle the complex reality contained in the rest of the Report also found an interested audience “*

The following chapters discuss these issues in greater detail as part of the construction of environmental indicators for the sustainable development of Tropical Uplands in Vietnam.

## II THE PILOT STUDY

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*This research took place within a framework of a broader EC Research Programme. This chapter describes the objectives and methodology of the EC Research Programme and of his specific study on environmental indicators, the state of Thai Nguyen Province's environment, and the selection of appropriate Environmental Indicators to reflect Thai Nguyen Province's Key environmental challenges.*

*Thai Nguyen faces a number of challenges to its environment. Especially significant are population pressures - in terms of in-migration, patterns of settlement and land use - and their impact on forest, soil and water resources.*

*This chapter builds on the previous methodological discussion to define environmental indicators that are appropriate for local policy making in tropical upland areas. The outcome of the chapter is in the recommendation for the selection of a pressure index, a state index, and a response index to describe each of the four main forms of environmental degradation in Tropical Uplands - deforestation and loss of biodiversity, soil erosion, risk of water shortage, and water pollution.*

*This chapter also reviews some of the ongoing work by international organisations that are working in developing land degradation indicators using the STRESS concept to better define the selection of specific environmental parameters to develop these indices.*

## 2.1 THE EC PROGRAMME FRAMEWORK

### 2.1.1 Objectives of the EC Research Programme and of the present pilot study on Environmental Indicators

This research on environmental indicators took place within the framework of a broader multidisciplinary research programme supported by the European Commission (DG XII) and coordinated by the Institute of Research for Development (IRD, formerly called ORSTOM). The Programme was implemented in partnership with the Institute of Geography of the National Centre for Natural Science and Technology of Vietnam (IG), the French Institute of Pondichéry (India), the Agronomic Faculty of Science of Gembloux (Belgium), the Catholic University of Leuven (Belgium) and the laboratory of Environment of the University of Paris VII-Diderot. The core research Programme, initiated in April 1995, was completed in November 1999.

Uplands make up 75 per cent of Vietnam's territory. The principal objective of the EC Programme is to support decision-making processes in connection with environmental protection and sustainable management of Vietnamese Tropical Uplands. To establish this decision-making support system, the following four activities were undertaken:

1. Construction of a database for three pilot zones in the Vietnamese Uplands: Bac Kan, Thai Nguyen and Lam Dong Provinces<sup>5</sup>. This database is managed by a Geographical Information System (GIS), using remote sensing. The three pilot provinces were selected from Vietnam's 66 provinces, because they typify the environmental, socio-cultural and economic conditions that characterise much of the Tropical Uplands of Vietnam. Table 11 details the principal characteristics of the three provinces studied.
2. Development of a Environmental Information System, based on the database, to support decision-making for the sustainable management of the Vietnamese Uplands. The model was designed to be applicable to the remainder of the Vietnamese Uplands, and also to other countries in the region (e.g. Laos, Cambodia) with similar characteristics of broken relief, strong monsoon rains, tropical forests, new incidence of slash-and-burn agriculture by migrants, rain-fed agriculture, and a very high risk of soil degradation.
3. Using medical geography techniques of analysis, establishment of linkages between agricultural problems and health; in particular in relation to malaria, which is endemic in the Tropical Uplands of Vietnam.
4. Reinforcement of research potential in Vietnam to ensure the continued maintenance of this Environmental Information System, its improvement and expanded application within the region.

Research on environmental indicators was undertaken to further the research Programme's second component - the development of a GIS-based decision-making support system for the sustainable development of Vietnamese Uplands. It was implemented through the following five stages:

1. Using a comprehensive consultation process, to identify and create a hierarchy of the main problems experienced by the various stakeholders in tropical upland areas of Vietnam: national and international scientists, provincial decision makers and managers, district and commune representatives.
2. Assessment of existing data: some data were immediately available while other data had to be updated or newly collected through field survey.
3. Structuring of biophysical and economic data in a common GIS database.

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<sup>5</sup> Bac Kan and Thai Nguyen previously formed one province called Bac Thai. The province of Bac Thai was subdivided into two new provinces in November 1996.

4. Communication of collected information to the appropriate provincial policy-makers, and training of local government staff to operate and maintain the system.
5. Using the GIS database development of environmental indicators to support decision-making, and application of this system to land conservation issues in the pilot provinces.
6. Communication of Programme findings in a form usable to provincial decision makers.

**Table 11 - Key Geographical Features of the Pilot Provinces**

	<b>Thai Nguyen</b>	<b>Bac Kan</b>	<b>Lam Dong</b>
Location of the provincial capital	75 km north of Hanoi	125 km north of Hanoi	200 km northeast of Ho Chi Minh City
Provincial town	Thai Nguyen	Bac Kan	Dalat
Superficie	3 532 km <sup>2</sup>	4 867 km <sup>2</sup>	9 780 km <sup>2</sup>
Number of inhabitants	1 060 300	310 000	954 710
Average population density	300 people/km <sup>2</sup>	64 people/km <sup>2</sup>	97 people/km <sup>2</sup>
Range in elevation	30 - 1590 m	250 - 1530 m	200 - 2150 m
Gross provincial product <i>per capita</i>	US\$ 132 in 1997	US\$ 64 in 1997 and \$ 71 in 1998	US\$ 169 in 1998
Provincial upland area in percentage	60%	100%	90%

Source: Programme STD3 CT94-0310.

## **2.1.2 The Geographical Information System**

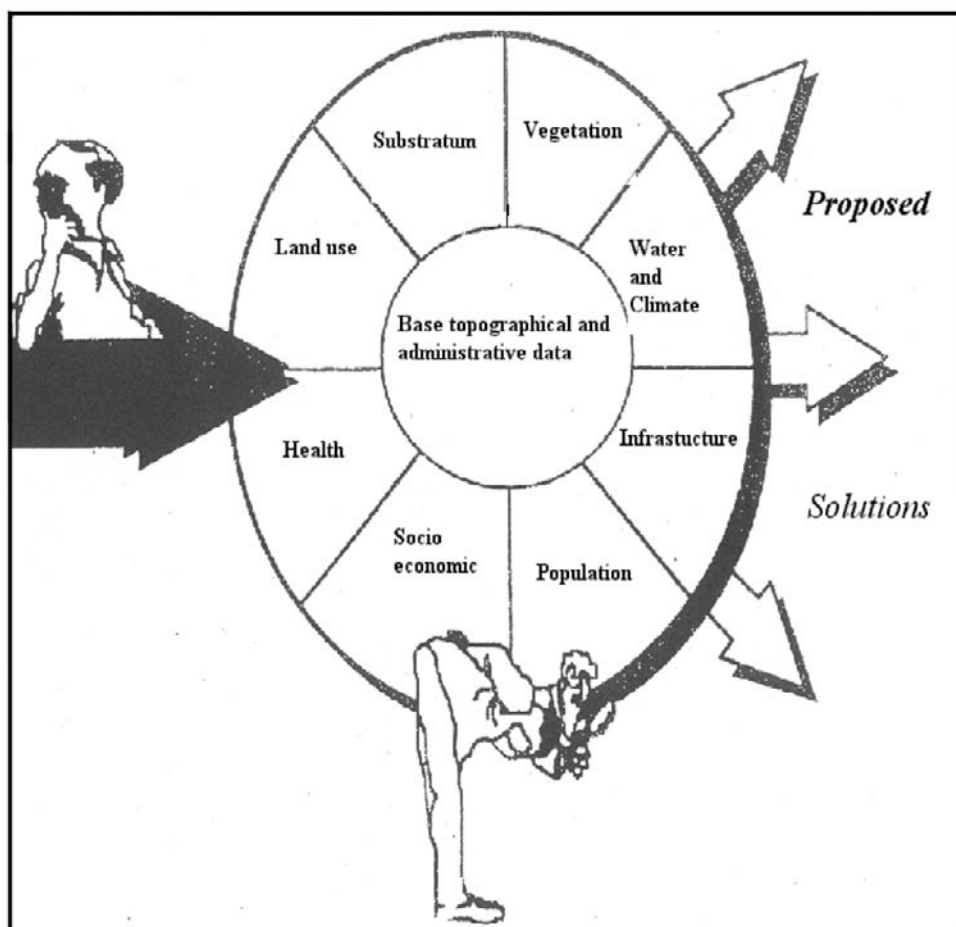
The development of the three provincial GIS databases constituted the main focus of the Research Programme, around which the rest of the Programme's communication and decision-making support activities were structured.

### 2.1.2.1 Structure of the provincial GIS databases

The database consists of a central structure containing basic information, around which thematic information, organized according to groups of scientific disciplines, is arranged (figure 13).

The central structure contains topographical and administrative base maps. These base maps were mainly produced by creating digital versions of existing topographical maps with scales of 1/50,000 and 1/100,000. These base maps are structured by geographical coordinates, contour lines, geodesic points and dimensional points, hydrographic networks, roads and railroad networks, habitat, and administrative borders. The topographic map is particularly important as it provides a profile of the very hilly landscape: where land slope is a major constraint in the exploitation of Uplands.

**Figure 13 - Structure of the GIS Database.**



Source: P. Brabant, J.C. Castilla, S. Darracq, Y. Glemarec, Le Duc An, Nguyen Tram Cau, V. Simorreux (Cahiers Agricultures-1997)

Table 12 shows examples of “water and climate” and “substratum” data collected for the province of Thai Nguyen.

**Table 12 - Attributes of “Water and climate” and “Substratum” Data Base Themes**

Water and climate	Substratum
Natural hydrographical network Canals Water infrastructure Hydro-electrical plants Surface water Ground water Meteorological data Hydrological data Bioclimatic zones Areas liable to seasonal flooding	Landscapes: karstic areas, mountainous areas, valleys, plains, plateaus, etc. Geomorphological units and relief Geology: lithology, stratigraphy, tectonics, mineral resources Soils: distribution, description, physical, chemical and mineralogical attributes, degradation status, risk of degradation.

In terms of software and hardware configuration, the GIS database was developed using ARC/Info 7.03 on a SUN workstation. ARC/Info is a software product developed by the Environmental System Research Institute (ESRI).

This software is currently the GIS market leader. It functions on a number of operating systems, including UNIX, DOS, WINDOWS NT and WINDOWS 95, and can read information recorded in most of the relational data bases currently in use worldwide. ARC/Info can also produce geographical data for a number of ESRI derived products such as PC ARC/Info and Arcview (GIS desktop).

While a UNIX workstation is essential to run a large GIS database at the national level, it will be possible to use lighter products such as PC ARC/Info and Arcview functioning on Windows at the provincial level. The adoption of lighter hardware systems at the provincial level will reduce training requirements and facilitate the broad diffusion and use of the database at more local levels of government.

#### 2.1.2.2 Data acquisition

For each database theme, a working group was established which brought together scientists from the research Programme and from the relevant provincial engineering departments. The methodology used for the collection of data is illustrated by the following activities carried out by the "Substrata" working group: (i) research and data collection on soils, the geological substratum, and landforms; (ii) data verification to gauge whether data were directly usable, or if data required updating; (iii) conducting the field surveys; and (iv) preparation of new documents resulting from the above work.

Topographical, geological and tectonic data, provided by the central government, are considered relatively stable through time and were used directly. Similarly, socio-economic data, provided by the engineering departments of the provinces, were directly used and were not updated. But five data sets for each pilot province had to be revised: soil, vegetation, surface water resources, land cover, and land use. This task was completed within the Programme time limits through to the use of remote sensing techniques.

A Landsat image covers 34 225 km<sup>2</sup>, a surface area more than three times larger than the surface of the largest pilot province, Lam Dong (9 953 km<sup>2</sup>). One image each was enough to cover the provinces of Lam Dong and Thai Nguyen but - because of the angle of projection - two were required for Bac Kan province.

Significant nebulosity in the high plateau of Vietnam, where there are altitudes higher than 2,000 metres at Lam Dong, limited the availability of images. Two good quality Landsat images with a ground resolution of 30 m were nevertheless acquired. That taken in March 1992 covers the entire province of Lam Dong. This corresponds to the end of the dry season, a period that allowed mountain areas that had been cleared and cultivated to be distinguished. The other image was taken in October 1994, and covers the province of Thai Nguyen and most of the province of Bac Kan. This timing - the end of the rainy season - is less favourable, because contrasts between the different types of vegetation cover are less pronounced. Moreover, some rice fields were still being cultivated, giving the potential for cultivating fields to be confused with natural vegetation.

Two panchromatic SPOT images (black and white; spectrum visible from 0,51µm to 0,73µm, with a ground resolution of 10 m) were acquired for a detailed study for the provinces of Thai Nguyen and Lam Dong. Also, two Radarsat images (from Canadian satellite with a synthetic radar antenna with a high resolution of around 10m), were obtained for the province of Thai Nguyen; the first radarsat image was dated August 1996, and the other image was dated December 1996. The radarsat images were used to quantify the extension of the flood zones during the rainy season, when cloud cover prevents analysis using Landsat or SPOT images. The interpretation of the remote sensing images was sometimes supplemented by those of aerial photographs, in particular in the province of Lam Dong (air missions in 1952, 1969, and 1992).

## **2.2 THE STATE OF ENVIRONMENT IN THE PILOT PROVINCE OF THAI NGUYEN**

To fully integrate the information available through the GIS database into a decision policy formulation, the final activity of the Programme's second component involved the development of a limited number of environmental indicators. The principal objective of the development of these indicators was to facilitate communication of the information collected to local decision-makers, and to other relevant parties.

The Programme completed its first database for Thai Nguyen Province. Accordingly, the environmental indicators were developed on an experimental basis for this province only. Nevertheless, the indicators and methodologies of aggregation were selected in order to be easily transposable to the two other pilot provinces and, possibly, to the entire Uplands region of Vietnam. Before discussing the criteria that informed the selection of these environmental indicators, the present chapter briefly describes the state of the environment and the principal mechanisms of land degradation in the pilot province of Thai Nguyen.

## 2.2.1 State of the Environment in Thai Nguyen Province

### 2.2.1.1 The physical environment

The province of Thai Nguyen in Vietnam is located in the transition zone between the Red River Delta and the mountains of North Vietnam, which constitutes the furthest reach of the Himalayan chain. Map 1 (see Appendix I - Maps) indicates the location of the pilot Province of Thai Nguyen<sup>6</sup>. Map 2 shows the distribution of population in the Province.

This area of Vietnam's piedmont presents a highly contrasting relief. The topographic profile of North Vietnam on a northwest axis, as shown in Figure 14, is representative of the relief and soils in Thai Nguyen Province. The Province's overall topography is shown in Map 3. Based on these documents, four major zones can be identified (P. Brabant - S. Darracq, 1999):

1. The plains: The very flat zones cover a limited area in the northwestern part of the deltaic plain of the Red River and the river terraces of the Song Cau and Song Cong rivers, the principal waterways of the province. The plains are largely covered by irrigated rice fields.
2. The low hills: This is a zone of plains strewn with small deforested hills, that have frequently been replanted with eucalyptus. The flat low zones are cultivated by irrigated rice. Dwellings are generally located along the circumference of the hills at the bottom of the slopes.
3. The high hills: These are an extension of the low hills. A few hills are found scattered on the plains, but these hills become more numerous and higher towards the mountainous zone where they account for most of the land surface. They are variously covered with natural shrub, bush vegetation, eucalyptus plantations or tea plantations. The few cultivable low-lying areas are given over to irrigated rice cultivation when water is available.
4. The mountains: The slopes have a wide range of vegetation types, from dense original forest - still present on some high peaks - to recent herbaceous fallow resulting from abandoned slash and burn agricultural land. But the most widespread cover consists of degraded forest and bush. In the valleys, which intersperse the mountains and are often very broad, the dominant agriculture remains irrigated rice.

### 2.2.1.2 Pressures on the physical environment

To understand the challenges to sustainable rural development faced by Thai Nguyen Province, it is important to understand its land ownership history. The province has been occupied by the *Tay* ethnic group of peoples for thousands of years. The *Tays* have primarily cultivated flooded rice in the low-lying areas once a year, supplemented by slash and burn agriculture at the bottom of the slopes. The ethnic *Dao's* people, then the ethnic *H'Mongs* people, who arrived less than two centuries ago, limited themselves to itinerant slash and burn agriculture at higher elevations, and continued this farming system until agricultural collectivisation was imposed by the Government (GRET, 1995). Today, eight ethnic minorities live in the province: the *Tay*, *Nung*, *Dao*, *H'Mong*, *San Chi*, *San Diu*, *Cao Lan*, and *Hoa*. These minority groups represented about 25 per cent of the total population in 1997, while the main population group of Vietnam, the *Kinhs*, accounted for 75 per cent of the total population in 1997. The demographic growth rate decreased from 2.12% to 1.97% in 1998.

The Northern part of Vietnam's independence in 1954 led to the introduction of land reforms, which focused largely on the removal of large landowners and a redistribution of land. The quasi-complete

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<sup>6</sup> The names and the administrative boundaries of the 66 provinces of Vietnam are given map 9.

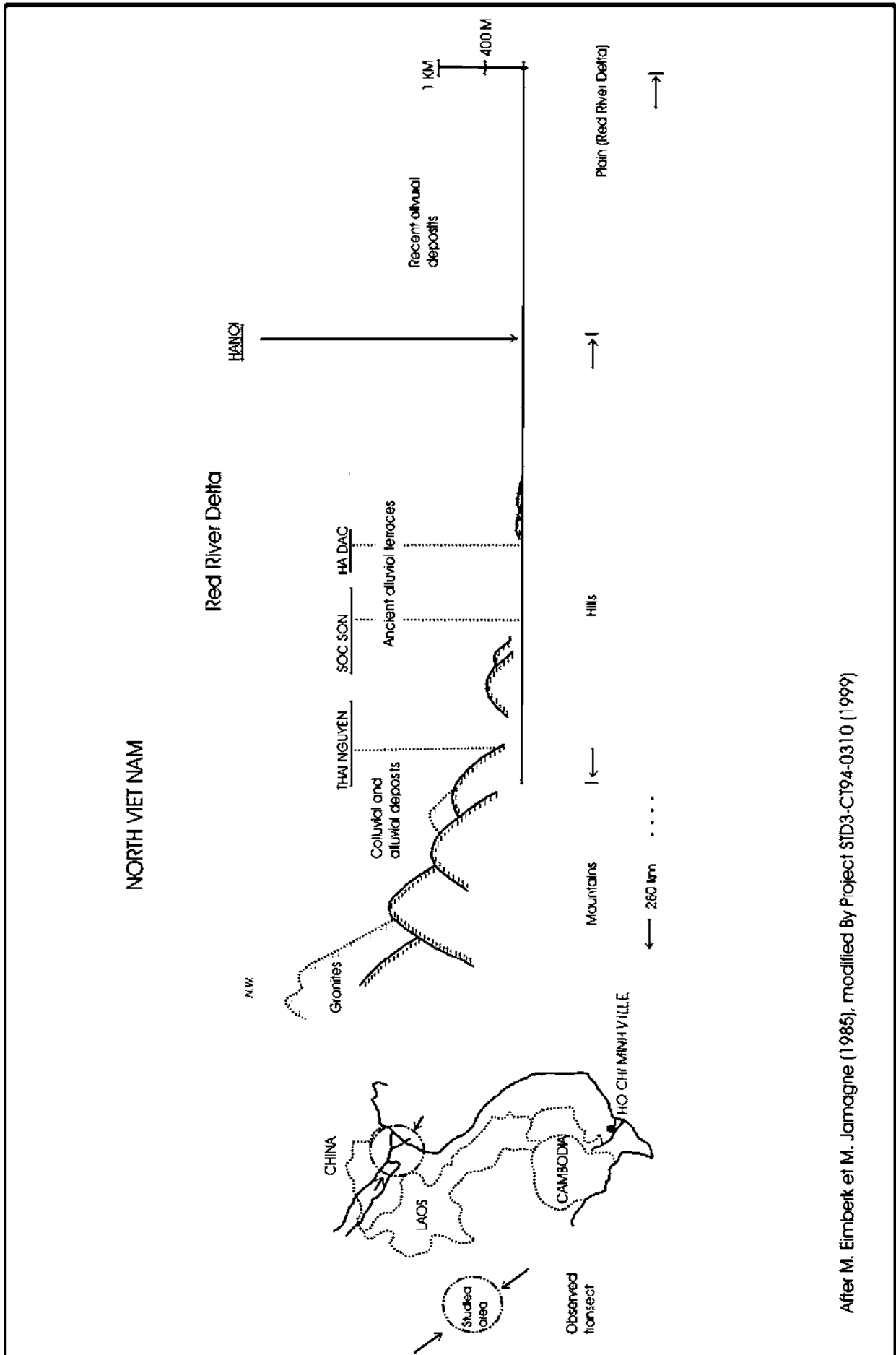
collectivisation of the means of production started in 1960. Populations were clustered in the valleys where important hydraulic irrigation installations were established. At the same time, the State introduced significant technical innovations in rice cultivation. Consequently, slope cultivation was abandoned in favour of substantial intensification of paddy rice cultivation in the valleys; with the use of river-fed irrigation, this enabled two rice crops to be grown each year, instead of the single previous crop. Permanent settlements were established to settle Dao communities and to accommodate Kinh immigrants arriving from the Red River Delta.

This period of collective agriculture continued for twenty years. In 1981, financial problems experienced by the co-operatives, along with widespread corruption, stagnation in production, and peasant's lack of interest in collective agriculture prompted the first measures to be taken towards the decollectivatisation of agriculture (Resolution Number 100, Government of Vietnam, 1981). Land was then allocated individually; livestock previously owned by co-operatives was sold to peasants, who were also provided with economic incentives to increase production. From the 1980s, population growth forced the government to authorise the resumption of slope cultivation, at least on the foothills.

In 1988, Resolution Number 10 (Government of Vietnam, 1981) marked a further step in the process of agricultural decollectivatisation. Lands were allocated to peasants for at least five years, labour points disappeared, and the role of the co-operative was reduced to the work of tax collection. And in 1989, the application of Resolution Number 10 in the north of Thai Nguyen Province led to the return of lands to their pre-collectivisation ownership. Those who had been settled in the area meanwhile (Daos and Kinh immigrants) found themselves dispossessed and had to look for new lands on the slopes and secondary valleys, where they resumed clearing patches of the forest for slash and burn agriculture. Today, young people who settle in the area encounter the same problem of lack of available lands that began in 1989 and are also forced to live on the slopes.

Soil and environmental degradation in tropical Uplands result from a combination of demographic pressure and unclear land ownership, along with very low agricultural productivity and food shortages. Surveys carried out in several communes of Thai Nguyen Province by the GRET/CNEARC Programme show that half of the farmers are unable to grow enough food to meet their needs from rice cultivation in the valleys and must, consequently, exploit hilltops with slash and burn agriculture: more intensively (GRET, 1995). However, traditional practices of slash and burn agriculture are no longer suited to the current demographic pressure and the production framework, particularly in terms of land ownership.

Figure 14 : Schematic transect of North Viet Nam



After M. Eimberik et M. Jamagne (1985), modified By Project STD3-CT94-0310 (1999)

### 2.2.1.3 Land cover and use

Based on satellite images and field surveys, this Programme established an inventory of land use in Thai Nguyen Province. Table 13 contains the preliminary results of this inventory - which are also shown on Map 4.

**Table 13 - Land use in Thai Nguyen**

Land use	Location	Sub-total of the Province (%)	% of the Province
Dense natural forest never or little affected by human activities	Dense forests on karst	2.60 %	7.80 %
	Dense forests on other substrata	2.00 %	
	Open forests	2.10 %	
	Open forests on karst	1.10 %	
Zone with spontaneous vegetation : shrubs, bushes, herbaceous species or bamboos	Mountains	28.70 %	38.70 %
	Hills	10.00 %	
Cultivated areas	- Annual crops in plains and valleys (dominated by irrigated crops)	31.50 %	49.90 %
	- Annual crops on mountains and hillsides (rainfed crops)	14.20 %	
	- Permanent crops (tea plants, fruit trees and others)	4.20 %	
Others	Water bodies	1.00%	3.80 %
	Open mines	0.25%	
	Dense urban settlement	0.25%	
	Rural settlement	2.30%	
<b>TOTAL</b>			<b>100.00 %</b>

Source: Programme STD3 - CT94-0310 (P. Brabant, S. Darracq, 1999).

Map 5 represents these different types of vegetation cover, and Map 6 shows the location of natural forests which have been unaffected or minimally affected by human activity. The Programme estimated - by interpretation of satellite images - that natural forest covered 27,700 hectares, compared with the 74,100 hectares stated in provincial statistics (Inception Report, Province of Thai Nguyen, project STD3-CT94-0310). This important difference is largely attributable to various definition of "natural forest". Insert 3 provides the forest definition adopted by this Programme.

The principal species found in dense forests in Thai Nguyen Province are: *Dipterocarpus retusus*, *Vatica tonkinensi*, *Aphanamixis polystachya*, *Dracantomelum duperraenum*, *Dsyoxylum gobarum*, *Elaeocarpus dubius*... and other species; on the karst: *Burretiodendron hsienmu*, *Dimerocarpus breneri*, *Diospyros pyrrocarpa*, *Ficus gibbosa*, *Pometa pinnata*, *Taxotropis ilicifolius*... In addition, the dominant species in open forests are: *Gossipium arboreum*, *Sterculia thymenocalyx*, *Livingstonia chinensis*, *Antidesma fordii* (T. Bouix, 1998).

Population pressure and severe forest degradation have led to the disappearance of much of the biodiversity in Thai Nguyen Province. Large mammals such as tigers, leopards and bears, that were formerly widespread, have totally disappeared from the Province. And the last representatives of many species of monkeys, reptiles and birds are critically endangered. However, a huge diversity of fauna and flora are still preserved in the remaining forest formations. The Provincial Department of Science, Technology and Environment (DOSTE, 1995) estimated that there were 522 different plant species in the area of former combined province of Bac Thai.

### Insert 3 : Forest definitions adopted by the Programme STD3 - CT 94-0310

Natural forest: Tree formations undisturbed or minimally disturbed by human activity; or formations previously cleared, but which have regenerated naturally for a period of at least 60 years without further disturbance. Canopy cover of more than 70 per cent.

Dense natural forest: Tree formations with canopy cover of more than 70 per cent where the height of trees is 25 metres in zones below 600 m ASL; and with four layers of vegetation. At higher altitudes and on karsts, the height of canopy is 15 metres with only three layers of vegetation.

Open natural forest: Areas that initially had dense tree cover, but which have been moderately exploited. A canopy cover of 40 to 70 per cent and irregular vegetation layers.

Secondary forest: Degraded natural forest in a state of regeneration. The reconstitution of the biomass can be completed in 60 to 80 years, sometimes more. The period necessary for the reconstitution of the biodiversity is much longer: in the order of a millenium or more.

Deforestation: Destruction of natural forests or regenerated secondary forests with dominant tree formation.

Clearing: Destruction of vegetation by shifting cultivation. These clearings take place on old shrubby fallows, or bamboos.

Afforestation: Natural regeneration of a degraded forest.

Reforestation: Establishment of plantation, often with single species of trees.

Barren lands: Translation of the Vietnamese expression « Dat trong ». This refers to tracts of land which should be covered with forests according to legislation, but which in fact are not. However, spontaneous vegetation can be very dense, consisting of shrubs, bushes, or herbaceous species. These lands are seldom barren of all vegetation, so the term « barren lands » is not strictly appropriate.

At least 17 new species of reptiles and amphibians have been discovered in the Nature reserve of Tam Dao in the southwest of the province since 1982. More than 108 species of snakes were identified at Tam Dao - Vietnam's highest peak at 1,592 m - which makes up 4 per cent of the global total of 2,700 species (M. McRae, 1999). By this criteria, this nature reserve shelters one of the most diverse and richest ecosystems of the planet.

This exceptional biological diversity is explained by the geographical position of the Nature. The mountain of Tam Dao is a transition zone where species of Southeast Asia's tropical forests are represented along with species from the temperate forests of Southern China and from the alpine forests of the East Himalayan Chain. Moreover, Tam Dao rises abruptly from the Red River Delta and represents a small protected island that supports strong endemism. This biodiversity is threatened today by a domestic and international tourist market that is currently experiencing significant expansion. The forest formations at the boundaries of the reserve are gradually being cleared to make way for tourist complexes, while an illicit but active trade in poaching biodiversity species is in full operation (M. McRae, 1999).

In addition to the loss of biodiversity, clearing also leads to substantial soil erosion, as well as an increased frequency and severity in flooding during the rainy season and the drying up of numerous rivers in Thai Nguyen Province during the dry season (DOSTE, 1995). Soil erosion also occurs at the same time through sheet and linear (rill and gully) erosion.

To date, few soil surveys have been carried out to determine the precise extent of such soil erosion and much uncertainty exists as to its severity. Indeed, the importance of natural vegetation regeneration (54.3 per cent of natural regeneration - see Table 13) may significantly mitigate the impact of deforestation on soil erosion. For this reason, an objective of this Programme was to thoroughly study this fundamental question for its impact on the sustainable development of Vietnamese Uplands. The findings on this question are detailed later in this volume.

Map 7 shows the Programme's findings on the morpho-pedological distribution of the soils in Thai Nguyen Province. Generally, the soils are of average quality with low mineral and organic content. A number of mechanisms explain the degradation of these soils. In addition to erosion, the age-old practice of rice-growing without sufficient organic fertilisers have caused an intense impoverishment of the surface soil horizons in the nice cultivated plains, as well as the development of a compact and very dense soil layer close to the ground surface (M. Eimberck, M. Hardy, M. Jamagne, 1987).

#### 2.2.1.4 Mineral Resources

The province of Thai Nguyen is rich in minerals. The Provincial Department of Science, Technology and Environment (DOSTE) identified 117 different mines in the former province of Bac Thai of which 19 were classified as «large», 11 as «average» and 87 as «small». The open pit mines of Thai Nguyen, along with those in the province of Quanh Ninh, provide most of the country's coal production. They also produce iron ore, zinc, lead and several precious metals such as gold and silver. The province of Thai Nguyen is also an important centre for the production of stone used in construction.

From an environmental point of view, the coal of North Vietnam is of high quality with a low sulphide concentration (typically less than 0.5 per cent, similar to that of coal in Quanh Ninh Province). This low sulphide concentration means that its combustion, even in great quantity, contributes only marginally to the formation of acid rain (MOSTE/UNDP, Red River Delta Master Plan, vol.27, 1995).

An environmental report on the former province of Bac Thai (DOSTE, 1995), which used to include the current provinces of Thai Nguyen and Bac Can, singles out open-pit mining as an important cause of deforestation, water and air pollution, and destruction of arable land. Moreover, gold mining causes particularly high arsenic and mercury concentrations in rivers. In many areas, concentrations of CO<sub>2</sub>, SO<sub>2</sub>, lead and mining-related solid particles exceeding ten times the environmental legal standards have been detected. Emissions resulting from lead and tin mining were identified as contributing to serious cerebral and nervous public health disabilities, especially in infants.

UNICEF recently established a programme to monitor heavy metals in drinking water, particularly arsenic, in Vietnam. Although accurate statistics for Thai Nguyen Province are not yet available, extremely high arsenic concentrations, up to 2 mg/l, have been detected in other provinces bordering the Red River Delta<sup>7</sup>.

#### 2.2.1.5 Water resources and water pollution

##### *a. Water resources*

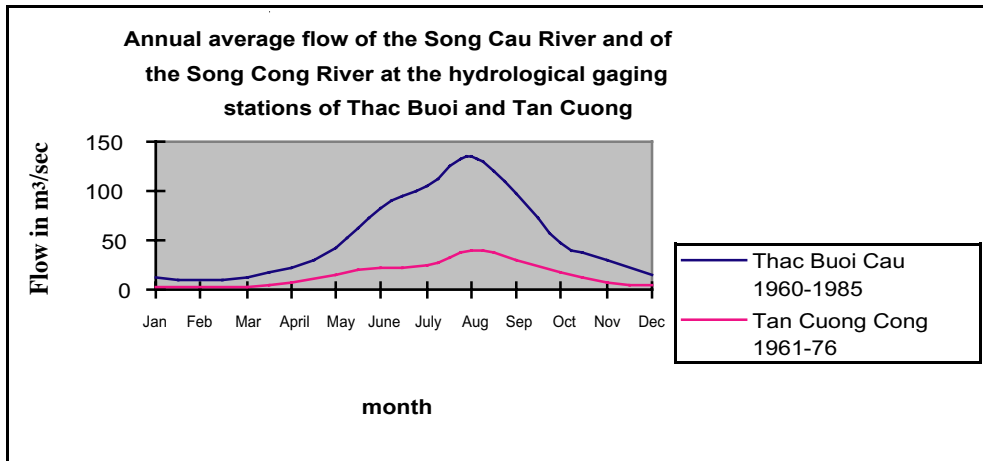
Thai Nguyen Province is located in the Thai Binh River basin. The Duong River connects the Thai Binh River basin to the Red River basin. Thai Nguyen Province can sometimes give the impression of having an abundance of water resources. For example, a major environmental report on Thai Nguyen Province states *“the province has important surface water resources, totalling approximately 2 billion m<sup>3</sup>. This water resource benefits not only Thai Nguyen Province, but also the provinces of Bac Giang, Bac Ninh Vinh Phuc and the town of Hanoi”* (DOSTE, 1997).

But this impression of abundant water resources is misleading, because of the very strong seasonal variability of Northern Vietnam hydrology. According to hydrological data collected by this Programme and stored in the project GIS, the river flow discharge of the three consecutive low water months accounts for only 5 to 6 per cent of the annual flow of the Song Cau River and Song Cong River, the two principal rivers of Thai Nguyen. Map 8 shows the location of the hydrological stations in Thai Nguyen and Figure 15 presents the monthly average river flows at the gaging stations of Thai Bui and Tan Cuong. This very strong seasonal variability of the hydrology results in high flood risks during the rainy season ; and water shortage risks during the dry season. Consequently, the ability to fully respond to the agricultural, industrial and domestic water requirements of the province is substantially affected seasonally over the entire year.

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<sup>7</sup> The maximum tolerable arsenic concentration in drinking water as recommended by WHO is 0.01 mg/l. This extremely stringent maximum concentration reflects the strong correlation between arsenic concentration in drinking water and increased incidence of a number of cancers.

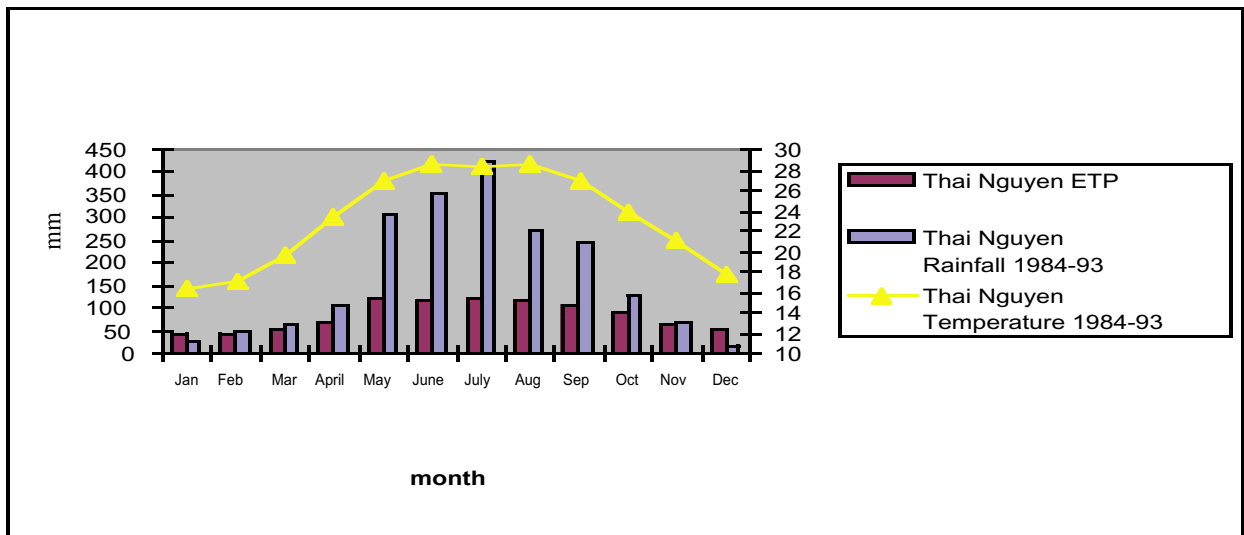
**Figure 15 : Annual water quantity of the two principal rivers flow patterns of Thai Nguyen Province**



This variability in river flow results from a significant seasonal pattern of rainfall. In a normal year, Thai Nguyen Province receives an average of 1,500 to 2,000 mm of rainfall. The ombrothermic diagram of the Thai Nguyen station (Figure 16), suggests that this volume of water would be enough to ensure normal rice crops, if it were regularly distributed. Unfortunately, rains fall abruptly, often in storms. Moreover, the dry season lasts for five months from November to March. During this period, monthly precipitation scarcely exceeds 15-60mm, compared with 250-450 mm per month during the rainy season.

The dry season coincides with the winter rice planting, and is one of the two annual high water demand periods. Because of the irregularity of rainfall, irrigation is essential all the year around to ensure rice production that is sufficient to feed the population. This results in substantial water withdrawals for agricultural purposes during the low water period. The impact of these seasonal shortages on agricultural production is compounded by the very limited capacity of existing reservoirs. (Silver, 1999).

**Figure 16 : Ombrothermic diagram of the meteorological station of Thai Nguyen**



In terms of ground water resources, shallow aquifers are present under the entire province, but notably in the south of the province. These aquifers comprise a shallow layer (4 to 20 meters thick) of very fine geological materials with a low yield but with sufficient capacity to supply drinking water to populations using hand-dug wells. They also comprise a deeper layer of coarser materials with a moderate flow. In places, a deep aquifer can also be reached through karstic fissures. This deep aquifer can offer good groundwater flows (CERPAD/DANIDA, 1996).

*b. Water pollution*

Little information is available on water pollution in Vietnam. The country's water quality monitoring system remains at a nascent stage. The Hydro-Meteorological Institute of Vietnam (HMI) began a monthly monitoring programme of water quality in 48 localities in 1991. Unfortunately, this programme only focuses on a very limited number of parameters, i.e. pH, temperature, cations, anions and electrical conductivity (WB, ADB, FAO, UNDP, 1996).

In 1995, the Ministry of Science, Technology and Environment (MOSTE) introduced a monitoring network for surface water quality. Its purpose was to collect information necessary for the preparation of quarterly and annual reports of State of Environment in Vietnam. These reports are classified "confidential" and are not available to researchers (MARD/DANIDA, 1999).

The following evaluation of the impact of each of these sources of pollution in Thai Nguyen Province is based on the Programme's GIS and recent reports from the relevant provincial Departments concerned with pollution monitoring and mitigation.

Biological and chemical pollution

Agriculture is the main economic sector in Thai Nguyen province. The rapid development of small and medium-sized enterprises is, however underway. In 1997, 141 government enterprises and 120 private companies were listed in Thai Nguyen Province (Vietnam Business, 1997). The principal industrial sectors are mining, metallurgical industry, mechanical workshops, the production of construction materials, food-processing industries and garment manufacturing industries. The most important enterprises are located in the Provincial Capital Thai Nguyen City, and include breweries, an iron and steel plant and a tin and lead foundry.

Only the main provincial urban centres are partially served by drinking water systems. The provincial capital Thai Nguyen City is served by four water supply systems, but these systems supply water to less than thirty per cent of the population. Those households not benefiting from city water supply must rely on individual wells or springs for their water supply (DOSTE, 1995). Domestic and industrial waste water is directly discharged into Provincial rivers without preliminary treatment. Although Thai Nguyen City produces more than 26,000 tons of solid waste per annum, there is only one landfill site for the city in operation at Doc Lin.

It is difficult to evaluate precisely the impact of urban and industrial pollution in Thai Nguyen Province. Apart from eight water analyses carried out in the province in 1995, this Programme was only able to obtain a number of relatively old water quality analyses carried out at the hydrological stations of Thac Buoï and Gia Bay on the Cau river (see Map 8). The data from the Thac Buoï station cover the period 1964-1985 and the data from Gia Bay cover the period 1972-85. These analyses cover only a very limited number of parameters (pH, COD, cations, anions and hardness). Other than for COD, measurements did not include fundamental parameters of water quality like BOD, heavy metals, total coliforms or persistent organic compounds.

Any pollution assessment environmental indicator based on such a limited data set should be regarded as extremely tentative. Keeping this in mind, data from Thac Buoï and Gia Bay gaging stations is considered to indicate a good chemical quality of the water in the Cau River for the concerned periods. An analysis of the data of these two river gaging stations compared against Vietnam's and WHO's water quality guidelines is given in Appendix V.

The water quality analyses made in November 1995 include measurements of the biological oxygen demand, dissolved oxygen and made in principal heavy metals. The results of these analyses are detailed in Appendix V. These analyses seem to indicate a very good water quality, and suggest that water in Thai Nguyen was almost free of organic pollution and heavy metals at the time of testing in November 1995. Unfortunately, these analyses do not include measurements of faecal coliforms and cannot provide any information on faecal contamination at the measurement sites.

A review of recent reports from provincial environmental management departments and international organisations on water pollution in Thai Nguyen can help to update and qualify that data. A 1997

Provincial report on the environment signals “important” pollution of the Cau river in the industrial zones of Thai Nguyen Province (DOSTE, 1997). This pollution seems to be localised within the immediate vicinities of the industrial and urban centres. A water supply and sanitation study in Thai Nguyen Province conducted by DANIDA and CERPAD in 1996 reports biological oxygen demands ranging from 1 to 8 mg/l, with the concentration of coliforms ranging from 0 to 100,000/100 ml and of dissolved oxygen from 6-10 mg/l in the Cau River downstream from Thai Nguyen City. In light of these results, the DANIDA and CERPAD concluded that organic pollution was relatively low in terms of impact on the aquatic environment, but that faecal pollution could be substantial. The mortality and morbidity profile of Thai Nguyen Province seems to confirm this analysis. This health profile reveals a high prevalence of waterborne diseases associated with faecal contamination, such as dysentery, diarrhoea and intestinal parasites. Table 14 lists the incidence rates of the six most common diseases in the province:

**Table 14 - Incidence rates of common diseases in Thai Nguyen (1996)**

Disease	No. of cases 1996	Incidence per 100,000 per year
Pneumonia	9 438	943
Diarrhoea	6 846	684
Sore throat	4 866	486
Acute Respiratory Infections	4 831	483
Parasites	1 660	166
Skin diseases	856	85

Source: CERPAD/DANIDA, 1996.

The incidence of diarrhoea in Thai Nguyen Province of 684 per 100,000 people, compared with the national average of 1,327 per 100,000 inhabitants (1995), is probably underestimated. This point is considered more later in this study. But even with an underestimated rate of diarrhoea, waterborne diseases related to faecal contamination dominate the profile of mortality and morbidity in Thai Nguyen Province. The high incidence of faecal contamination may be explained by: (i) the general use of human excreta as organic fertilisers in the north Vietnam; (ii) drinking water supply relying on un-protected wells and direct use from rivers; and (iii) widespread practice of open air defecation and low use of sanitary latrines.

#### Physical pollution

The average annual concentrations in sediments measured at the Thac Bui, Giang Tien, Cau Mai and Tan Cuong hydrological stations (see Map 8) vary between 108 and 245 mg/l. These concentrations are far higher than the standards recommended for drinking water supply, industrial production, recreational activities or protection of aquatic ecosystems, given in Table 15. Suspended particles affect the quality of water in a number of ways. Turbid water is difficult and expensive to filter and its purification requires large amounts of disinfecting chemicals. The agrochemical compounds and heavy metals transported by river sediments can lead to the eutrophication of reservoirs, and to mercury and arsenic poisoning. By burying organisms living on the riverbeds and by reducing the intensity of solar radiation, the sediments are also harmful to aquatic life (Jain and al. 1993).

Although up to 50 times higher than norms for drinking water supply, these sediment concentrations are relatively low when compared with those recorded at other locations in Vietnam in the upstream sections of the Red River and the Da river (values higher than 1000 mg/l) ; and in down stream sections of most rivers in North Vietnam.

**Table 15 - Maximum water turbidity by use**

Water use	Max. Turbidity (mg/l)
Drinking water supply	5
Industry	
- Canning	10
- Cooling	50
- Brown Wrapping Paper	25
- Art Paper	5
- Textiles	5
Recreation	
- Swimming	10
- Boating	20
Preservation of aquatic ecosystems	35

Source: Chang, 1982, Jain and al., 1993

It should also be noted that high turbidity is not a recent phenomenon that can be immediately correlated with the dramatic deforestation that has been taking place for the last fifty years. As far back as 1935, it was noted that the Red River "carries significant quantities of silts, from  $0.5\text{kg/m}^3$  during the dry season to  $3.5\text{ kg/m}^3$  during the high waters" and that the Cau, Tuang and Luc-Nam Rivers "carry much less (from  $0.1$  to  $1\text{ kg/m}^3$  of silts) than the Red River" (René Dumont, 1935).

With such high concentrations, a further problem associated with suspended sediments is the reduction of the economic life of water resources infrastructure. Given that there are large data gaps in Vietnam's hydrological records, it is important to stress that strong differences in professional opinion exist on the impact of sedimentation on the economic life of water resources infrastructure in the country. An example of the differences in professional opinion on the impact of sedimentation in the rivers in the north of Vietnam is given through different estimates in the economic life of the Hoa Binh Reservoir located in the Da River. The World Bank's Environment Sector Review (World bank, 1995) estimates that the volume of sediments carried by the Da River is such that the Hoa Binh reservoir, the largest reservoir in Vietnam, intended originally to have a lifespan of 250 years, will actually be filled within 50 to 70 years. On the other hand, based on measurements of sediment concentrations in the Da river and of annual changes in the surface of the reservoir, MOSTE and UNDP estimate the reservoir's lifespan at more than 150 years, all other conditions remaining constant (Red River Delta Master Plan, Background Paper 1, 1995).

### 2.3. SELECTION OF INDICATORS

Building both on the methodological discussions of Chapter 1 and on the above analysis of the main environmental challenges in the uplands of Vietnam, the section establishes the rationale for the typology of indicators to be developed by the Programme. Notably, it establishes the rationale for the adoption of the STRESS methodology and, accordingly, for the selection of a pressure index, a state index and a response index to describe each of the four major forms of environmental degradation in the Uplands: (i) deforestation and loss of biodiversity; (ii) soil erosion; (iii) water shortage; and (iv) water pollution. This section then reviews on-going work by a number of international organisations engaged in the development of STRESS indicators/indices for land degradation and shows how this comparative analysis informed the selection of specific parameters for the construction of this Programme's environmental indices.

#### 2.3.1 Criteria for the selection of environmental indicators

In accordance with the policy decision making processes to which this Programme is designed to contribute, the selection of the indicators complies with the three following basic criteria of: (i) policy making relevance; (ii) analytical soundness; and (iii) measurability.

### 2.3.1.1 Policy Relevance

The main users of the GIS system will be the provincial decision-makers responsible for the formulation of development and investment policies. The land degradation indicators were designed to respond to the specific needs and interests of these provincial policy decision-makers. The first task of the indicators was therefore to synthesize, interpret and qualify the information collected by this Programme so as to make technical information directly relevant to a non-specialist audience. The second task was to highlight the chain of causality that links the mechanisms of degradation and regeneration, to help decision-makers resolve complex management conflicts in the most effective way possible. In line with the complexity of the decision-making processes, the third task for the indicators was to establish a close dialogue between decision-makers and natural resource managers for the sustainable development of the tropical Uplands.

Single parameter indicators - such as the percentage of organic matter in soils, or the concentration of suspended solid particles in rivers - require a certain technical investment in order to be understood. Single parameter indicators are also difficult to correlate directly with development policies or precise decisions in investments. Hence, aggregated indicators or indices, which are inherently more accessible and relevant for political decision-makers, needed to be constructed, to serve as the interface between the primary data managed by the GIS, and local decision makers. The interface had to be limited to a range of only three or four indices. If more were to be used, the profusion of indices could generate a degree of confusion and could interfere with an accurate interpretation by the end-users of the results.

In order to provide information appropriate to the various stages of the economic development and investment decision-making process and to a dynamic vision of the environment, these few distinct indices had to describe the pressures on the environment, the state of the environment and the responses to environmental pollution.

As discussed in Section 2.2, the most critical environmental challenges for the sustainable development of Thai Nguyen Province appear to be: (i) deforestation and loss of biodiversity; (ii) soil erosion; (iii) risks of water shortage; and (iv) water pollution. To meet the policy-making relevance requirements detailed in the above paragraphs, it was decided that this Programme would adopt the STRESS methodology (see section 1.1.2.1) and would develop a pressure index, a state index and a response index to describe each of the four major forms of environmental degradation in Thai Nguyen Province.

### 2.3.1.2 Analytical soundness

An "ideal" environmental indicator should rely on consensus for validity. Such consensus is, unfortunately, often missing. Even when it does exist and an "ideal" indicator is immediately measurable, the definition of maximum tolerable thresholds of degradation remains a difficult exercise (see 1.2.7.2). But the importance and relevance of the indices to be developed by the Programme depended to a large extent on the analytical soundness of the maximum tolerable thresholds adopted.

In accordance with the objectives of this Programme, environmental indicators had to contribute to the sustainable development of the pilot provinces. This was not a question of systematically trying to protect all the ecosystems in these provinces, but rather to prevent misguided investment and development decisions that entail unacceptable social and environmental costs. It is a search for the optimisation of human, environmental and financial resources, in line with the anthropocentric approach for environmental management described in 1.2.7.3.

To provide achievable objectives to local policy makers, it was decided to found these thresholds - as far as possible - on the best and worst results obtained at the appropriate administrative level for a given environmental component, rather than in comparison to theoretically desirable values. This methodology is therefore very close to the approach adopted by the UNDP for the aggregation of the HDI from 1990 to 1994 (see section 1.2.7.1).

It was decided to develop indicators based on existing administrative units to: (i) facilitate the aggregation of socio-economic data and physical data; (ii) the definition of pragmatic thresholds; and (iii) to make possible a comparison of the performance of different administrative units. This comparison

would facilitate the identification and the dissemination of successful initiatives. It would prevent the repetition of less successful experiments, and would encourage a degree of competition among the performance of district and provincial administrations.

### 2.3.1.3 Measurability and information available through GIS

As discussed in section 1.1.2.1, the information available to inform officials about environmental management is often fragmented, even in countries that conduct highly sophisticated statistical operations. This fragmentation of information is particularly severe in Vietnam for technical, financial and political reasons.

In their common report on poverty elimination (1996), UNDP and UNICEF emphasise the presence of an "information void" in Vietnam, and views the absence of reliable and detailed information as a major constraint for the country's economic development. The report notes, for instance, that Vietnam is one of the very few countries in the world not to publish the country's economic statistics in "International Financial Statistics", the IMF's annual reference review of the performance of all countries.

But even when information does exist in Vietnam, serious questions regarding its reliability remain. Statistics in Vietnam are collected and directly transmitted by the local authorities to central administrations. In the absence of independent data collection, a large majority of those responsible for compiling the data may find it beneficial - as well as convenient - to inflate or reduce certain figures in order to obtain additional funds or an unrealistically impressive evaluation of performance. Many institutions also have information monopolies, as the only agencies by law entitled to collect certain data. These monopolies exclude the possibility of independent verification of the quality of some data.

Environment is among the sectors most affected by this information void in Vietnam. In their study of the establishment of a development plan for the Red River Delta (1994), MOSTE and UNDP record the following weaknesses of the environmental monitoring system in Vietnam:

- Ability to monitor only a very limited number of parameters, and not for all factors for which environmental standards exist;
- Inconsistency of the measured parameters from one year to the next, and between one site and another;
- Absence of computerization of data to facilitate filing and analysis;
- Duplication of tasks and absence of coordination among the various environmental monitoring institutions;
- Absence of mechanisms to use the results from monitoring and evaluation to influence decision-making for development.

Discussing the reliability of measurements, the World Meteorological Organisation, in a document entitled *"Report on a Sectoral Support Mission To The Socialist Republic Of Vietnam"*, underlines the low quality of the meteorological and hydrological data. The absence of an environmental monitoring system makes it extremely difficult to define the causes and the effects of environmental pollution, as well to design and to evaluate the various strategies available to solve these environmental problems.

Paradoxically, this absence of environmental monitoring system leads to extremely high expenditures in information collection. Many data collection exercises are conducted each year to address this information void and to enable the formulation of specific programmes. These data, collected in an ad hoc manner, are seldom properly archived; and new studies are thus required to gather the same data again and again to meet the information needs of new programmes. The monitoring equipment procured and the expertise developed for each of these data collection exercises are seldom re-used.

The true cause of the information void has less to do with the availability of expertise or funding, but rather is rooted in the institutional attitudes of Vietnam's decision-makers. With the public sector continuing to play a dominant role in the allocation of resources in Vietnam, UNDP and UNICEF stress that a fundamental change in the culture of information is necessary to allow better decision-making and a greater quality of public investments : *"Doing so will require a fundamental change in culture and*

*attitudes towards sharing information, as well as training of more people in surveying, accounting, auditing and electronic information management systems".*

It goes without saying that this information void represents a major constraint for this Programme. In agreement with the criterion of measurability, the data necessary for the construction of the environmental indicators had to be immediately available through the GIS or to be accessible at no or low cost. The development of a separate data collection programme was not an option. So it was decided to use a replacement (or proxy) indicator when the "ideal" indicator was not immediately measurable.

It was also decided to base environmental indicators on official data that were not subject to controversy or dubious interpretation. As mentioned earlier, a key objective of this Programme's environmental indicators was to facilitate a dialogue between decision makers and natural resources managers, not to initiate a debate on the validity of provincial statistics. To evaluate responses to environmental pollution, this Programme decided to avoid indicators that were difficult to interpret such as land reform, tariff policies or the percentage of truly protected forests. For example, the redistribution of forestlands to the communities can either reduce or worsen deforestation, depending on how redistribution is managed (J. Carle, 1996). In the absence of precise information on the methods of forestland redistribution, such an indicator of response to deforestation, which is not directly interpretable, could not be selected.

### **2.3.2 Selection of land degradation indicators**

The Programme's four STRESS indices relate to land degradation in its broadest sense. A number of international organisations and working groups have been engaged in the development of STRESS indicators/indices for land quality/degradation for many years. To assist in the selection of the specific land degradation indices to be developed by the Programme, this section compares the land quality/degradation indicators developed by OECD, the United Nations Commission for Sustainable Development, the World Bank and the International Working Group on Land Quality Indicators (LQI).

#### 2.3.2.1 Indicators of forest degradation

Table 16 compares the different STRESS indicators of forest degradation developed by OECD, the UNCSO, the World Bank and the LQI Working Group.

Primeval forests are the richest natural habitats on earth in terms of terrestrial biodiversity. They also have a strong influence on soil and water conservation. They protect the soil against the impact of raindrops and slow down water run-off, allowing the water time to infiltrate into the ground. In contrast, a recent plantation of eucalyptus or of other rapid growth species offers only poor soil cover and only marginally improves the infiltration of water into the soil.

Vietnam is engaged in an ambitious programme of afforestation based on the planting of a highly limited number of tree species. But the environmental impact of this afforestation programme is likely to be of marginal benefit if encroachment on natural forests is not simultaneously reduced.

Indices of forest degradation have to capture both the qualitative and quantitative characteristics of forest cover to be useful for the development of Vietnam's tropical Uplands. The concept of forest quality was introduced only recently in Vietnam. For a long time, the term "sustainable development of forest resources" was understood in the context of a sustainable wood supply for forest industries. This volumetric approach is clearly reflected by the priority given to the development of forest industries in Vietnam's Tropical Forestry Action Plan (Ministry of Forestry, 1988) and in the State of the Forest maps published by FIPI (Forest Inventory and Planning Institute).

**Table 16 - Comparison of forest degradation indicators**

<b>Indicators of forest degradation</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
OCDE	Actual harvest /productive capacity	Area, volume and structure of forests	Forest area management and protection
UNCSD	Wood harvesting intensity	Forest area change	Managed forest area ratio Protected forest area as a per cent of total forest area
World Bank	Land Use change	Area, volumes and distribution; value of forest	In/Output ratio, main users; recyc. rates
LQI (Forest degradation and forest clearance for agriculture)	Ration between harvest of wood and estimated regrowth; illegal cutting within forests; shortage of fuelwood, as indicated by high prices  Observed clearance of forest areas for cultivation; ratio of cultivated to cultivable land	% Degraded forests  % Decrease in area of forest cover	Increased adoption of agroforestry; Improved community participation in forest protection and management.  Government legislation to protect forest, and effectiveness of its implementation; public awareness campaigns for forest protection, and their effectiveness; increased afforestation; reduction in rate of forest cover loss

Biodiversity measurements and their analysis have been a hotly debated theme over the past five decades, but no clear consensus of how biodiversity measurements should be made has emerged (W Reid, J.McNeely, D.Tunstall, A.Bryant and M. Winograd, 1993). Thai Nguyen's dense and natural open forests, which are undisturbed or minimally disturbed, shelter the majority of the province's remaining biodiversity. In the absence of a global and consensual indicator of biological diversity, the forest indices developed by the Programme focus only on forests that have been subject to minimal or no disturbance, to reflect both forest degradation and biodiversity loss.

Based on the above concepts, and in line with the consensus on STRESS forest indicators that emerges from the comparison given in table 16, the selected indicators for forest degradation for the tropical Uplands of Vietnam are listed in Table 17.

**Table 17 - Indicators of forest degradation for the Uplands of Vietnam**

<b>Indicators of forest degradation</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
Forest and biodiversity loss	Land use change	Area, density, and structure of forest not or minimally disturbed	Reforestation by plantation and afforestation by natural regeneration

### 2.3.2.2 Indicators of soil degradation

A major objective of this Programme was to evaluate with greater precision the extent of soil degradation in Vietnam's Uplands. In addition to soil erosion, the existing technical literature reports extensive physical soil degradation by compaction, and chemical degradation by losses of nutritive elements in the plains of Thai Nguyen Province (Eimberck, Hardy, Jamagne, 1987). However, further research is required to identify the root causes of this reported chemical degradation.

This study will focus on the mechanisms of soil erosion and on their causal linkages with deforestation and water. However, an exclusive focus on soil erosion may give an impression that the mechanisms of soil degradation without soil movement are of secondary importance in Thai Nguyen Province. To avoid such misunderstanding, attention will also be paid to soil degradation *stricto sensu* (without soil movement) in the interpretation of the results of the soil erosion indicators. Table 18 compares various indicators of soil erosion proposed by OECD, the UNCSD, the World Bank and the LQI Working group.

**Table 18 - Comparison of Soil Erosion Indicators**

Indicators of soil erosion	Pressure	State	Response
OCDE (desertification and erosion)	Erosion risks: potential and actual land use for agriculture Change in land use	Degree of top soil losses	Rehabilitated areas
UNCSD	.....	.....	.....
World Bank	Human-induced soil degradation	Climatic classes and soil constraints	.....
LQI (water erosion on arable land)	Extend of cultivation of sloping land without adequate conservation measures	Rates of erosion (t/ha/year), obtained by field measurement or modelling; Extent and severity of visible signs of erosion	Extend of adaptation of soil conservation practices; Number of farmer associations active in conservation; abandonment of land formerly cultivated

The OECD indicators for soil erosion seem the best adapted to the mechanisms of degradation met in the pilot provinces. The soil erosion indicators selected for the Uplands of Vietnam are detailed below:

**Table 19 - Indicators of soil erosion in the Uplands of Vietnam**

Indicators	Pressure	State	Response
Soil erosion	Erosion risks, obtained by spatial modelling	Rates of erosion (t/ha/year), obtained by inventory of extent and severity of visible signs of erosion	Extend of adaptation of soil conservation practices

### 2.3.2.3 Indicators of water degradation

Table 20 compares the different indicators of degradation of water resources developed by OECD, USCSD, World Bank and the LQI Working Group.

**Table 20 - Comparison of Indicators of water degradation**

<b>Indicators of water degradation</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
OCDE (water resource and eutrophication)	Intensity of use of water resources Emissions of N and P in water	Frequency, duration and extend of water shortages BOD/DO, concentration of N and P in inland waters and in marine waters	Water price and user charges for sewage treatment % of population connected to sewage treatment plants Market-share of phosphate-free detergents
UNCSD	Annual withdrawals of ground and surface water Domestic consumption of water <i>per capita</i>	Groundwater reserves concentration of faecal coliforms in freshwater BOD in water bodies	Water-treatment coverage Density of hydrological networks
World Bank	Intensity of use	Accessibility to population (%)	Water efficiency measures
LQI (Lowering of the groundwater table and/or salinization)	Farm water requirements estimated to be in excess of groundwater recharge. Inappropriate water pricing	Falling water tables; reports of crop failure/shortfall through insufficient irrigation water or through salinization or water logging. Appearance of patches of saline soil	Implementation of improved measures for irrigation water management; adoption of management practices that increase water use efficiency; trends in expenditure on maintenance of distribution canals; initiation of soil reclamation schemes

Because of the strong seasonal variation in rainfall, Vietnamese uplands experience temporary but critical water shortages. Indicators of water resource degradation will have to reflect both water availability and water pollution in Thai Nguyen Province. This Programme therefore developed two series of qualitative and quantitative indicators of water resources degradation, see Table 21.

**Table 21 - Indices of water degradation for the uplands of Vietnam**

<b>Indicators of water resource</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
Water shortage	Intensity of use	Frequency, duration and extend of water shortages	Adoption of water use efficiency practices
Water pollution	Emissions of pollutants	Concentration in pollutants	Investments in pollution control services and programmes

### 2.3.2.4 GIS Interface / Land Degradation Indicators

Based on the discussion presented above, Table 22 lists, all the land degradation indicators developed for the Vietnamese Uplands by this programme.

**Table 22 - Indices of land degradations for the uplands of Vietnam**

<b>Environmental Indicators</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
Forest and biodiversity loss	Land Use change	Area, density, and structure of forest not or minimally disturbed	Reforestation by plantation and afforestation by natural regeneration
Soil erosion	Erosion risks, obtained by spatial modelling	Rates of erosion (t/ha/year), obtained by inventory of extent and severity of visible signs of erosion	Extend of adaptation of soil conservation practices
Water shortage	Intensity of use	Frequency, duration and extend of water shortages	Adoption of water use efficiency practices.
Water pollution	Emissions of pollutants	Concentration in pollutants	Investments in pollution control services and programmes

### **III CONSTRUCTION OF ENVIRONMENTAL DEGRADATION INDICES**

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*This chapter describes the methods of aggregation used to develop environmental indicators for the Tropical Uplands of Vietnam. Information quality and availability was a significant constraint, and often required proxy indicators to be identified and used in place of primary indicators.*

*A number of universally accepted methods for constructing aggregated indicators exist. But almost all of those methods were developed for temperate ecosystems, and are not necessarily applicable to the unique conditions of tropical areas. This chapter reviews some of their main methodological limitations and looks at options for adapting these indicators to the tropical context, and at possible alternatives. It explains when and why methodological innovations are introduced, and their potential impact on interpretation of the resulting aggregated indicators.*

### 3.1 CONSTRUCTION OF THE FOREST AND BIODIVERSITY LOSS INDEX

The vegetation map for Thai Nguyen includes sixteen types of forest and shrubby formations (see Map 5). The dense and natural open forests, which are undisturbed or minimally disturbed, shelter the majority of the province's remaining biodiversity. In line with what has already been discussed in Section 2.3.2.1, this analysis of forest degradation and the loss of biodiversity relates exclusively to these forests.

#### 3.1.1 The forest and biodiversity loss risk index

##### 3.1.1.1. The principal causes of forest degradation in the uplands of Vietnam

Vietnam's forest cover is estimated to have decreased from 67 per cent of the total country surface to 29 per cent between 1943 and 1991. From 1991 to 1995, the total forest surface seems to have increased marginally (see Table 23).

**Table 23 - Forest cover trends in Vietnam from 1976 to 1995 (hectares x 1000)**

Types of forests	1976	1980	1985	1990	1995
Natural forests	11,107.7	10,186.0	9,308.3	8,430.7	8,252.5
Replanted forests	92.6	422.3	583.6	744.9	1,049.7
Total forest area	11,169.3	10,608.3	9,891.9	9,175.6	9,302.2

Source: Reforestation in Vietnam from 1976-1995, after MPI/UNDP-1997.

Some authors recommend a high degree of caution in interpreting this reported increase in forest cover, because of the statistical distortions caused by a modification in the criteria for the definition of a forest in the mid 1980s (World Bank, 1995). Moreover, substantial increase in the area of replanted forests mask a continuing reduction in natural forests. Ecosystems of priceless biological diversity have been replaced by forest monocultures of reduced biological and hydrological value. Le Ba Thao (1999), President of the Association of Geographers in Vietnam, summarizes this impact in the following report:

*“The current speed of afforestation can, at best, only partially compensate for the areas of forest that have been denuded or burned to make essarts, with the difference that one is planting shrubs while the other is cutting down large trees especially“.*

The immediate causes of forest degradation in the Vietnamese Tropical Uplands include: (i) agricultural clearing by migrants; (ii) recurring agriculture; (iii) spontaneous forest fires; (iv) commercial exploitation and extraction of wood; (v) collection of wood for fuel; (vi) insects, rodents and diseases; (vii) development of rural infrastructure; (viii) mining and the exploitation of mineral resources; and (ix) degradation due to military conflicts. Table 24 presents an estimate of the importance of each of these causes of deforestation. A detailed description of these immediate causes of deforestation is given in Appendix VI.

**Table 24 - Relative importance of the main direct causes of deforestation in Vietnam (hectares x 1,000)**

Region	Fire Damage (1990)	Itinerant Shifting cultivation (1991)	Firewood (1992)	Logging (1991)	Total without firewood
Northern Mountains	0	35	115	17	52
Northern Midlands	0	10	11	23	33
Red River Delta	0	0	33	5	5
North Central Coast	1	7	96	4	12
South North Central	0	15	46	4	19
Central Highlands	4	95	69	8	107
North-East Mekong	2	15	78	4	21
Mekong Delta	11	3	32	13	27
Totals	18	180	480	78	276

Source: FIPI 1990, TFAP 1991. 1992 World Bank estimates (World Bank, 1995).

#### Insert 4 : The main causes of forest loss in Vietnam: claims and Counterclaims

Expert explanations of the causes of forest loss include:

- *“Three quarters of the detrimental deforestation practices can be attributed to the populations that have been resettled in [New Economic zone] areas”.* Nguyen Van Thang (in Buffett, 1997).
- *“Whilst war, policy changes, economic development, and the introduction of new technologies have all been linked to steady decline of Vietnam’s natural forests, population expansion is arguably the fundamental, underlying cause of deforestation”* Poffenberger and Nguyen Huy Phon in Poffenberger (1998). However, as pointed out by Boyce (1990, in Buffett, 1997) *“ to identify population as the root cause of the problem is to mistake a symptom for the cause”.*
- A feasibility study prepared by the Asian Development Bank (1996) starts its report with this Statement: *“forests in Vietnam are being depleted at a rapid rate due to logging and shifting cultivation”* (Asian Development Bank, 1996).
- *“The direct and indirect effects of the war are also blamed for forest loss : in addition to the effects of war (bombing and chemicals), extensive logging took place in some upland regions, to generate timber revenues to support the war. Commercial timber production continued to dominate forest policy through the 1980s as the country tried to resurrect its economy after the war ”* (Poffenberger et al, 1997).
- UNDP (n.d., in Buffett, 1997) estimates that *“of an annual loss of 200 000 hectares of forest, 50 per cent is lost to firewood and logging, 25 per cent to clearance for agricultural land, and 25 per cent to forest fires”.*
- The Forest Science Institute of Vietnam estimates that the causes of forest loss are fivefold: *“Excessive logging, shifting cultivation, land reclamation (for example for coffee plantations), agent orange during the war (contributing to the loss of 2 millions hectares of forest) and forest fires”.*
- *“Other variables such as tenurial systems, the “opening” effect of roads, access to technology such as chainsaws, the rise of cash-cropping<sup>8</sup>, and government policies on taxation, subsidies, etc. are also frequently discussed”* (Swartzendruber, 1994).

Most official documents do emphasize the roles of population growth and destructive patterns of slash and burn, although Swartzendruber (1994) quotes the Rainforest Action Network (1992) and others who suggest that the focus on shifting cultivation may be nothing more than an effort to distract attention from the financial and political forces responsible for environmental degradation through commercial logging for export, and places the blame on government agencies who allocate access to concession.

<sup>8</sup> The expansion of industrial crops such as coffee, pepper, and rubber is seldom mentioned as a major cause of deforestation in Vietnam. However, the findings of STD3-CT94-0310 seem to confirm its importance in the deforestation of the pilot provinces, in particular Lam Dong Province (P. Brabant, personal communication, 1999).

In the absence of a reliable forest information system in Vietnam, it is important to be aware of the uncertainty associated with all forestry estimates. By way of illustration, Insert 4 illustrates the often contradictory theories advanced by various organizations and experts for the relative importance of the immediate causes of forest degradation in Vietnam (IIED, 1998).

By and large, the different hypotheses in Insert 4 fail to distinguish between the fundamental causes of deforestation (demography, poverty, accessibility, tax systems, etc.) and immediate causes (clearance agricultural land, extractive exploitation of wood, recurring agriculture, etc). This important distinction between cause and effect is crucial to the analysis of the results obtained from the forest degradation indices.

### 3.1.1.2 Aggregation of a forest and biodiversity loss pressure index for the uplands of Vietnam

The forest pressure index should allow for consideration of the combined weight of the cause-effect influences given above. A consensus seems to exist on the adequacy of the variation of land cover to reflect these combined pressures. Indeed, the variation of land cover provides the opportunity to communicate the extent and progression of deforestation immediately and visually. This Programme developed land and vegetation maps based on a Landsat image from October 1994. The GIS does not yet incorporate complete historical data for an analysis of land and forest cover trends before and after this date. This was not possible as certain documents - air photographs in particular - were not made available to the Programme.

This study therefore used three vegetation maps to construct the forest and biodiversity loss pressure index. These maps were provided by Vietnam's FIPI (Forest Inventory and Planning Institute), and date from 1943, 1983 and 1993. By comparing these three sets of data, the variation in cover of dense and open forests during the last fifty years was estimated. Since the data for these three periods are available at the national level, this methodology allows itself to be extended to the entire hill and uplands zone of Vietnam.

It must be stressed, however, that serious questions exist as to the validity of FIPI's 1943 vegetation map. The map, digitalised and produced by FIPI itself, is based on the "Map of the Indo-China Forest" to a scale of 1/2,000,000 prepared by Paul Maurand dated 1943. Before the development of air photography, forest inventories were often cursory operations that involved a projection of local inventories, of greater or lesser accuracy, on a wider surface area that in reality was never properly surveyed. In his recent work on the history of the organization and work of the French forest services in Indo-China from 1862 to 1945, F. Thomas argues that the lack of financial means and the dearth of forest personnel at the time certainly did not allow P. Maurand to do otherwise.

A further issue of vital importance to this study concerns the dating of the Maurand map. F. Thomas (1999) writes that:

*"The Indo-China Forest was published in 1943, but Maurand also published an article similarly entitled "The Indo-China Forest" in the Indo-China Economic Bulletin in 1938 at the end of which one finds the same forest map with the only modification being the borders of the provinces of Cambodia and Laos which were lost by France in its conflict with Thailand in 1941. The 1943 map is in fact that of forests in Indo-China in 1938. Moreover, this article of the Indo-China Economic Bulletin is the publication of a report that was made to the Seventh International Congress of Tropical and Subtropical Agriculture that took place at Paris in 1937. We cannot say whether at the time of this report Paul Maurand already had this map in his possession. Finally, we have discovered recently in the archives in Hô Chi Minh City, a series of forest maps published by the Indo-China Geographical Service between 1930 to 1932. These maps are those which served as a model for Maurand in the preparation of his forest map for the entire Indo-China".*

Work in progress by F. Thomas is expected to confirm that Maurand's 1943 forestry map - which all foresters today use as a reference for the state of vegetal cover at the end of the colonial period - in fact dates from 1930. It is evident that this would represent a crucial change in this study's perspective of the reduction in forest cover in Thai Nguyen Province. The purpose of this analysis is therefore solely to provide a better understanding of the pressures on forest cover in the course of the past fifty years

without the pretence - or, indeed, the benefit - of unquestioned historical accuracy. The percentage in forest decline for each district of the pilot province of Thai Nguyen over the last fifty years was calculated using Arcview's *geoprocessing function*.

The percentage of deforestation was obtained using the equation:

$$i = \sqrt[n]{\frac{S_p}{S_m} - 1}$$

where:

- i = annual deforestation rate from year m to year p;
- f<sub>m</sub> = forest cover in year m;
- f<sub>p</sub> = forest cover in year p;
- n = number of years from m to p.

This percentage was compared with the national average of deforestation generally taken to be 1.6 per cent from 1943 to 1991. On the basis of this comparison, five classes of pressure on the forest were identified, ranging from 1 (very weak) to 5 (very strong):

**Table 25 - Rating of Deforestation Pressure**

Annual deforestation rate (%)	Index of Forest Degradation Pressure	Index Description
< 1	1	Very low
1 - 1.5	2	Low
1.5 - 2	3	Intermediate
2 - 2.5	4	High
>2.5	5	Very high

The raw data relating to variations in forest cover do not indicate the respective importance of different mechanisms of forest degradation. A huge diversity of opinion exists and very little accurate data on the fundamental causes of forest degradation is available. But with the importance of this issue in the definition of rural development policies, this study attempted a preliminary analysis of the fundamental causes of variation in forest cover in Thai Nguyen. Using the GIS spatial overlay function, the impact of the following four factors were also modelled: (i) topography and the road grid system; (ii) population density; and (iii) types of vegetation and soil.

### 3.1.2 Aggregation of the forest state index

#### 3.1.2.1 Importance of size and shapes in forest degradation

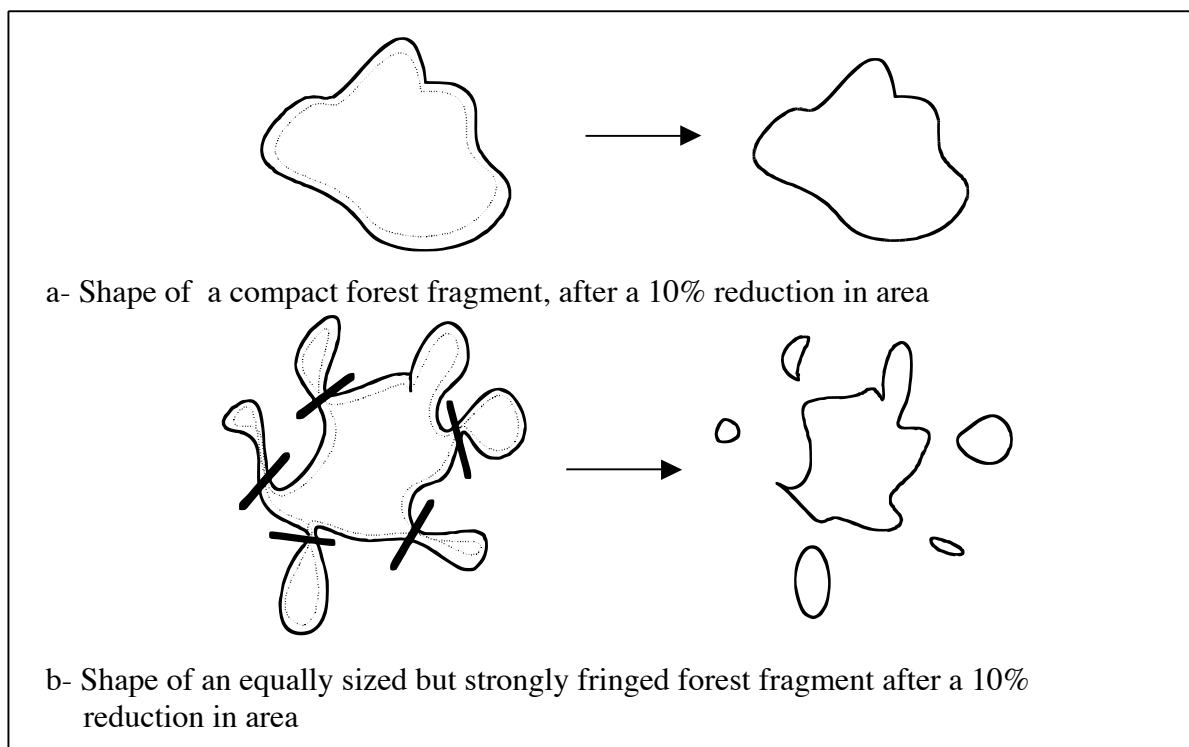
The representation of the circumference of dense and open forests in Map 5 only partially reflects the true extent of degradation of the forest that remains in Thai Nguyen province. This cartographic representation visualizes the spatial distribution and the density of forest fragments, but provides only a superficial impression of their dimension and form.

The size and shape of the forest fragments have a direct bearing on their resistance to the mechanisms of deforestation. The capacity of a forest area to regenerate after clearing is directly proportional to the size of the deforestation. Size is also important for the conservation of biodiversity. A single forest fragment

of 10,000 hectares will offer much greater protection of its biodiversity than ten separate fragments of 1,000 hectares.

Although largely important, size of a forest fragment alone cannot fully reflect a forest's resilience. Two identically sized - but differently shaped - forest fragments will resist the mechanisms of deforestation differently. A compact forest area will have greater resistance to erosion at its edges than a strongly fringed fragment. A reduction of 10 per cent in the cover of a compact forest will reduce the total forest perimeter, but will not modify its overall structure. But a highly fringed forest experiencing similar deforestation will tend to break into smaller sized fragments, and thus be more fragile. This concept is illustrated in Figure 17.

**Figure 17 : Importance of compactness in forest resilience to degradation**



### 3.1.2.2 Determination of the size and shape of forest fragments

To reflect more precisely the actual vulnerability of the remaining undisturbed forests in Thai Nguyen Province, an index of the state of forest degradation simultaneously should describe the spatial distribution, the density, the size and the shape of the various forest fragments. This study uses methodology developed by Thomas Bouix (1998) as a starting point, but modifies his initial classes, thresholds and equations of aggregation to analyse smaller forest areas with greater accuracy, and to give greater weight to the “shape” of the forest fragment. The smaller forest formations play a very important role as an indicator of deforestation. Whereas variations in larger formations are difficult to detect, monitoring of small formations allows an immediate evaluation of the impact of forest protection policies.

The size of a forest is defined here as the area of a plot of a given type of forest. In line with the general approach of this study to determine thresholds, the degree of degradation for the size of forest fragments are not fixed according to a minimum theoretical value, but instead are fixed according to the relative value of individual forest plots compared to the entire forest area in the province. The various forest formations of Thai Nguyen Province are thus classified into five classes based on the method of natural breaks<sup>9</sup>.

<sup>9</sup> These thresholds represent sudden and major breaks in a series of values. This method minimizes value variations within the same class.



The current Vietnamese Government policy is to keep more than half of the country under forest cover. The index of the state of forest vulnerability is assessed in relation to this objective. To fully reflect the state of the forest by the four parameters of density, spatial distribution, dimension and form, this calculation uses only forests of very low to medium values of forest fragility.

**Table 26 - Rating of the State of Forest Vulnerability in Thai Nguyen Province**

Area under forest cover of very low to average vulnerability	Index of state of forest vulnerability	Index description
> 40	1	Very low
30-40	2	Low
20-30	3	Intermediate
10-20	4	High
10<	5	Very high

### 3.1.3 Aggregation of an index of response to forest degradation

An indicator of response to the degradation of forest resources of Thai Nguyen Province should reflect, as far as possible, the effectiveness of official forest protection policies introduced for the Vietnamese Tropical Uplands.

FIPI regards forest lands as “all lands having a slope of more than 25 degrees”, irrespective of the actual land cover (FAO, 1996). FIPI estimates the total forested area in Vietnam (*Dat lam nghiiep*, or forest lands) to be 19.1 million hectares<sup>10</sup>.

Vietnam’s priorities in developing its forest sector are summarised as follows (UNDP/FAO, 1996):

1. Designation of 6 million hectares as “protected forest” (Phong Ho) for the conservation of soil, water and biodiversity;
2. Designation of 3 million hectares as forests of reserved use (Dac dung), that includes national parks, cultural conservatories, etc.;
3. Designation of 10 million hectares for the commercial exploitation of wood (San xuat);
4. Mobilisation of one million households to the development of agro-forestry;
5. Promotion of dispersed plantations of trees close to settlements and privately owned gardens.

In line with these objectives, Vietnam’s Ministry for Agriculture and Rural Development adopted the following classification of “forest lands” (UNDP, 1997):

**Table 27 - National Classification and Estimated Area of “Forest Lands” in Vietnam (in Ha)**

<b>Total forest area</b>	19,163,000
• Forested lands	9,175,600
• Deforested lands	9,988,000
<b>Production forest</b>	11,816,100
• Forested lands	6,106,900
• Deforested lands	5,709,200
<b>Reserved use forest</b>	5,900,500
• Forested lands	2,391,200
• Deforested lands	3,509,300
<b>Protected forest</b>	1,446,700
• Forested lands	676,800
• Deforested lands	769,900

Source: UNDP/MPI (1997).

<sup>10</sup> Three different land classifications have been conducted by (1) the General Department of Land Administration (GDLA), (2) the Forest Planning and Inventory (FIPI), and (3) the National Institute for Agricultural Planning and Prediction (NIAPP). Given the different classification criteria adopted, substantial discrepancies exist in their respective estimates of existing forest cover. In contrast to the figures given by FIPI, GDLA estimates the total forest cover in Vietnam at 9.3 million hectares while NIAPP reports 15.2 million hectares.

The two major challenges that drive this approach are soil erosion control and the maintenance of a sustainable supply of wood. The suitability of this soil erosion control policy is discussed in later pages.

The forest plan, which was revised in 1997, expects that among the 5.7 million hectares designated as lands for forest production and currently without forest cover, 2 million hectares will be afforested by natural regeneration, 2 million hectares will be re-timbered with new plantations, and one million hectares by the development of a system of agroforestry directly managed by small farmers until 2003 (MPI/UNDP, 1997). This plan's objective is ambitious - it aims at afforestation of more than 700,000 hectares per year, or of more than 2 per cent of the national surface annually. It is probable that the deadline for the achievement of these objectives will be pushed back to 2010 when the plan is finally agreed to.

Some authors have expressed scepticism of the reported increase in forest cover in Vietnam in recent years. The impact of forest protection policies therefore deserves closer scrutiny. The index of response for forest degradation should ideally be based on the aggregation of results for conservation of protected areas, and of reforestation by plantation, by afforestation and by agro-forestry.

This monitoring of forest cover changes should also ideally be conducted by remote sensing and ground truthing. This approach is currently being used experimentally by FIPI. Meanwhile, the indicator of forest response for this study is based on official afforestation and plantation statistics provided by the provincial authorities. In the absence of statistical data on agro forestry, this parameter is not incorporated in this first index of response to forest degradation. The annual reforested and afforested areas in a particular district was proportionated to the total area of the district. This approach enabled a comparison of the performance of the various districts in Thai Nguyen Province with national policies for forest protection and development.

The afforestation and reforestation efforts of each district in Thai Nguyen Province were assessed in relation to the national objective of the 2 per cent annual increase in forest cover stated in Vietnam's forestry plan, as follows:

**Table 28 - Rating of Response To Forest Degradation**

Annual percentage of reforestation and afforestation	Index of response to forest degradation	Index description
> 4	1	Very good
3-4	2	Good
2-3	3	Intermediate
1-2	4	Poor
0-1	5	Very poor

### 3.2 CONSTRUCTION OF THE SOIL DEGRADATION INDEX

#### 3.2.1 Aggregation of the soil erosion risk index

Sheet erosion, linear erosion and mass movement are the three principal mechanisms of soil loss in the hills and mountainous zones of the Tropical Uplands Vietnam. The factors influencing these three water erosion processes are numerous, their causes diverse, and their ground surface expressions are varied and sometimes contradictory.

This section briefly identifies these principal soil loss factors using the Universal Soil Loss Equation (Wischmeier et al., 1958; Wischmeier and Smith, 1978). The methodology adopted by the World Bank to construct an index of susceptibility to soil degradation in Vietnam is then described. And finally, a methodology for the aggregation of an erosion risk index in the Vietnamese Tropical Uplands is suggested.

This chapter discusses only the points necessary for a full understanding of the methodology of aggregation. A bibliographical review of the principal mechanisms of soil erosion is found in Appendix VII, and provides fuller references.

### 3.2.1.1 Identification of the factors influencing water erosion

The Universal Soil Loss Equation (USLE) is the most widely used model for estimating soil erosion. In 1958, Wischmeier, a statistician with the Soil Conservation Service in the United States was given responsibility for analysing and collating over 10,000 annual records of erosion on plots and small catchments at 46 experimental stations on the American Great Plains. The objective of Wischmeier and Smith (1960, 1978) was to establish an empirical model for predicting erosion on cultivated fields to enable soil conservation specialists to choose the measures needed to keep erosion within acceptable limits, given climate, slope and agricultural production factors.

This model sees water erosion as a function of rainfall erosivity and of the resistance of the environment. This resistance comprises soil erodibility, topography, vegetation cover and the erosion control practices that are put in place. The equation is a multiplicative function, so that if a factor tends towards zero, erosion will also tend towards zero. The basic equation for this model is:

$$A = R * K * SL * C * P$$

Where:

- A = computed soil loss per unit area, expressed in the unit selected for K and for the period selected for R (usually in tons per hectare);
- R = the rainfall erosivity index. It is generally expressed in the same units as A; in this case, it is the only term of the right hand of the equation having a dimension;
- K = soil erodibility is a function of the organic matter and texture of the soil, its permeability and profile structure of the soil. It varies from 0.7 for the most fragile soils to 0.01 in the most stable soil;
- SL = the topographical factor, allowing comparison of local topographical conditions with standard conditions; it depends on both the length and the gradient of the slope;
- C = the plant cover factor is a simple relation between erosion on bare soil and erosion observed under a cropping system. It varies from 1 on bare soil to 0.001 under forest;
- P = this factor takes into account specific erosion control practices such as contour tilling, or terracing. It varies between 1 on bare soil with no erosion control, to about 0.1 with tied ridging on a gentle slope.

The validity of Wischmeier's empirical equation for conditions other than those of the Great Plains in the United States has been questioned by many experts (French Ministry for Co-operation and Development, 1991; E Roose, 1994; UNEP, ISRIC, 1995), who stressed the following intrinsic limitations of the USLE model:

1. *It applies only to sheet erosion.* The source of energy in this model is rainfall. However, if the contribution of the rain's kinetic energy is important for a gentle slope, it becomes secondary to the energy of run-off in slopes with angles steeper than 15 per cent (see Appendix VII). The model thus does not apply to linear erosion nor mass erosion.
2. *It is not valid for isolated storms.* This model is based on statistical analysis and applies only for average measurements over 20 years. This point is particularly important in tropical areas where, because of the great variability of rainfall condition from one year to another, calculations of average soil losses are valid only when the observations are spread over a sufficiently long period (Ministry for Co-operation and Development, 1991).

3. *There is a problem of scale.* This model is based on data from small areas (100 m<sup>2</sup>) or sloped basins with a very limited surface area (a few hectares). It thus appears to be little suited to the modelling of erosion for medium or large catchment areas.
4. *It neglects interactions between various factors.* Soil reacts in very different ways to the force of rain, depending upon ground slope, on soil type, and on the surface quality of the soil. It is therefore difficult to give independent values to each index.

Some of these limitations are especially important in the context of this study. In particular, the model applies only to sheet erosion in plains and in low hill areas, but not to mountainous areas where mass movement and linear erosion dominate. For slopes steeper than 15 per cent, other factors such as seismicity, the nature of the substratum and geology - which are key concerns in mass erosion - must also be taken into account.

### 3.2.1.2 Index of susceptibility to soil deterioration developed by the World Bank

As part of a sectoral study for environment in Vietnam, the World Bank (1995) constructed an Index of Susceptibility to Deterioration. The purpose of the index was largely to estimate the pre-disposition of soil to erosion in Vietnam.

Recognizing the limitations of the USLE model in the Vietnamese context, the World Bank considered the following erosion factors in preparing their index: (i) slope; (ii) geology; (iii) soils; (iv) seismicity; and (v) climate. The importance given to geology and seismicity would suggest a focus on mass erosion resulting from the Vietnam's undulating relief.

Noting that climate and seismicity influence very wide areas - unlike soil, slope and geology, which affect specific smaller areas - the World Bank decided to view climate and seismicity as facilitating elements and not as inherent factors of water erosion.

Consequently, the World Bank decided to group slope, soil and geology in an index of inherent soil fragility, and to give to this Index twice the weighting of seismicity or climate in aggregating the Index of Susceptibility to Deterioration. The inherent fragility of the soil equates to the predisposition of a soil to erosion, while the seismicity or the erosivity of the climate are seen as factors of «probability».

The World Bank index gives a value of 1 to soil with low inherent fragility, and 3 for soils with strong inherent fragility. A value of 0 is given for a weak degree of seismic activity, and a value of 1 is given for a high degree of seismic activity. The erosivity of the climate was similarly estimated. With this weighting, five levels and eight combinations of susceptibility of a soil in Vietnam to erosion were identified, as follows:

**Table 29 - Rating of the soil susceptibility to erosion**

Susceptibility rating (ascending order)	Inherent susceptibility of soil to deterioration (high**, low-)	Degree of seismic activity (high**, low-)	Erosivity of climate (high**, low-)
1	-	-	-
2	-	*	-
2	-	-	*
3	-	*	*
3	**	-	-
4	**	*	-
4	**	-	*
5	**	*	*

Notes: 1 = least susceptible (most stable) and 5 = most susceptible.

A consolidated map of soil susceptibility to erosion was developed by overlaying the maps drawn up for each of these factors. A classification of the provinces of Vietnam most susceptible to erosion was compiled by superimposing this map of soil susceptibility to erosion on the administrative map of Vietnam.

In its report, the World Bank stressed that a GIS should ideally be used to construct such an index to permit regular updates. Since the majority of the data necessary for the preparation of the index was available only on paper, it was decided to superimpose a series of transparencies manually. Table 30 details, by region, the results of the World Bank research.

The World Bank's Index of Soil Susceptibility, in its present form, has a number of definite limitations. It notably suggests that the pilot province of Lam Dong has little risk of erosion, with 24 per cent of the considered soil classified as 1, and 75 per cent classified as 3. But the contrary is suggested by local ground observations carried out by this Programme, which show that the soil erosion in Lam Dong Province is reaching alarming proportions because of the very strong erosivity of the current land use and cultivation practices.

These differences between the World Bank's theory and field observation are explained by the fact that the World Bank's index does not take into account the fundamental influence of vegetation cover, farming systems and erosion-control practices employed in a country. The work of Wischmeier and his successors show that these factors are critical in determining the risk of erosion. Roose (1994) stresses that among the conditional factors of erosion, vegetation cover is certainly the most important factor since erosion can fluctuate between 1 and 1,000 tons by hectare when all other factors remaining equal, the vegetation cover of a plot decreases from 100 per cent to 0 per cent.

**Table 30 - Vietnam's susceptibility to soil erosion by Province (World Bank, 1995)**

Region	Class 1	Class 2	Class 3	Class 4	Class 5
North Mountains	2%	10%	41%	44%	3%
Northern Midlands	1%	26%	55%	11%	8%
Red River Delta	0%	75%	20%	0%	5%
North Central Coast	4%	25%	39%	29%	4%
South Central Coast	29%	21%	27%	23%	0%
Southern Highlands	33%	0%	66%	0%	0%
North-east Mekong	98%	0%	2%	0%	0%
Mekong delta	100%	0%	0%	0%	0%
Total (not WB)	29%	14%	37%	18%	2%

### 3.2.1.3 Determination of a soil erosion risk index for Vietnamese Tropical Uplands

Taking account of the limitations of the USLE index and the World Bank Soil Susceptibility Index, this Programme developed an Index of Risk of Soil Erosion which includes both the factors influencing mass erosion in mountainous zones, and the importance of vegetation cover and cultivation practices on soil erosion. This new index incorporates the following factors: (i) slope; (ii) morpho-pedology; (iii) rainfall erosivity; (iv) vegetation cover, farming techniques and erosion control practices (terraces, etc).

- A. *Slope*. Slope influences erosion by its form, gradient, length and position (see Appendix VII). Seven levels of slope identified by this Programme allow the influence of this key factor on soil erosion to be computed. Based on those seven slope levels, Table 31 shows the five classes of risk selected to reflect the influence of slope on soil erosion. The exact influence of the slope varies according to the type of soil.
- B. *Erodibility of soil and geology*. In the United States, Wischmeier and Smith (1978) calculated multiple regressions between the erodibility of soil and twenty-three different parameters for the soil under natural and simulated rainfall on reference research plots. After simplification, it was shown that soil erodibility depended mainly on the amount of organic matter, the texture and the structure of the soil, and its permeability.

**Table 31 - Influence of slope gradient on the risk of soil erosion**

Slope classes (expressed in %)	Influence on the risk of erosion (classes in ascending order)
0-3	1
3-8	2
8-15	3
15-25	4
25-40	4
40-60	5
> 60	5

Subsequent work by Wischmeier and Singer (1978, in Roose, 1994) found that some additional factors need to be considered to better evaluate soil erodibility. They referred in particular to the soil's iron and free aluminium content, the type of clay and the value of salinity. With knowledge of the texture and structure of the surface horizons, their levels of organic matter and of iron and free aluminium content, plus some observations on the soil profile, an initial estimate can be made of the resistance of the soil to sheet and rill erosion.

Since the highest-level soil classifications do not take these parameters into account, Roose (1994) stresses that there is no clear relation between erodibility and currently recognized soil types. In the absence of detailed information on these parameters at the provincial level in Vietnam, the adoption of a soil type to estimate soil erodibility seems, however, to be most suitable methodology in Vietnam.

Using a soil map prepared by the National Institute of Agricultural Policies and Planning (NIAPP), the World Bank identified «degraded grey» soils and «red and yellow» soils as particularly prone to erosion. This soil classification was developed jointly at the beginning of the 1970s by Vietnamese and Soviet soil scientists. Unfortunately, it can be difficult at times to correlate this with the FAO-UNESCO soil classification system, which is widely used as an international reference.

For example, «degraded grey soils» includes soil types developed on very different geological materials to which rice growing practices over centuries has given common morphological attributes and physicochemical properties in the surface horizons (INRA, 1987). «Degraded grey soils» can originate from old deltaic deposits as well as from alterites of sandstones-schists and of granites. Moreover, these «degraded grey soils» are found in the plains and lowland areas of Thai Nguyen and seem to be more sensitive to physical and chemical degradation without soil movement, than to erosion.

To better correlate the effect of morphology and of soil types on erosion, this study adopted the typology shown in Table 32. This is based on the morpho-pedology map of Thai Nguyen Province developed by the Programme, and in line with FAO-UNESCO's soil classification system.

The susceptibility of the morpho-pedology type of soil units to erosion, meanwhile, is based on a review of existing literature and ground observations carried out by Pierre Brabant (personal communication, 1999), an experienced IRD soil scientist. This classification allows full account to be taken of the influence of geology on mass movements. In contrast to alluvial deposits, schists and sandstones present plans of preferential cleavage or fracture, which make them relatively sensitive to mass movement, especially if the dip is parallel to the slope.

**Table 32 - Influence of morpho-pedology on the soil's susceptibility to erosion**

Unit	Landscape	Geology and Lithology	FAO-UNESCO System	Susceptibility to erosion
Valleys	Flood prone Sedimentary basins	Quaternary Alluviums (with annual deposits)	Eutric Fluvisols Gleyi-eutric Fluvisols	1
	Sedimentary basins not prone to flooding	Quaternary Alluviums (without recent deposits)	Eutric Fluvisols	1
	Sedimentary basins	Quaternary Alluviums (with irrigation on alluviums)	Cumulic Anthrosols Eutric Fluvisols	1
	Glacis occupying small grooves or adjacent to major valleys	Colluviums	Eutric Regosols Dystric Cambisols	1
Northern border of the Red River Delta and Nui Coc lake plain	Lightly incised valleys with large interfluves marked by narrow valleys	Old Alluviums and recent alluviums -colluviums	<i>Hills:</i> Dystric Cambisols, Ferric Alisols. <i>Shallow:</i> Eutric Luvisols	2 1
		Argillite and recent alluviums -colluviums	<i>Hills:</i> Ferric and haplic Acrisols, Dystric leptosols <i>Shallow:</i> Eutric Luvisols	2 1
		Sandstone and other quartz rocks and recent alluvium-colluvium	<i>Hills:</i> Dystric Leptosols, Ferric and haplic Acrisols, <i>Shallow:</i> Eutric Luvisols	4 1
Low hills	Convex hills separated by large lowlands	Quartz or Schists, Quartzite Schist or calco-schist	<i>Hills:</i> Haplic Acrisols, Dystric cambisols <i>Shallow:</i> Eutric Fluvisols	4 1
		Granite	<i>Hills:</i> Haplic Ferralsols, Haplic Acrisols <i>Shallow:</i> Eutric Fluvisols	3 1
		Gabbros	<i>Hills:</i> Ferralic Cambisols, <i>Shallow:</i> Eutric Fluvisols	3 1
	Convex hills separated by narrow lowlands	Schist, Quartzite Schist or calico-schist	<i>Hills:</i> Dystric Cambisols, Dystric Leptosols, <i>Shallow:</i> Eutric Fluvisols	4 1
		Old Alluviums	<i>Hills:</i> Dystric Cambisols, Haplic Acrisols, <i>Shallow:</i> Eutric Fluvisols	3 1
		Granite	<i>Hills:</i> Haplic Ferralsols, Haplic Acrisols <i>Shallow:</i> Eutric Fluvisols	3 1
Hilly zones transitioning to mountains	Irregular hills separated by V-shaped valleys organised in a dendritic network	Schist, Quartzite Schist or calco-schist	Dystric Cambisols, Dystric leptosols, Haplic Acrisols	5
		Granite	Haplic Acrisols Xanthiques Ferralsols, Cambisols dystric	4
Mountainous zones	Very fringed mountain areas	Quartzite Schist and sandstone	Dystric Leptosols, Humic Cambisols, Ferralic Cambisols Dystric Cambisols	5
	Very fringed mountain areas with isolated karstic formations	Schists interlaced with limestone sheets	Dystric Leptosols, Ferralic Cambisols Haplic Alisols Haplic Phaeozems, Lithosols.	5
	Tam Dao Mountain	Rhyolite	Dystric Leptosols, Umbric Leptosols	5
	Moderately fringed mountain areas with domed peaks	Granite	Ferralic Cambisols, Boulders	4
		Gabbros	Ferralic Cambisols	3
Turreted Karsts	Highly crystallised limestone	Lithosols, Phaeozems Limestone, Haplic Lixisols	1	

Source: P. Brabant, personal communication (1999).

- C. *Erosivity of Rains.* Wischmeier (1978) combined the kinetic energy of each rain storm multiplied by the maximum intensity of rain in 30 minutes (in mm/h) to make a unique index of erosivity (EI30). On a map similar to isohyets, curves of Iso-erosivity could be established (see Appendix VII). Such curves are not available for Vietnam. A total of 121 pluviometric stations were originally established in Vietnam, including 97 to the north of the 17th parallel. Only seven of them are currently operational in the Tropical Uplands of the south of the country. This data has been synthesized only in the form of an isohyet map. But the Hydrometeorological Service of Vietnam has analysed these few data to produce an average daily intensity, a maximum value, a probability of event of 1, 5, 10, 20 and 50 per cent.

In the absence of Iso-erosivity curves, the World Bank retained a probability of 20 per cent for an average daily precipitation of 150 mm as a reference point, to identify those stations where intensity of precipitation were likely to be highly erosive. This Programme has data on daily maximum precipitation over a duration of ten years for only three weather stations in Thai Nguyen province. Because of the lack of information available on the maximum rainfall intensity in the pilot provinces, the methodology developed by the World Bank at the national level could not be applied to the pilot provinces. Instead, this study calculates the annual isohyets of Thai Nguyen based on average rainfall data available over a common period of observation for the concerned meteorological stations. A strong correlation is assumed between average annual rainfall, the probability of rainfall of strong intensity, and a given rainfall erosivity level. Table 33, gives the results of these assumptions using the available data.

**Table 33 - Rainfall erosivity in Thai Nguyen Province**

Average Annual rainfall (mm)	Rainfall erosivity (by order ascending from 1 to 5)
<800	1
800-1400	2
1400-2000	3
2000-2600	4
>2600	5

- D. *Influence of Vegetation cover and farming techniques.* Vegetation cover is effective in preventing erosion to the extent that the vegetation cover absorbs the kinetic energy of raindrops, covers a large proportion of the soil during periods of the year when rainfall is most aggressive, slows down runoff, and keeps the soil surface porous (Roose, 1996).

While an appropriate land use that respects a soil's properties can compensate for soil's inherent susceptibility to erosion, deforestation and inappropriate agricultural practices will heighten a soil's susceptibility to erosion.

Some cultivation methods are particularly harmful to soil conservation. The most damaging methods include: (i) the absence of plant cover during the monsoon rain season; (ii) the simplification of crop rotation; (iii) conversion of already fragile lands to agriculture; and (iv) overgrazing.

Other farming practises and anti-erosive measures, however, lead to a reduction in water run-off and in damage caused by erosion. The most widely used farming techniques with anti-erosive measures are: (i) cultivation along contour lines; (ii) countoured ridging; (iii) cultivation along contour lines, divided by grassy bunds; (iv) terracing; (v) natural or artificial mulching; (vi) artificial mulching with products such as polyvinyl acetate; and (vii) plant cover (leguminous).

It is, however, important to note that the impacts of anti-erosive practices may be conflicting. Thus, practices aiming to reduce water run-off to limit linear soil erosion may, in fact, create conditions conducive to mass soil erosion.

This Programme's land use classification covers both the principal types of land cover and cultivation methods in the tropical Uplands of Vietnam. Table 34 shows values given to the respective influences of vegetation cover and cultivation methods on the risk of soil erosion in Thai Nguyen Province.

**Table 34 - Influence of plant cover and cultivation practices on the Risk of Erosion**  
(1 = low risk, 4 = high risk)

Soil Occupation	Description	Influence on the soil erosion
<b>Forest land</b>		
Protected	Dense protected forest (theoretically, Tam Dao mountain from 600m upwards)	1
Non-Protected.		
• Thick evergreen Forest or semi-deciduous	• Cultivated and recent fallow land (<4 years) covers less than 5% of the total area	1
• Herbaceous vegetation.	• "Dat trong", in Vietnamese ("Barren lands")	2-3
<b>Agricultural land</b>		
Non-terraced irrigated agricultural land with both annual and perennial crops	Exclusively rain-fed and permanent agriculture on the slopes of the hills and mountains covers only limited areas.	4
Irrigated agricultural zones in the planes	Located in the province's meridional areas. Irrigated paddy dominant.	1
Irrigated agricultural zones in mountain valleys	Located in the low-lying areas and narrow valleys of the mountains and in the valleys of the hilly zone	1
Irrigated and rain fed agricultural zones		
• Dominant crop	• The high hills, with perennial crops on hills and irrigated paddy in low zones	2-3 (hills) and 1 (low land)
• Diverse production	• In the large mountain valleys, in the low hills, and in the dolines and calcium-dominated low zones	1
<b>Forest and Agriculture land</b>		
Recurring Agricultural land.		
• Crops and recent fallow covering 5% to 25% of the land	• Recurring annual rain-fed crops and recent fallow (< 4 years) on slopes cover between 5 and 25% of the total area. No terraces.	2
• Crops and recent fallow covering more than 25% but less than 75% of the land.	• Recurring annual rain-fed crops and recent fallow (< 4 years) on the slopes cover between 25% and 75% of the total area. Occasional terraces.	3-4
Mosaic of agriculture and forestry land		
• Perennial crop dominant	• Irrigated crops in low-lying areas, and rain-fed agriculture in the hills - mostly tea and orchards - cover an area greater than forests	1 (low land) and 4 (low hills)
• Forest plantations and shrubland dominant	• Mainly located in the higher hills. Forests cover more area than cultivated land.	2

Source: Soil occupation map of Thai Nguyen Province: P. Brabant (1999).

### 3.2.1.4 Aggregation of a soil erosion risk index

The index of risk of soil erosion was constructed by aggregating the above-described factors: slope; soil erodibility and geology; erosivity of rainfall, vegetation cover and farming techniques. Given the predominant influence of vegetation cover and farming techniques in the tropical uplands, double weighting was given to this factor in the aggregation equation, below. Furthermore, this approach clearly distinguishes a soil's inherent vulnerability to erosion from the influence of inappropriate land use.

$$RA = (R + K + S + 2C)/5$$

Where:

- RE = Risk of soil losses, from 1 (very weak) to 5 (very high);
- R = Index of rainfall erosivity, from 1 (very weak) to 5 (very strong);
- K = Soil erodibility and geology, from 1 (very weak) to 5 (very high);
- S = Slope, from 1 (very slight) to 5 (very steep);
- C = Vegetation cover and cultivation practices, from 1 (very weak) to 5 (very strong).

This equation enables an estimate to be made of the risk of erosion at the scale of a morpho-pedological unit. To allow for a comparison between different administrative units, such as those in Vietnam, an estimate is also made of the risk of erosion at a province or district scale, based on the percentage of soils which present a low or very low risk of erosion (1 or 2), as shown in table 35:

**Table 35 - Rating of the risk of soil erosion**

Soils presenting a risk of erosion low or very low (%)	Soil erosion risk index	Index Description
> 80	1	Very low
60-80	2	Low
40-60	3	Intermediate
20-40	4	High
<20	5	Very high

### 3.2.2 Aggregation of a soil erosion state index for the uplands of Vietnam

#### 3.2.2.1 Methodologies of estimating soil erosion

Globally, land degradation remains a controversial subject. Estimates of the extent of land degradation - which can vary by up to 100 per cent between two different sources - can be exaggerated by national interests in order, perhaps, to boost or obtain financing and an increased political mandate (P. Brabant, S. Darracq, K. Égué, V. Simonneaux, 1996). There are several ways to estimate the state of erosion:

- Field investigations that compare, count and classify the visible signs of erosion.
- Adaptation of estimation models of soil losses to local conditions utilising experimental plots.
- The measurement of suspended particles in the hydrological network.

This Programme adopted the first approach - analysis of the visible signs of erosion - to assess the state of erosion in Thai Nguyen Province.

#### 3.2.2.2 Aggregation of the soil degradation state index, based on visible signs

Based on extensive field surveys, and analyses of satellite images and cartographic documents, the Programme prepared an inventory of visible signs of erosion as well as of visible signs of soil degradation *stricto sensu* (without soil movement). This inventory was prepared according to the methodology used by the IRD's study of the State of Soil Degradation in Togo (P. Brabant, S. Darracq, K. Égué, V. Simonneaux, 1996). The methodology rests on the definition of three principal parameters: the type, the extent and the degree of soil degradation. This study focuses exclusively on the inventory's

“erosion” component<sup>11</sup>. Three types of erosion are discussed: sheet erosion, linear erosion and mass movement.

The extent of erosion is the proportion of ground subjected to a certain type of erosion in a given area. The extent of erosion is calculated, and expressed in percentage terms that are then weighted in five categories as shown in table 36.

**Table 36 - Rating of the extent of erosion**

Extent of erosion (%)	Erosion extent rating	Meaning
< 5	1	Very low
5 –15	2	Low
15-30	3	Intermediate
30-50	4	High
>50	5	Very high

The degree of degradation caused by erosion expresses the extent of the erosion at a given place (P. Brabant, 1997). Tables 37 and 38 - developed by P. Brabant (1997) - present the principal variables contributing to the evaluation of the degree of surface erosion and linear erosion.

**Table 37 - Rating of Sheet Erosion**

Indicators	Degree	Class
Shows signs of natural erosion, which vary according to the soil type and land conditions. The land is not usually cultivated, but is covered by spontaneous vegetation or located within a protected area without human activities.	Nil - very low	1
Reduction of the humus layer to < 1/5 in covered soil. Depositions of sand may be observed up against small obstacles such as clumps of grass or stones. Fine fractions of soils are accumulated in land depressions. Little, if any, decrease in the soil's productivity.	Low	2
Reduction of the humus layer to between > 1/5 and < 1/3 in covered soil. Partially uprooted clumps of grass; find sand and silt accumulate on the surface. Crusting covers less than 10% of the surface. Decrease of around 25% in the soil's productivity.	Average	3
The humus layer reduces by half. Frequent uprooted clumps of grass. Numerous deposits of sand and silt in the lowland areas. Much crusting over the soil surface. Barren land without spontaneous vegetation can cover from 10 to 25% of the area. Productivity can reduce by up to 50%.	High	4
A reduction of up to 3/4 in the humus layer. This layer may sometimes have totally disappeared over a large part of the area. Visible roots several centimetres long. Spontaneous vegetation cover is very much reduced. Large areas of barren land. Abundant fine and coarse sand sediments in lower areas along the drainage systems. Much crusting. Highly reduced herbaceous cover. Barren land without spontaneous vegetation can cover up to 50% of the area. Soil productivity decreases by more than 75%. The land is often deserted.	Very high	5

(P. Brabant - Evaluation Methodology of Land Degradation status (1997).

<sup>11</sup> Land degradation with soil movement.

**Table 38 - Rating of Linear Erosion**

Indicators	Degree	Class
Limited, or no, signs of linear erosion.	Nil-very low	1
Small erosion rills in the arable layer. Signs of erosion disappear after tillage, even with a hoe.	Low	2
Rills occasionally reaching the lower horizon of the arable layer - do not disappear with hoe tillage.	Average	3
Gullies reaching the lower layers of the soil, up to 1 metre deep in some parts. Mechanical tillage is still possible, but difficult. Reduced soil productivity.	High	4
Numerous deep gullies up to 10 m deep and of 5m wide. Mechanical tillage impossible. Soil movement take place along the gullies. Cultivation of the land is difficult for both annual and perennial crops, as well as for livestock breeding. No transactional value, and this land is often deserted.	Very High	5

Source: P. Brabant - Evaluation Methodology of Land Degradation status (October revision 1997).

The index of the state of soil erosion is obtained by the following equation:

$$IEE = (DE + EE)/2$$

Where:

IEE = Index of state of erosion, from 1 (very weak) to 5 (very strong);

DE = Degree of erosion, from 1 (very weak) to 5 (very high);

EE = Extent of erosion, from 1 (very weak) to 5 (very high).

This equation of aggregation enables an estimate to be made of the state of erosion on a plot scale or on a morphological-soil unit scale. As with the Risk of Erosion, the State of Erosion on a province or district scale is estimated using the percentage of lands characterised by slight or very weak erosion (1 or 2), as given in table 39:

**Table 39 - Rating of Soil Erosion Status**

Soil presenting a low or very low erosion status	Soil erosion state index	Index description
> 80	1	Very low
60-80	2	Low
40-60	3	Intermediate
20-40	4	High
<20	5	Very high

### 3.2.3 Aggregation of a soil erosion response index

The afforestation of former forest lands is the cornerstone of the strategy to combat soil erosion in Vietnam. It is important to remember that FIPI classifies all land with a slope of more than 25 degrees (about 47 per cent of Vietnam's total surface area) as forest, regardless of whether there is actual forest cover on that land.

To allow closer monitoring of the implementation of this erosion control strategy, this work uses the percentage of classified forest lands actually under forest cover as the response indicator to soil erosion. The resulting classes of response to soil erosion are as given in table 39:

**Table 40 - Rating of the Response to Erosion**

Percentage of lands categorised as forest lands and actually under forest cover	Index of response to soil erosion	Index description
> 80	1	Very strong
60-80	2	Strong
40-60	3	Intermediate
20-40	4	Poor
<20	5	Very Poor

Reforestation of more than 80 per cent of classified forest in a given zone indicates a very strong response to soil erosion (value = 1). Reforestation of less than 20 per cent, meanwhile, indicates a very weak response to the national strategy to combat erosion (value = 5).

## 3.3 CONSTRUCTION OF A WATER SHORTAGE INDEX

### 3.3.1 Construction of a water shortage risk index

In general, a country can collect only part of its annual water supply from precipitation by using dams, small reservoirs and direct pumping of water from rivers and aquifers. The closest and most economic sources are used first. It then becomes increasingly difficult and expensive to access the more distant sources.

The risk of water shortage is generally estimated using the intensity of resource use. A working group comprised of nine United Nations agencies (UN, 1997) has expressed the intensity of water use by the total annual gross volume of ground and surface water withdrawn for water use, including conveyance losses, consumptive uses and return flows, as a percentage of the annual renewable water supply, using the following equation:

$$WP (\%) = 100 [ 1 - (AW/AR) ]$$

Where:

- WP = Pressure on the water reserves (%);
- AW = Annual withdrawal of renewable water resources (m<sup>3</sup>);
- AR = Annual renewal water supply (m<sup>3</sup>).

The United Nations Report distinguishes four main categories of pressure on water according to the percentage of the water resources taken:

- *Low water stress.* Countries that use less than 10 per cent of their available freshwater resources generally do not experience major water stress;

- *Moderate water stress.* It was observed that the pressure on water resources begins as soon as the use of fresh waters exceeds 10 per cent of the renewable water reserves, and becomes more marked as soon as this rate reaches 20 per cent. Countries whose water consumption lies between 10 to 20 per cent generally state that the availability of fresh water becomes a limiting factor, and that important investments are needed to increase provision and to reduce water demand;
- *Medium-High water stress.* When a country's water consumption is between 20 to 40 per cent of its annual provision, substantial attention is given to resolving problems of competition for water between the different sectors of human activity and the needs of the aquatic environment. Important investments are necessary to increase the efficiency of water use;
- *High water stress.* Use of more than 40 per cent of the annual water supply of a country represents an extreme water shortage. This situation poses a very strong risk that surface and groundwater will be overexploited, with the consequent degradation of the aquatic environment. The installation of a desalinisation infrastructure may be necessary, dramatically increasing the cost of water and industrial production costs. In such cases, water can become the most important factor limiting a country's economic development.

An annual indicator of pressure on water resource was developed in this Programme in line with the equation and the threshold levels defined by the United Nations. Table 41 presents these thresholds.

**Table 41 - Rating of Water shortage Pressures**

Percentage of freshwater used	Water shortage pressure index	Index description
< 10	1	Very low
10-20	2	Low
20-30	3	Moderate
30-40	4	High
> 40	5	Very high

### 3.3.2 Construction of a water shortage state index

The purpose of his index is to reflect the frequency, duration and degree of periods of water shortage. Prolonged water shortage threatens the following vital functions of the hydrological system:

*Agricultural Production.* Because of the irregularity of precipitation, irrigation is essential throughout the year to ensure the maintenance of rice production sufficient for the food needs of the population in Vietnam's Uplands. Fishing and aquaculture also play an essential role in meeting these food needs. Irrigation and the sustainable management of water resources is therefore essential to ensure food security in Thai Nguyen Province.

*Industrial and Urban Development.* Significant water shortage results in increased competition and conflict between water users. Water is a major input in the majority of industrial processes. But water represents only a small share of industrial production costs (1 to 2 per cent) in the areas where a proper water supply system exists. A study conducted by HABITAT in Lagos (1990) showed that water could represent up to 20 per cent of the production costs where there is a shortage of water.

*Recharge of ground water.* Ground water plays a crucial part in the provision of water supply to the population and the regulation of river flows. Surface water shortages will quickly lead to the overexploitation of ground water resources and a reduction in ground water recharge from surface water.

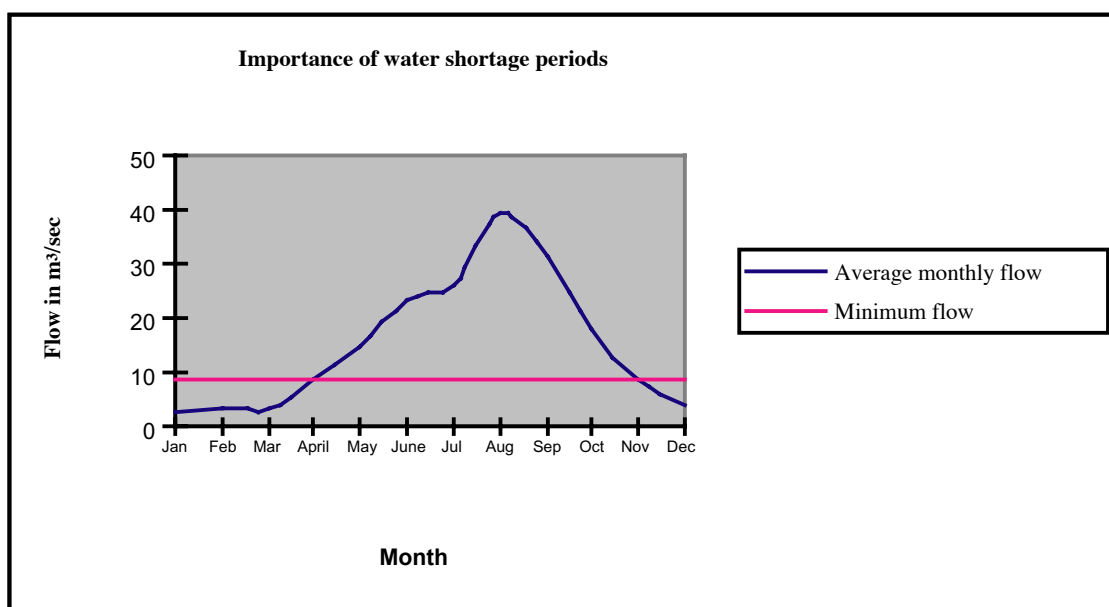
*Maintenance of aquatic life.* A minimum flow must be maintained throughout the year to ensure the survival of the aquatic ecosystem.

*Purification of pollutants.* To a certain threshold, water plays a powerful role in the natural purification of pollutants<sup>12</sup>. This threshold is a function of the total water flow; and the load, nature, temporal and spatial distribution of the pollutants.

*Energy, transportation and recreation.* Hydroelectric energy is the primary source of energy in North Vietnam. The hydrographic network also plays an important part in the domestic transport of goods and people in the country. Although difficult to quantify, society places also a high value on recreational activities such as boating and swimming as well as the more subtle spiritual and aesthetic qualities of freshwater systems.

The key objective of sustainable water resource management is therefore to ensure a minimum flow throughout the year to respond to the various demands exerted on water resources, and to maintain the whole range of socio-economic and environmental functions of freshwater systems. The water shortage state index must, therefore, stress this fundamental concept.

**Figure 18: Periods of Water Shortage in An Average Year in Thai Nguyen Province, Vietnam**



**Table 42 - Rating of water shortage status**

Number of months not meeting the minimum flow	Water shortage state index	Index description
1	1	Very low
2	2	Low
3	3	Moderate
4	4	High
≥ 5	5	Very high

<sup>12</sup> Assimilation processes vary between surface and ground waters. The main water surface purification processes include dilution, sedimentation, flocculation, volatilisation, biodegradation, aeration, and ingestion by living organisms. Before reaching ground waters, pollutants are filtrated by a soil column. The soil pollutant assimilation processes include aerobic and anaerobic decomposition, filtration, ionic exchanges, absorption and dilution.

Figure 18 illustrates the importance of this concept of minimum flow in the context of strong seasonality in the hydrological cycle. The monthly average flow in a theoretical standard water body in the tropical uplands of Vietnam is represented by a hydrographical curve. A horizontal line visualizes the minimum flow necessary to preserve all of the critical freshwater system functions. This graphical approach makes it possible to highlight the number of months per annum during which the average monthly flows are not sufficient to maintain the minimum flow, and the importance of these deficits. It is important also to note that minimum flow is a function of socio-economic and ecological conditions in a given period and will vary strongly over time. If the concept of minimum flow is fundamental, its value is relative.

To highlight the frequency, duration and importance of periods of possible water shortage in Thai Nguyen Province, this study estimated the desirable low water level for each of the province's major catchment area. With that estimate, the index of the state of water shortage was calculated based on the number of months per annum where the average monthly flows are not sufficient to maintain the minimum flow.

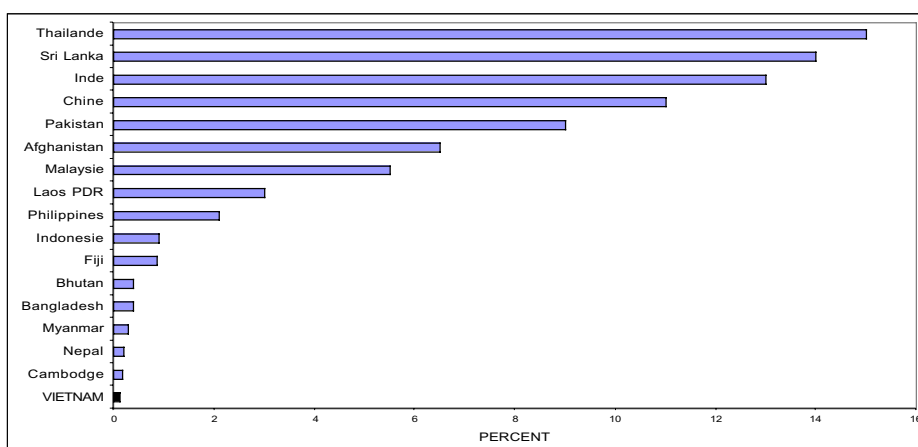
This index estimates the potential for water shortage in the absence of water infrastructure regulating the seasonal flow. This point is considered further in constructing the index of response to water shortage.

### 3.3.3 Construction of a water shortage response index

Although irrigation is essential for agricultural production in the hills and Uplands, it is also by far the largest consumer of water. In this context, several possible solutions, both structural and non-structural, are envisaged for mitigating seasonal water shortages:

*Regulation of seasonal flows.* The use of dams to increase the water storage capacity allows the seasonality of the hydrological cycle to be mitigated, and the frequency of floods and droughts to be reduced by storing excess water during the rainy season and releasing this excess water to supplement low flows during the dry season. Vietnam currently has the lowest water storage capacity in Asia (see Figure 19).

**Figure 19: Storage Capacity as a Percentage of Annual Renewable Water Supply**



*Total cost recovery for water supply.* The true water storage capacity of existing dams in Vietnam is substantially lower than the theoretical capacity because of budgetary constraints that limit their maintenance and proper operation (M. Silver, 1999). The price of water is determined administratively in Vietnam. In general, it covers only two-thirds of the total costs for operation and maintenance (MOSTE/UNDP, RRDM, Background Paper 4, 1995). A reform of the water pricing structure would

seem to be a pre-condition for the rehabilitation of the country's existing infrastructure and sustainable increase in the capacity to mitigate the seasonality of Vietnam's hydrological cycle.

*Increase in the efficiency of the irrigation system.* The Asian Development Bank estimates that the efficiency of the irrigation network in Vietnam is 30 per cent (ADB, 1998). Again, reform of the water pricing structure would seem to be a precondition for the rehabilitation of the existing irrigation perimeters and a development of more water-economic techniques of irrigation.

*Allocating water use rights.* The determination of minimum flows during the low water flow season, and the allocation of maximum water withdrawal rights to various users are powerful tools for the economic and environmental optimisation of water resources (World Bank, Technical Paper 198, 1994).

*Agricultural diversification.* Rice cultivation is particularly water-demanding (FAO, 1996). The increasing popularity of new crops, such as sweet potato or corn, could result in a lower demand for agricultural water.

The construction of new dams for hydropower production, flood control and irrigation has been a top priority of the Government of Vietnam since the beginning of the 1990s. This dam construction programme may account for nearly 20 per cent of the total public investment of the country during this decade.

**Table 43 - Public Investment in the Water Sector (\$ million)**

Sector	1991-1996 (estimates)	1996-2000 (targets) <sup>13</sup>
Hydropower	400	1 940
Urban water supply	280	872
Urban sanitation	-	890
Irrigation, drainage and flood control	400	653
Canals	-	116
Rural water supply and sanitation	-	30
Total water investments	1 080	4 501
Total public investments	4 000	15 600

Source: *Vietnam Infoterra Newsletter 3/97*.

In terms of environmental protection, the regulation of water flows using dams is a powerful remedy. But it can kill the patient if the dosage is even marginally off-target. If the growth in storage capacity is not closely related to the maintenance of a minimum level of low water flow, it is likely to result in an increase in irrigated surfaces in the short term, but will not improve availability and water quality for other users. In the long term, it will result in even greater pressures on water resources and an increased risk for the aquatic ecosystem and public health.

In line with the national public investment programme of Vietnam, this study used the increase in the capacity of flow regulation as an indicator of response to water shortage. But this interpretation is closely associated with the concept of the maintenance of a minimum flow to preserve the vital functions of the hydrological system during periods of low water levels. An attempt to calculate the effective volume stored by the existing reservoirs in Thai Nguyen's two main catchments was then made, followed by an estimate of the additional volume of water required to maintain the minimum dry season flow. Then the percentage of this deficit currently addressed by the effective volume stored by existing dams was calculated. The following equation reflects this approach:

$$CM = (V-S)/100$$

<sup>13</sup> In the absence of a voluntarist policy of cost recovery and of promotion of the private sector, World Bank concluded that it was unlikely that the public investment plan be implemented in accordance with above-mentioned targets.

Where:

- CM = Capacity of maintenance of the minimum flow to preserve the vital functions of freshwater eco-systems during the low dry season flows (%);
- V = Missing volume of water required to sustain the minimum flow (m<sup>3</sup>);
- S = Effective volume of water stored by the existing dams (m<sup>3</sup>).

The index of minimum flow support capacity is divided into five categories based on percentages obtained, as shown in table 44:

**Table 44 - Rating of the Response to Water Shortage**

Percentage of minimum flow supports by dams	Water shortage response index	Index description
>80	1	Very high
80-60	2	High
60-40	3	Intermediate
40-20	4	Poor
< 20	5	Very poor

### 3.4 CONSTRUCTION OF A WATER POLLUTION INDEX

#### 3.4.1 Construction of a water pollution risk index

##### 3.4.1.1 Selection of the pollutants included in the water pollution risk index

The principal sources of water pollution in the tropical Uplands of Vietnam are: (i) faecal contamination due to the practice of open air defecation and a low number of sanitary latrines; (ii) suspended particles in water resulting from soil erosion; (iii) contamination of surface water by untreated domestic and industrial waste; (iv) waste water from mining activities and mineral extraction; and (v) agrochemical compounds. A more detailed description of each of these sources is provided in Appendix VIII.

Ideally, an indicator of water pollution should reflect all of these sources of contamination. But the embryonic state of the water quality monitoring system suggests that such an approach may not be feasible in Vietnam in the immediate future. This study therefore focused on the principal sources of water pollution.

Faecal contamination seems to be the major source of biological water pollution in Thai Nguyen Province, whereas sedimentation is the main form of physical water pollution. Chemical and organic pollution of industrial and domestic origin, meanwhile, appear to be limited and only affect the immediate surroundings of the industrial parks of Thai Nguyen and Song Cong (see 2.2.2.4).

Vietnamese decision makers are particularly concerned by the impact of sedimentation in the control of floods<sup>14</sup> and the lifespan of hydraulic works. A major objective of the reforestation programme and redistribution of forest land to farmers in Vietnam is the control of sedimentation.

Relatively minor importance, meanwhile, is attached to the problems of faecal contamination in rural areas. For long, diseases transmitted by water and human excreta were regarded as a natural and unavoidable part of human life in rural areas. It was only in 1996 that Vietnam, in close association with UNICEF, began its first public investment plan for provision of safe drinking water supplies and sanitation services in rural areas (see Table 41).

<sup>14</sup> When depositing sediment carried by water flows raises the waterbed level and the height of the flows. Hence, the bed of the Red River, confined for centuries by the dikes, stands now for several meters above Hanoi. Sedimentation obliges the Department of Dike Management and Flood Control to regularly increase the height of thousands kilometers of dikes along the Red River.

The problems of sedimentation have already been examined in developing the soil erosion index. Therefore, faecal contamination was selected as a water pollution indicator to stress a mechanism of degradation that is too often ignored or underestimated in development policies.

#### 3.4.1.2 Construction of the faecal contamination risk index

Faeces are the principal source of pathogenic bacteria in water. Water contaminated by faeces poses a serious danger to public health. Contaminated water can only be used as drinking water after disinfection (e.g. chlorination) and, in certain cases, cannot even be used for bathing.

Faecal emissions were estimated by multiplying the degree of risk of faecal contamination resulting from sanitary practices in the pilot zones by the density of the population, as follows:

$$\text{IRFC} = \text{Pop.} * \text{RFC}$$

Where:

- IRFC = Index for the risk of faecal contamination of water, 1 (very low) to 5 (very high);
- Pop = Density of population (hab./km<sup>2</sup>);
- RFC = Risk of faecal contamination associated with existing sanitary practices.

The degree of risk associated with each type of sanitary practice was identified in accordance with an UNICEF study on the incidence of hookworms resulting from various sanitation practices (UNICEF, 1995) and the study of drinking water and sanitation carried out by DANIDA and the CERPAD in Thai Nguyen Province in 1996. Table 45 represents the thresholds values obtained.

**Table 45 - Rating of Water Pollution**

Sanitary facilities	Water pollution risk index	Index description
Septic Tanks	1	Very low
Double Vault Composting Latrines	2	Low
One-vault Latrines	3	Moderate
Over Water Latrines	4	High
Open Defecation	5	Very high

The classes of risk of faecal contamination were then obtained by the method of natural breaks.

#### 3.4.2 Construction of a water pollution state index

The ideal indicator for the state of water pollution would be the total length of rivers where the level of water quality is below the recognized standards of quality for the type of use (drinking, irrigation, recreation, industry, etc). To achieve this ideal indicator, regular analyses of the biological, chemical and physical composition of water should be conducted throughout the year, and throughout the country. A list of the principal parameters of biological, chemical and physical quality of water is given in Appendix V.

Vietnam currently does not have the financial means or the technical capacity necessary to establish such an exhaustive monitoring system. Given the importance of the risk of faecal contamination, even limited water quality monitoring in the uplands could however be initiated, concentrating initially on fundamental parameters of the biological quality of water like the concentration of faecal coliforms and the biological oxygen demand at 5 days (BOD<sub>5</sub>). Such measurements would be particularly important in periods of low water flow. Insert 6 briefly illustrates the applications of these two indicators of organic and faecal water pollution. A matrix interpreting these parameters is provided in Appendix V.

**Insert 5: Two fundamental parameters of biological quality of water:  
Concentration in faecal coliforms and BOD<sub>5</sub>**

**Concentration of faecal coliforms.** Faecal contamination is the main source of pathogens in natural waters. The presence of coliform organisms in water is regarded as evidence of faecal contamination, as their origin is the intestinal tract of humans and other warm-blooded animals. Faecal coliforms are used as a surrogate for pathogens to assess the quality of water hygiene. Escherichia coli (E. coli), the thermotolerant and other coliform bacteria, the faecal streptococci and spores of sulphite-reducing clostridia are common indicators of this type.

**Biological Oxygen Demand.** BOD<sub>5</sub> is an empirical test to provide a measure of the level of organic pollution in a body of water. The test involves the incubation of a diluted sample for a period of five days and is usually referred as the BOD<sub>5</sub> test. Micro-organisms use the oxygen in the water for biochemical oxidation of pollutants, which are their source of carbon. BOD<sub>5</sub> measures the amount of oxygen consumed for the micro-biological decomposition of organic material in water.

The BOD<sub>5</sub> test is widely used to determine the organic strength of sewage and industrial wastes in terms of the oxygen that would be required to oxidize organic matter if that waste were discharged into natural waters in the absence of adequate treatment. It is a key test in evaluating the purification capacity of receiving water bodies, and in determining the maximum permissible discharge of waste containing organic material in these water bodies.

As discussed in Section 2.2.1.5, a programme of regular measurements of these water quality parameters does not yet exist in rural Thai Nguyen Province. A proxy indicator must therefore be chosen to make an estimate of the state of faecal contamination of water in the province. The proxy-indicator will have to satisfy the three conditions of measurability, of accuracy of analysis and political relevance presented in Section 2.3.1:

*Measurability.* For an easy update of the indicators for the state of water quality, it is important to choose a routinely collected, multidimensional indicator to satisfy other development objectives prioritised by appropriate Government of Vietnam agencies.

*Policy Relevance.* Water is perceived to be abundant in Vietnam and its preservation is seldom considered as a major issue. The proxy-indicator of the state of water quality should therefore contribute to a greater awareness of the importance and increasing stress on this resource.

*Accuracy of analysis.* The proxy-indicator should allow precise measurements to be taken of the impact of faecal contamination, a major source of water pollution.

The incidence of diarrhoea diseases was thus selected as a proxy indicator for water quality in the Thai Nguyen Province. That incidence of diarrhoea diseases is, of course, closely associated with the faecal contamination of water. Data on diarrhoea diseases are collected monthly by the Vietnam provincial centres of preventative medicine, allowing the human and economic costs generated by water pollution to be emphasised. The national annual average of the incidence of diarrhoea was 1,327 cases per 100,000 inhabitants in 1996. On this basis, the following tolerance levels were selected:

**Table 46 - Rating of Water Pollution Status**

<b>Incidence rate of diarrhoea (case/year/100 000 hab.)</b>	<b>Water pollution status index</b>	<b>Index description</b>
< 500	1	Very low
500 – 1000	2	Low
1000 – 1500	3	Moderate
1500 – 2000	4	High
> 2000	5	Very high

### 3.4.3 Construction of a water pollution response index

In addition to environmental sanitation education, a major option to reduce faecal contamination in water is to increase access to drinking water supply and sanitation services (WSS). In order to assess on-going efforts to control faecal contamination, the access rate to drinking water and sanitation services in rural areas was adopted as the response indicator.

The socio-economic databases managed by the GIS of this Programme do not currently contain information on the WSS infrastructure in the pilot provinces. So, to conduct this analysis with acceptable reliability, the WSS database developed by UNICEF in Vietnam was used. This database covers the whole of Vietnam. The methodology developed for Thai Nguyen may therefore be readily applied to the country's other hill and upland zones.

Map 9 shows the percentage of the population that has access to WSS services in Vietnam (primarily drinking water). The beneficiaries directly finance most WSS systems in rural areas. It was only in 1996 that the Government began supporting WSS in rural areas through the WATSAN (water and sanitation) programme, which was initiated by UNICEF at the beginning of the 1990s and which the UN Agencies still co-finance. Map 10 shows the percentage of the population that has obtained access to WSS services through that WATSAN programme.

The thresholds for assessing investment efforts aimed at reducing faecal contamination of water in rural areas were established by reference to the best and the worst results recorded at the national level. This approach stresses realistic objectives that are within the reach of local policy makers. Accordingly, provincial averages of access to WSS services were divided into five classes of response to water pollution, using the method of natural breaks. These thresholds were used to assess on-going efforts at the district level in Thai Nguyen province to provide a water pollution response index.

**Table 47 - Rating Of The Response Of Water Pollution**

<b>Percentage of population having access to WSS services</b>	<b>Water pollution response index</b>	<b>Index description</b>
43-65	1	Very strong
35-42	2	Strong
27-34	3	Intermediate
19-26	4	Poor
8-18	5	Very poor

## **IV ENVIRONMENTAL INDICES: ANALYSIS OF THE RESULTS**

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*In this chapter, the results obtained from the various aggregated indicators are described and analysed.*

*Using indicators of size, shape and distribution, this chapter shows that the extent and acceleration of forest degradation gives cause for concern. Population pressure, accessibility and the transport infrastructure all play significant, interrelated roles in deforestation. The findings of the forest indicators also question the practicality of existing forest protection policies.*

*Soil erosion is often thought to be a highly significant determinant of land degradation in Vietnam. This assessment is, however, not borne out by this study, which suggests that land cover is, for the most part, adapted to the soil's inherent vulnerability to erosion. In addition, the strength of natural vegetation regeneration, and the absence of seasonal breaks in vegetative growth, may significantly mitigate the impact of deforestation on soil erosion.*

*Water resources, meanwhile, are found to be a major potential constraint to the development of the tropical Uplands of Vietnam. Tropical uplands can give the impression of possessing abundant water resources. But this impression is misleading, because of the strong seasonal variability in precipitation. In Thai Nguyen Province, this is compounded by inefficient water use and excessive reliance on irrigation.*

*Despite the information and methodological constraints highlighted in Chapter 3, this chapter suggests that environmental indicators are in reality an effective support to policy decision-making in tropical areas. But even when environmental indicators cannot directly support decision making because of their inherent constraints, they serve to illustrate the need for more and better environmental data upon which important decisions on environmental policy must continue to be based. In summary, the indicators can increase the capacity of decision makers to promote the sustainable development of Vietnam's Uplands and of tropical uplands in other countries in the region.*

## 4.1 INDICES OF FOREST DEGRADATION

The objective of this study is not to prepare an in-depth report on the province of Thai Nguyen or, indeed, to analyse the main causes of environmental degradation in the uplands of Vietnam. The objective of this study is to develop instruments of communication and dialogue for the sustainable management of natural resources. The analyses of the results given in this fourth and final chapter should therefore be seen as demonstrating the decision-making support potential of environmental indicators and not as an exhaustive exploitation of the data gathered by this Programme.

### 4.1.1 The Forest and biodiversity loss risk index

Selected indicator: Variation of forest cover.

#### 4.1.1.1 Description of results

Maps 11, 12 and 13 show the forest cover of the province of Thai Nguyen, according to FIPI, in 1943, in 1983 and 1993. Maps 14, 15 and 16 represent the positive or negative variations of this forest cover from 1943 to 1993, from 1943 to 1983 and from 1983 to 1993. These maps were obtained using Arcview's merging function.

Maps 17, 18 and 19 represent the variations of forest cover during these three periods expressed as a percentage of annual deforestation, by district in the province. The forest areas and the percentages of deforestation per district for the three analysis periods are tabulated in table 48.

**Table 48 - Annual Variations in Forest Cover (%) for 1943-1983, 1983-1993 and 1943-1993**

DISTRICT	Forest - 43 (ha)	Forest - 83 (ha)	Forest - 93 (ha)	Variation 43-83 (%)	Variation 83-93 (%)	Variation 43-93 (%)
Dai Tu	26 632	13 962	6 793	- 1.63	- 7.5	- 2.7
Dinh Hoa	24 451	19 156	5 910	- 0.61	- 12.5	- 2.9
Dong Hy	31 468	11 228	1 729	- 2.6	- 20.6	- 6.0
Pho Yen	6 719	6 094	484	- 0.2	- 28.8	- 5.4
Phu Binh	6 467	1 025	1	- 4.7	-	-
Phu Luong	21 119	5 525	1 542	- 3.4	- 13.6	- 5.4
TP Thai Nguyen	2 390	1 095	1	- 1.9	-	-
TX Song Cong	-	-	-	-	-	-
Vo Nhai	31 598	26 936	16 240	- 0.4	- 5.2	- 1.3
<i>Total</i>	<i>150 848</i>	<i>85 025</i>	<i>32 701</i>	<i>- 1.4</i>	<i>- 10</i>	<i>- 3.1</i>

Section 3.1.1 discussed the significant questions concerning the validity and the exact dating of the forest map reported for 1943. To a lesser extent, similar questions also arise about the validity of the inventories reported for 1983 and 1993. Map 20 compares the forest areas identified by FIPI in 1993, and by this Programme in 1994.

More resources were available for the preparation of the Programme's map than for FIPI's map. Although both maps were prepared by interpreting satellite images, this Programme's map was further refined by ground truthing. It was thus possible to identify forests on karst deposits that do not appear on FIPI's map.

FIPI's maps appear to be sufficiently accurate for a qualitative analysis of forest cover variations and the communication of a powerful message to local decision-makers. However, it is considered better to use the more accurate map produced by this Programme to construct the index of the state of forest vulnerability in Thai Nguyen Province.

#### 4.1.1.2 Analysis of results

*Extent of deforestation.* An immediate conclusion that emerges from analysis of this indicator is the extent of deforestation. On the basis of available information, the average annual rate of deforestation of Thai Nguyen Province was 3.1 per cent between 1943 and 1993 (see Table 48). This figure is compared with an already extremely high national average of 1.6 per cent during this same period. In line with the classification suggested in Section 3.1.1 for the index of pressure on forests (Table 25), deforestation in Thai Nguyen province is regarded as being very strong (class 5).

*The rate of deforestation in Thai Nguyen Province increased rapidly between 1983 and 1993.* The average annual rate of deforestation rose from 1.4 per cent for the period 1943-1983; to 10 per cent for the period 1983-1993. Rates of deforestation of more than 20 per cent per annum were recorded in the districts of Dong Hy and Pho Yen. Natural forests disappeared entirely in the districts of Thai Nguyen and Phu Binh.

This acceleration of deforestation is consistent with the agrarian history of Thai Nguyen Province as described in Section 2.2.1.2. From the 1980s, population growth and scarcity of land required the provincial authorities to authorize side slope cultivation. Young people who subsequently settled the area encountered the same problem of land scarcity and also had to grow crops on the slopes. The acceleration of deforestation in the province of Thai Nguyen would therefore seem to result from the increasingly strong pressure exerted by a rapid population growth competing for fast declining agricultural land resources.

Rather than examining the exact causes of deforestation at this point, it is more useful to identify the factors that have contributed to the survival of the remaining residual forest plots.

##### a. Topography

Accessibility is a key component in modelling forest degradation in the uplands of Vietnam. In high population density areas, non disturbed forest remains only on sites which are difficult to access because of their topography or the absence of road and river networks.

An overlay of the GIS themes «Altitude» and «Residual Forest Plots», as shown in Map 21, clearly shows the importance of the topographic factor. There is an almost perfect correlation between altitude and forest cover. Nearly 80 per cent of residual forests are located at an altitude of over 600 meters. It should also be noted that 600 meters is in theory the elevation limit above which land clearing is prohibited.

##### b. Road and Hydrographic Networks

Decision makers generally recognize the importance of topography on deforestation, but the importance of roads is much less understood. The construction of roads is closely associated with deforestation in most of the tropical world. Roads are powerful instruments with which to promote economic development, but in rural areas roads also provide access to forests previously protected by their isolation.

Not all rural roads have the same impact on economic development and the environment. Decision-makers have tended to promote extensive development of the road network to cover the entire country. But remote roads, far removed from urban centres, generate few economic benefits. But the same remote roads can endanger unique biological preserves and prove enormously damaging to soil and water conservation.

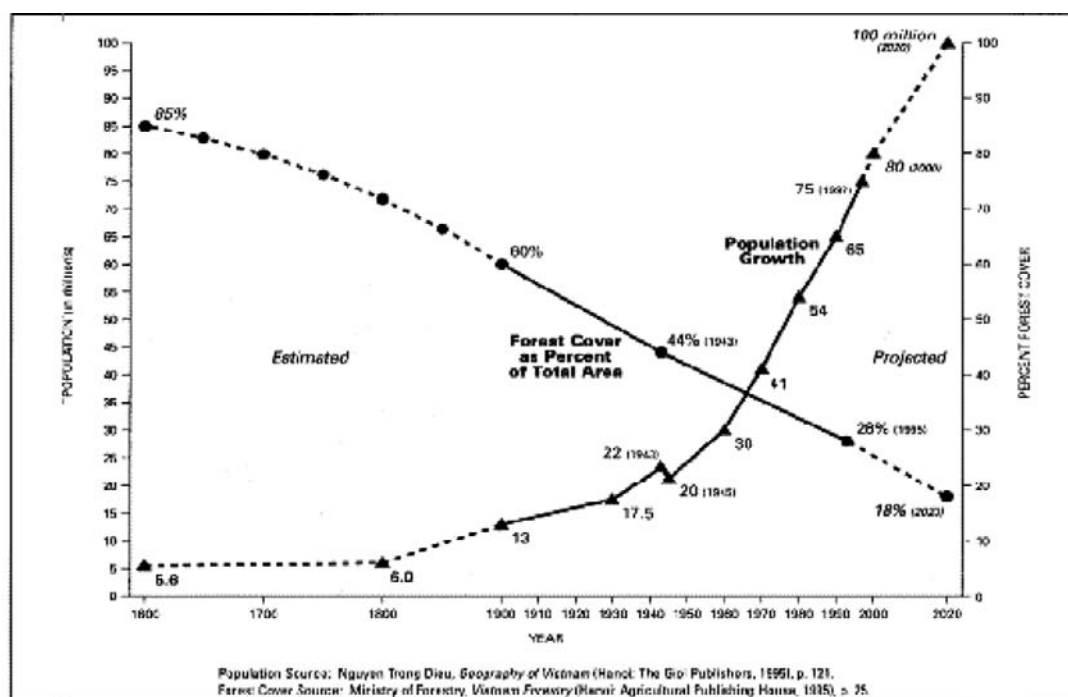
The World Bank therefore recommends an intensification and not an extension of road networks (K. Chommitz and D. Gray, 1995). Thus, construction of new roads should primarily be concentrated in high population density areas and belocated near markets. Roads should not be constructed in areas that are marginally populated, removed from markets and with a poor economic potential, and often containing critical biological diversity.

Map 22 represents the overlay of “Road network”, “Hydrographic Network” and “Human Settlement” for Thai Nguyen Province. The impact of the road network on deforestation is clearly visible in the southeastern part of Vo Nhai district, where roads serve only scattered settlements but seem to have contributed significantly to deforestation. Analysis of the northeastern sector of Vo Nhai District shows, however, that in the absence of roads, people are still able to reach the alluvial valleys and isolated forest plots using the rivers and waterways. This point is shown more clearly by Map 23 of Vo Nhai district.

c. Population Density

High population density, along with poverty, is a fundamental cause of deforestation in Vietnam (J. Carle, 1996). This close relationship is illustrated in Figure 20 (Asia Forest Network, 1998) which shows the relationship between population growth and forest cover in Vietnam.

**Figure 20: Historical Population and Forest Cover Trends in Vietnam**



The average population density in Vietnam was 223 habitants/km<sup>2</sup> in 1995 (IUCN/UNDP, 1999) ; but this population density was not evenly distributed. Population density increases to 500 habitants per km<sup>2</sup> of arable land and to over 1,100 hab./km<sup>2</sup> in the agriculturally rich Red River Delta. The demographic growth rate remains very high and the population could double in the next 40 years to come (UNDP/IUCN, 1999). National statistics state that in 1996, 24 million people were already living on lands classified as forest in Vietnam (UNDP/FAO, 1996).

In order to better highlight the geographical location of population, this Programme chose to present the theme «Human Settlements» rather than population density as shown in Map 22. The map shows a very strong correlation between human settlements and forest cover in the northern part of the province. But in the southern part of the Province, the designation of National Park appears to provide a certain protection to the large forest area of Tam Dao despite important human settlements in the district of Dai Tu.

d. Type of vegetation and of soils

The type of vegetation influences the vulnerability of forests to the extractive commercial exploitation of wood (different economic value of tree species), to spontaneous forest fires (increased vulnerability of

resinous species to fire in a dry climate, etc.) and to pests and diseases (mono-plantations of exotic species, etc). Very poor soil fertility also provides natural protection against clearing and recurring agricultural practices.

Karstic substratum constitutes just 5.6 per cent of the total Thai Nguyen provincial area, but represents 50 per cent of the dense and open natural forests remaining in the province. Mountainous topography, and a thin topsoil of very low natural fertility make agriculture impossible in these areas. Forest species growing on these karsts are of low commercial value (slender trunks, soft woods, etc). The poor soil substratum confers a natural protection to these forests against agricultural clearings and logging. This natural protection should not be over-estimated. For example, in the neighbouring district of Bac Son in Lang Son Province, forests on karsts were destroyed to collect fuel wood to dry tobacco, cultivated in valleys adjacent to the karstic formations (P. Brabant, personal communication, 1999).

There are also strong correlations in Thai Nguyen province between topography, road networks, hydrographic networks, population density, types of vegetation and soil on one hand, and deforestation on the other hand. With the available information, it would also be interesting to assess the impact of other key causes of forest degradation, such as land tenure and tax systems. With the strong correlations recorded between deforestation and the main causes of forest degradation in Thai Nguyen Province, a follow-up stage in the methodological research on environmental indicators could include the construction of an index of risk of forest degradation through GIS modelling, similar to the approach suggested for the index of risk of soil erosion (see Section 3.2.1).

#### 4.1.2 The Forest and biodiversity loss state index

Selected indicator: Area, Spatial Distribution, Size and Shape of Forests.

##### 4.1.2.1. Description of results

Maps 24, 25, and 26 present the residual forests plots as a function of the indicators of forest size and compactness, and of the index of state of forest vulnerability. Table 49 shows the percentage of forest cover remaining classified in five levels of forest vulnerability - from very low (1) to very high (5).

**Table 49 - Vulnerability of Thai Nguyen's Forests to Degradation**

Vulnerability Classes	Area	% of total forest area	% of total provincial area
1.- Very low	2,431	8.9	0.69
2 - Low	5,780	21.2	1.64
3 - Intermediate	5,431	20.0	1.54
4 - High	8,584	31.5	2.43
5 - Very high	4,981	18.3	1.41
Total	27,207	100	7.71

##### 4.1.2.2 Analysis of results

*Strong forest vulnerability.* Assessment of the state of forests by their density, spatial distribution, size and shape reveals that the residual forest plots are far more vulnerable than a simple representation by density/spatial distribution would suggest. Half of Thai Nguyen Province's dense and open forests is classified as «vulnerable» to «very vulnerable». The remaining undisturbed forests are characterised by intermediate to very low vulnerability, and cover less than 4 per cent of the province's total land surface. In line with the classification outlined in Section 3.1.2, the state of forest degradation can only be viewed as extremely high (class 5).

This state index also highlights those forest plots that are the most likely to disappear in the coming years. Without strong voluntary forest protection policies, only five forest plots on karsts should be expected to survive in the near future in Thai Nguyen Province. Three of these five plots may

subsequently undergo rapid degradation. The future of the dense forests of Tam Dao is more difficult to predict, because they are protected by National Park status. The high fragility of the northern and southern borders of Tam Dao, the high population density in the immediate fringes of the Park and the exponential growth in tourism combine to raise fears of gradual but substantial loss of even this Natural Park resource in the not to distant years to come.

*Weight of the compactness factor in the aggregation equation.* A key element in this analysis of the state of forest vulnerability is the importance given to the concept of compactness. As described in Section 3.1.2, the compactness indicator represents 25 per cent of the total weight of the index of vulnerability. As discussed previously it was decided to give relative importance to this factor, because of its critical role in the mechanisms of forest fragmentation. Given the very strong fragmentation of residual forest plots, the incorporation of this factor result in an index of high vulnerability for nearly one third of the dense and open forests in Thai Nguyen Province.

Map 27 shows the results obtained when increasing the weighting of 'size' from three to four in the aggregation equation of the index of forest vulnerability. In this case, most of the karstic forests and part of Tam Dao would have been classified as having low or very low vulnerability to degradation.

### 4.1.3 The Forest and biodiversity loss response index

#### 4.1.3.1 Description of results

Maps 28 and 29 represent the percentages of reforestation by plantation and afforestation in Thai Nguyen Province in 1993. Map 30 provides the index of total reforestation thus calculated. Statistics concerning natural regeneration are currently very difficult to acquire. Therefore, it was decided to take 1993 as an example, because provincial statistics were available for that year for both reforestation by plantation establishment and afforestation. These district-based statistics are provided in Table 50.

**Table 50 - Areas reforested by plantation and afforested in Thai Nguyen in 1993**

District	Population density	Forest plantations in 1993		Natural regeneration (afforestation) en 1993		Total reforested area in 1993	
	hab./km <sup>2</sup>	ha	%	ha	%	ha	%
Dai Tu	283	563	0.99	1 017	1.79	1 580	2.79
Dinh Hoa	185	361	0.70	636	1.24	997	1.95
Dong Hy	229	503	1.06	66	0.14	569	1.20
Pho Yen	480	113	0.39	311	1.08	424	1.47
Phu Binh	534	159	0.62	0	0.00	159	0.62
Phu Luong	340	124	0.33	1 577	4.22	1 701	4.55
TP Thai Nguyen	1 088	157	0.90	0	0.00	157	0.90
TX Song Cong	665	79	1.48	0	0.00	79	1.48
Vo Nhai	67	192	0.22	910	1.07	1 102	1.30
Total		2 251		4 517		6 768	

Source: Forest Inventory and Planning Institute (FIPI).

#### 4.1.3.2 Analysis of results

*Fairly satisfactory reforestation rates.* On the basis of the statistics provided by the province's forestry department and by FIPI, the reforestation results for Thai Nguyen Province are reasonably satisfactory. In line with the classification detailed in Section 3.1.3, the index of response to deforestation is 4, but comes close to 3. The total reforested area in 1993 (6,768 ha) exceeds the average annual losses in natural forests for the period 1983-1993 (5,232 ha). This is mainly due to the high rate of afforestation in Thai Nguyen Province. The district of Phu Luong, for instance, shows a natural regeneration rate of more than 4 per cent.

The comparison of this afforestation rate with the index of forest pressure requires a degree of caution when it comes to interpreting the results. An annual natural regeneration rate of more than 4 per cent is, indeed, difficult to reconcile with a rate of deforestation of 13.6 per cent in the same district of Phu Luong between 1983 and 1993 (see Map 19). In the absence of complementary data on the definitions adopted by each district in estimating afforestation, it is difficult to conduct a more in-depth analysis of the available data.

*A strategy of afforestation in line with population density.* Most efforts at reforestation through plantation establishment seem to be carried out in districts with high population density, such as the districts of Song Cong and Thai Nguyen in 1993; whereas the highest rates of natural regeneration are encountered in districts that are relatively less populated, such as the districts of Phu Long, Ding Hoa and Vo Nhai.

This approach to reforestation through plantation conforms to the new national forest development strategy that consists of promoting natural regeneration in less populated areas and commercial plantations near urban centres and markets to ensure an acceptable income for small agroforesters.

## 4.2 SOIL EROSION INDICES

### 4.2.1 Soil erosion risk index

Selected indicator: Risk of Soil Erosion, obtained by GIS modelling.

#### 4.2.1.1 Description of the results

Maps 31, 32, and 33 represent the influence of slope, morpho-pedology and rainfall on soil erosion. Map 34 illustrates the inherent vulnerability of the soil to erosion, and was estimated by overlaying these three factors. Map 35 shows the influence of land cover on erosion. And Map 36 provides the index of the risk of erosion obtained by overlaying the inherent soil vulnerability to erosion and the influence of land use on erosion.

#### 4.2.1.2 Analysis of results

*Land cover adapted to the soil's inherent vulnerability to erosion.* About two thirds of the soils in the province of Thai Nguyen demonstrate a strong to very strong inherent vulnerability to erosion. This is because of undulating relief, strong erosivity of the monsoon rains and presence of strongly erodible soil constituents.

But the current risk of soil erosion in the province seems to be limited, because its land cover is generally adapted to the inherent vulnerability of its soil to erosion. For example, soils on schists in the hills and mountainous areas, which are very vulnerable to erosion, are used primarily for recurrent agriculture, and cover 5 to 25 per cent of the terrain. The low erosivity of this type of land cover compensates for its strong vulnerability to erosion. As shown in Table 51, little more than 22 per cent of soils in the province currently present a strong risk of erosion, and only a negligible surface of Thai Nguyen Province seems exposed to a very high risk of erosion, at least in the near future. In line with the classification suggested in Section 3.2.1.4, the risk of erosion in the province of Thai Nguyen is seen as intermediate where 40-60 per cent of the land presents low or very low vulnerability to erosion.

**Table 51 - Soil at risk to erosion in Thai Nguyen, by area**

Erosion Risk	Area	
	Hectares	%
Very low	61 402	17.4
Low	111 251	31.5
Intermediate	102 560	29.0
Strong	77 991	22.1
Very strong	5	0
Total Province	353 209	100

The inappropriate development of fragile lands, meanwhile, can cause major erosion. The development of recurrent agriculture covering 25 to 75 per cent of the land on dystric leptosols in the mountainous area of Vo Nhai District leads to a high risk of erosion. The same causes and the same results are observed in the dystric leptosols of the hills that link the districts of Dai Tu and Phu Long. Appropriate land use management is, therefore, critical in controlling the risk of soil erosion in such areas.

*Weight of land cover in the aggregation equation.* A key element of the analysis of soil erosion risk is the importance attached to land cover. The weight given to land cover is double that of the other factors in the erosion risk index aggregation equation. This weighting reflects the overwhelming importance of vegetation cover as a conditional factor of erosion (Roose, 1994).

A second key element is the evaluation of the influence of recurrent agriculture on soil erosion. Recurrent agriculture is often cited as a major cause of deforestation and of soil erosion in official texts. However, this study considers recurrent agriculture to be only marginally erosive when it covers between 5 to 25 per cent of the terrain. Indeed, it considers that the land thus cleared is quickly and naturally reconquered by low shrubby vegetation that offers good protection to the soil. A lower weight given to land use in the aggregation equation, or a different estimate of the influence of recurrent agriculture on erosion, would have led - in both cases - to a more alarming assessment of the risk of soil erosion in Thai Nguyen Province.

#### **4.2.2 Soil erosion state index**

Selected indicators: Inventory of Visible Signs of Erosion.

##### 4.2.2.1 Description of the results

Based on comprehensive field surveys and interpretation of satellite images, P. Brabant (1999) prepared an inventory of visible signs of erosion and degradation without soil movement in the province of Thai Nguyen. Table 52 provides the results of this inventory, which was prepared for this Programme and carried out using the methodology described in Section 3.2.2.1.

Map 37 was produced based on this analysis. To avoid giving the impression that erosion is the only form of soil degradation existing in Thai Nguyen Province, Map 38 presents locations affected by water erosion as well as areas affected by physical and chemical soil degradation.

**Table 52 - Soil Erosion: Assessment by visual observation**

Index	Level	Erosion status			Remarks
		Dominant type	Intensity	Extent	
1	Very low	Sheet erosion	Low	Low	<i>Upland.</i> Uncultivated forest land, or forest land with little cultivation. Tends to be stable.
2	Low	<b>Sheet Erosion</b> <b>Linear erosion</b>  <b>and Mass erosion</b>	Low High High	Average	<i>Upland</i> - in cultivated or forest land where. ravines are located along routes used to unload logs or for cattle crossing. These ravines occupy less than 0.5% of the area.  Landslides are mainly found along roads or rivers and dykes, and are more common on schist land.
3	Low to average	<b>Sheet Erosion</b>	Low to average	Average to low	<i>Hilly uplands.</i> Covered hills and cultivated plains. Despite their steep slopes, hills are little eroded except for tea plantations. Clearing of hills tends to increase erosion.
4	Average	<b>Sheet erosion</b> and linear erosion.  <b>Sheet Erosion</b> Rare linear erosion and mass erosion	Average	Over 50% of the hills	<i>Hilly uplands.</i> Hills cultivated up to 75%. Water erosion is locally observed to the ravine level. Hills cultivated up to 75% of the area. Erosion on Hills tends to increase.  <i>Uplands.</i> Areas where permanent cultivation occupies between 25 and 75% the soil area. Short fallow periods expose the soil to rain erosion. Gullies and landslides occur on less than 1% of the surface of these areas. Erosion tends to increase rapidly.
5	High	<b>Sheet erosion</b>  <b>Sheet Erosion</b> Linear erosion and mass erosion.	High High	Over 75 %  Over 80 % of the hills	<i>Uplands.</i> Thin layers of highly eroded soil on, or at the top of, steep slopes. Herbaceous cover. Eroded soil tends to stabilise. But erosion may extend to land with insufficient fallow periods.  <i>Cultivated low hills:</i> Highly or totally eroded soil to the alteration layer.

Source: P. Brabant, 1999.

#### 4.2.2.2 Analysis of results

*Low soil erosion.* The percentage of soils in each of the five categories of state of soil erosion is given in Table 53. Three quarters of the provincial soils show little or very little erosion. Only 5 per cent of the province's land can be considered as strongly or very strongly eroded. In line with the evaluation methodology for soil erosion state described in Section 3.2.2, the state of soil erosion is generally estimated as to be low (2) in Thai Nguyen Province. The only places where very strong signs of erosion were detected are some low hills that have been recently retimbered with eucalyptus (P. Brabant, personal communication, 1999).

**Table 53 - Soil Erosion Status in Thai Nguyen by area**

Erosion status	Area (ha)	Percentage
1. Very low	59 449	17
2. Low	201 936	56
3. Intermediate	73 496	21
4. Strong	9 964	3
5. Very strong	6 018	2
Stretch of water	2 366	1
Province	353 229	100

*Importance of land cover.* The results shown in table 53 were most unexpected, given the importance attached to erosion control in existing environmental protection policies in place in Vietnam. They are nevertheless coherent with the results of risk of erosion obtained by GIS modelling. The results also justify the importance given to land cover in the aggregation equation of the index of risk of soil erosion.

These results also seem to validate the weighting given to recurring agriculture for its impact on soil erosion. A major portion of the province, exploited by recurring agriculture that covers between 5 and 25 per cent of the land, does not seem subject to erosion. But the areas of recurring agriculture that cover 25 to 75 per cent of the land, which were estimated to be very vulnerable to erosion (see Section 3.2.2) correspond well to the places where relatively strong erosion was observed during field thruthing. In line with this analysis, recurring agriculture, as it is currently practised in Vietnam (without measures for soil conservation), appears to be viable below a certain intensity; but is inappropriate beyond a certain threshold. When clearings remain limited, the land is immediately recolonised by protective and opportunistic vegetation, given the absence of breaks in the vegetation cycle.

#### 4.2.3 Soil erosion response index

Selected indicator: Percentage of Lands Classified as Forest and Currently Under Forest Cover.

##### 4.2.3.1 Description of results

FIPI considers all land whose slope is steeper than 25 degrees to be forest (FAO, 1996). Generally, the slope is expressed in degrees in Vietnamese documents. The forest coverage of slopes prepared by this Programme is divided into seven categories, with the slope expressed as a percentage and not expressed in degrees (see Section 3.2.1.3). There are two reasons for the use of percentages instead of degrees. First, the percentage of a slope is easier to measure locally by farmers with rudimentary means; and, second, the slope is expressed as a percentage by most international land management studies (P. Brabant, 1999). Table 54 indicates the relationship between degrees and percentage.

**Table 54 - Percentage And Degree of Slope**

Class	Slope expressed in %	Approximate value in degree
1	< 3	< 1.7
2	3 - 8	1.7 - 4.6
3	8 - 15	4.6 - 8.5
4	15 - 25	8.5 - 15
5	25 - 40	15 - 22
6	40 - 60	22 - 31
7	>60	> 31

To estimate Thai Nguyen's forest cover, all the lands whose slope was steeper than 40 per cent (above approximately 22°) were identified. Forested land covers 121,799 hectares, which is about 34 per cent of the province's total surface area. Table 55 illustrates the various types of land cover presently existing on these forest lands.

**Table 55 - Cover of Forested Land with greater than 40% slope**

Land cover code	Cover Type	Size (ha)	%
201	Thick, evergreen, large-leafed, semi-deciduous forest	19,697	16.2
209	Herbaceous or grass land	1,298	1.1
271	Irrigated or rain-fed agricultural zones - green, leafy crops dominate	657	0.5
272	Irrigated or rain-fed agricultural zones - diverse crop cultivation	3,219	2.6
331	Recurring agriculture lands - recent fallow covers 5 to 25%	66,250	54.4
332	Recurring agricultural land - recent fallow covers 25 to 75% of the land	16,554	13.6
341	Mosaic of agricultural and forest land - cultivated perennial crops dominate	2,917	2.4
342	Mosaic of agricultural and forestry land - plantations and fallow land dominate	7,637	6.3
-	Other	3,566	2.4
<b>Total</b>		<b>121,799</b>	<b>100</b>

#### 4.2.3.2 Analysis of results

*Good vegetation cover on steep land.* Only 16 per cent of land classified as forest in Thai Nguyen Province is actually under the cover of non-disturbed forest. This result may give the impression that the remaining 84 per cent of steep land in the province is exposed without defence to the mechanisms of soil erosion. This impression is immediately corrected when it is considered that land protected from erosion comprises that under forest cover and also that which benefits from a very good vegetation cover. So, if land that is under recurrent agriculture covering 5 to 25 per cent of the terrain (code 331) and land which presents a mosaic of agriculture and forestry with a dominance of forestry plantations and fallow (code 342) are added to the forest area (Code 201), it appears that 76.8 per cent of Thai Nguyen's steep land are effectively protected from all erosion by cover of dense shrubs or tall grasses. This largely explains the very low state of soil erosion observed in the province.

*A classification of forest lands little adapted to the erosion control requirements.* In line with the national strategy of reforestation of forest lands to control soil erosion, this Programme used the percentage of land under forest cover as an index of response to soil erosion. Since only 16 per cent of the land classified as forest in Thai Nguyen Province is currently under dense forest cover, this index gives a response of 5 (very poor) to soil erosion in the province. It was obvious from field truthing that such a result does not reflect the good protection provided by the cover of dense shrubs or tall grasses to a substantial majority of the steep lands in the province.

Rather than systematic reforestation, an effective soil erosion control strategy should attempt to maintain a good vegetal cover on sloped terrain. In line with such a strategy, an index that is more adapted to a realistic response to soil erosion would be the percentage of sloped land protected by good anti-erosive vegetation cover. In this case, an index of response to soil erosion in the province of 2 (good) for the province, very close to 1 (very good), would be obtained.

*A daunting task.* Forest lands represent more than one third of the total area of the province (see Table 55). To reforest all classified forest land would require a total reforestation of 102,101 hectares. This figure must be put in the context of total official reforestation of 6,768 ha in 1993, and an average annual loss of 5,232 hectares between 1983 and 1993 in Thai Nguyen Province. Even taking as reference the forest surplus of 1993 for which some reservations on this value have already been expressed, it would take almost 70 years to provide actual forest cover to all land currently classified as forest land in Thai Nguyen Province.

Moreover, such a systematic reforestation policy is not necessarily desirable. The present forest policy classifies land areas cleared long ago and now used for food production as forest. To expect that upland farmers will agree to reconvert these arable lands to plantations for the sake of erosion control would be unrealistic.

An alternative to solving the difficulties associated with the present land classification system would be to shift the focus of the classification from the degree of the slope to the types of land cover. Depending on the depth of topsoil, many types of land cover allow a sustainable development of land with a slope of up to 60 per cent. Consequently, one option would be to push the limit of lands designated exclusively for forestry back to 60 per cent, and to authorize certain types of cover that are more flexible and better adapted to realities of the agrarian system and current realities in the uplands of Vietnam on land with slopes of 40 to 60 per cent.

The total surface of sloped lands above 60 per cent is 45,236 ha in Thai Nguyen Province. Although it is still a daunting task, the systematic reforestation of only that land with slopes greater than 60 per cent seems to be a policy that would be more appropriate to the current erosion control conditions of the Vietnamese Tropical Uplands.

### 4.3 WATER RESOURCE DEGRADATION INDICES

#### 4.3.1 Water shortage risk index

Selected index: Intensity of Use of Water Resources (%).

##### 4.3.1.1. Description of results

A comprehensive analysis of Thai Nguyen Province's water resources would require data to be available on a daily basis over the longest period of time possible, using the greatest number of hydrological stations and parameters possible.

Hydrological data are disparate and of limited reliability in Vietnam (WMO, 1994). Moreover, such data are often classified as confidential. This Programme was obliged to restrict its use to the very limited hydrological data made available by the national Hydrometeorological Service (HMS). Only two of the nine hydrological stations recorded in the database of this Programme provide the basic information necessary for an analysis of the annual renewable water supply. Moreover, these data are aggregated in the form of averages for various periods.

Given these constraints, this study cannot pretend to be a complete analysis of Thai Nguyen Province's annual renewable water supply. It simply aims to illustrate the approach suggested for the construction of the risk index for water shortage. Much caution therefore is suggested when in interpreting these results.

##### *a. Annual renewable water supply of the two largest catchments of Thai Nguyen*

This Programme's GIS gives the following terms for the hydrological balance for the Cau and Cong watersheds at the hydrological stations of Thac Buoï and Tan Cuong (Report of this Programme, under HYDRO):

**Table 56 - The hydrological balance of the Song Cau and Song Cong watersheds**

<b>ID</b>	<b>Station</b>	<b>River</b>	<b>SB</b>	<b>P</b>	<b>E</b>	<b>S</b>	<b>P</b>	<b>R</b>
2	Thac Buoï	Cau	2220	1560	857	526	177	703
9	Tan Cuong	Cong	548	1867	949	796	122	918

Where:

- ID = identification number of the hydrological station;
- SB = catchment area (km<sup>2</sup>);
- P = amount of precipitations (mm);
- E = amount of evaporated water (mm);
- S = amount of run-off water (mm);
- P = amount of percolating water (mm);
- R = total amount of water flow (mm).

Given the crucial importance of the total catchment area in calculating annual renewable water supply, this study calculates the respective areas for the two watersheds using the GIS cover for the hydrographic network and the digital land model. A total surface area of 2,212 km<sup>2</sup> for the Song Cau section in Thai Nguyen Province, and 976 km<sup>2</sup> for the basin of Song Cong, within Thai Nguyen Province were obtained. The area calculated by the GIS for the catchment of Song Cong differs quite significantly from that provided by the hydrological database (548 km<sup>2</sup> instead of 976 km<sup>2</sup>). Since the hydrological station of Tan Cuong is located near the centre of the Cong watershed, it is possible that the figures provided by the Hydrometeorological Service refer only to that part of the Cong watershed upstream of the Tan Cuong station. This study uses an area of 976 km<sup>2</sup>, as calculated by GIS analysis.

While the Cong river watershed is contained entirely within the province of Thai Nguyen, the Cau River also drains part of Bac Can province (see Maps 39 and 40). Assuming that one of the sustainable water resource management objectives of Thai Nguyen Province will be to restrict its water consumption to water resources produced within the province, the analysis of annual renewable water supply and withdrawal from the Song Cau basin is limited to the portion which drains into the province of Thai Nguyen.

The annual renewable water supply (AA) of the two watersheds is estimated by the following equations:

$$\begin{aligned} AA_{\text{Cau}} &= R * SB * 1000 \\ &= 703 * 2216 * 1000 \\ &= 1,557,848,000 \text{ m}^3/\text{year} \end{aligned}$$

and

$$\begin{aligned} AA_{\text{Cong}} &= 918 * 976 * 1000 \\ &= 895,968,000 \text{ m}^3/\text{year} \end{aligned}$$

*b. Annual water withdrawal in the two largest watersheds of Thai Nguyen Province*

This value estimates the agricultural, industrial and domestic water consumptions based on the land cover maps produced by this Programme, and the data provided in the reports of the provincial government's environment and agriculture departments.

*Agriculture.* Agriculture is by far the largest user of water in the tropical uplands of Vietnam. The environmental report of the province of Thai Nguyen estimates that agricultural water withdrawal ranges from 0.8 to 1 billion m<sup>3</sup> per annum. Based on the land cover map and statistical data on the total irrigated area provided by the Department of Irrigation, this estimate can be further refined

The land cover data by watershed obtained by overlaying the land cover and the watershed maps is shown in Table 57.

**Table 57 - Land Cover in the Cong and Cau Watersheds (Ha)**

Land cover	Cong watershed	Cau watershed	Total area (ha)
Evergreen dense, or semi-deciduous, Forest	5,027.18	18,709.39	23,736.57
Herbaceous vegetation	1,652.42	757.53	2,409.95
Irrigated agriculture zones in the plains	19,759.87	17,984.20	37,744.08
Irrigated agriculture zones in mountain valleys	887.43	5,603.87	6,491.29
Irrigated and rain-fed agricultural zones - crop cultivation dominant	1,845.75	983.97	2,829.73
Irrigated and rain fed agricultural zones - diverse production systems	12,927.80	33,233.10	46,160.90
Recurring agricultural land - crops and recent fallow covering from 5 to 25 % of the land	20,711.20	81,997.94	102,709.14
Recurring agricultural land crops and recent fallow covering from 25 to 75 % of the land	8,619.96	16,677.40	25,297.36
Mosaic of agricultural and forest land with perennial crop cultivation dominant	6,858.25	5,679.82	12,538.08
Mosaic of agricultural and forest land with fallow and plantation dominant	13,574.06	31,514.44	45,088.50
Urban settlements	0.00	829.14	829.14
Rural houses with gardens	2,626.46	5,574.80	8,201.26
Open mining	128.56	451.40	579.96
Rivers and streams	584.25	841.18	1,425.43
Ponds and lakes.	2,439.86	568.38	3,008.24
<b>Total</b>	<b>97,643.07</b>	<b>221,406.57</b>	<b>319,049.63</b>

Source: After the land cover map produced by STD3-CT94-0310 programme.

The analysis of agricultural water use considers only the consumption of irrigated rice plots located in plains and in the mountainous valleys. An irrigated area of 23,587 ha in the Song Cau basin and 20,646 ha in the Song Cong basin, giving a total of 44,233 ha for Thai Nguyen Province, is therefore obtained. These figures are compared to the irrigated areas reported by the Province's Department of Agriculture (DART) and reproduced in Insert 6. It is not surprising that the irrigated area estimated by remote sensing is higher than that estimated by the Province's Agricultural Service, because the huge number of small perimeters make accurate estimation difficult (44,233 against 33,500). However, this 25 per cent difference might lead to a possible over-estimation of agricultural water consumption.

#### **Insert 6 : Agricultural water infrastructure in Thai Nguyen**

Number of irrigation systems: 2,027

Irrigation capacity:

- Winter/spring rice: 21,500 - 22,000 ha
- Monsoon rice: 33,000 - 33,500 ha

From the following water bodies/dams:

- Nui Coc Lake: 5,551 ha (capacity of 170 millions m<sup>3</sup>);
- Thai Huong dam: 2,400 ha
- 270 small dams: 6,099 ha
- 97 run-of-the-flow dams: 3,517 ha
- 144 pumping stations: 3,814 ha
- 1 514 temporary ponds: 5,486 ha

In addition to the irrigated areas in Thai Nguyen Province, Nui Coc dam and the other rivers located in the Song Cong watershed are reported to irrigate nearly 14,000 ha in the neighbouring province of Bac Giang (DART, after M. Silver, 1999). This figure of 14,000 ha appears to be very high given Nui Coc's estimated effective irrigation capacity of 11,500 ha. Therefore, only the figure of 6,000 ha, which corresponds to the difference between the capacity of effective irrigation of Nui Coc and the total land surface of Thai Nguyen Province irrigated from this dam, is used. A total surface area of 50,233 ha irrigated by the waters of Song Cau and Song Cong, including 44,233 ha in Thai Nguyen Province, is thus obtained. It is, nonetheless, to be remembered that this estimate can lead to an under valuation of agricultural consumption of waters from the Song Cong watershed. It is thus necessary to take this condition into account in the analysis of the results of water resource usage.

Based on the Penman-Montheih formula to calculate potential evapo-transpiration, the annual water demand for one hectare of irrigated rice was estimated to be 8,440 m<sup>3</sup> (see calculation details in Appendix VIII). This gives the following annual agricultural water consumption in both watersheds.

**Table 58 - Agricultural water consumption**

<b>Watershed</b>	<b>Irrigated area (ha)</b>	<b>Water consumption (m<sup>3</sup>/ha/annum)</b>	<b>Total consumption (m<sup>3</sup>)</b>
Cau	23,587	8,440	199,074,280
Cong	20,646	8,440	174,252,240
Bac Giang from Cong river	6,000	8,440	50,640,000
<b>Total</b>	<b>50,233</b>	<b>-</b>	<b>423,966,520</b>

*Industrial consumption.* Although the industrial sector represents only 4.7 per cent of economic activity in Thai Nguyen Province, the province's environmental report estimates that industrial water withdrawal is 345 million m<sup>3</sup>/year. This particularly high figure may be explained by the large water demands from provincial coal, paper and steelwork industries. Thus, 69 million m<sup>3</sup>/year is consumed only by the steelwork of Thai Nguyen city (UNIDO/Safège, 1994). The industrial and domestic water consumption of Thai Nguyen city was estimated at 7.2 m<sup>3</sup>/s by UNIDO and Safège in 1994, or close to 240 million m<sup>3</sup>/year.

Most of the industrial water is quickly returned to the hydrological system, and can be reused after natural purification of the pollutants. For the purposes of this purely indicative exercise, it is assumed that two-thirds of the water consumed by industry is returned to the hydrological system. The total industrial demand is then divided by three, and is estimated at 115 million m<sup>3</sup> per annum. The town of Thai Nguyen is situated between the Cau and Cong rivers. Most of the city's drinking water supply is provided by ground water and by the Nui Coc canal, which is supplied from the Song Cong catchment (UNIDO/Safège, 1994). It is estimated that three quarters of the water consumed by industry in Thai Nguyen Province originates from the Song Cong catchment.

*Domestic consumption.* Thai Nguyen's environmental report estimates domestic water consumption at 50 million m<sup>3</sup> per annum. This figure is substantially higher than the norms of water consumption in Vietnam, which are 50 litres per day per capita in rural areas, and 60 litres per day per capita in urban areas. This high figure for the province could also reflect livestock water requirements. But in the absence of additional information on this very high reported domestic demand for water, the national standards were adopted for this study's estimate of domestic water consumption which gives a total demand of 18,250 million m<sup>3</sup>/year (daily consumption per capita 50 litres x total provincial population 1,000,000 x 365 days per year). As estimated for industrial water, it is estimated that two thirds of domestic water is quickly restored to the hydrological system.

On the basis of these very tentative hypotheses, the annual water consumptions in the province are shown in Table 59.

**Table 59 - Water Shortage Risk Index**

Water -shed	Annual renewable supply (m <sup>3</sup> )	Agricultural consumption (m <sup>3</sup> )	Domestic consumption (m <sup>3</sup> )	Industrial consumption (m <sup>3</sup> )	Total consumption (m <sup>3</sup> )	Water resource use (%)	Index rating of water resource use
Cau	1,557,848,000	199,074,280	1,500,000	28,750,000	229,324,280	15	2
Cong	895,968,000	224,892,240	4,500,000	86,250,000	315,642,240	35	4
Total	2,453,816,000	423,966,520	6,000,000	115,000,000	544,966,520	22	3

#### 4.3.1.2 Analysis of results

As indicated in this chapter's introduction, considerable caution should be exercised in the interpretation of these results, based on fragmented hydrological data. Therefore, the assumed hypotheses for water consumption gives a 22 per cent utilisation of annual renewable water supply in Thai Nguyen Province, and a 35 per cent utilisation for the Song Cong watershed. This reflects a strong water pressure for the entire province, and a strong potential water shortage for the Song Cong watershed.

Although lower than the estimates of Thai Nguyen's Department of the Environment, these extremely high results for pressure on provincial water resources are unexpected. This situation poses a very strong public health risk because of the potential reduction of the natural purification capacity of the provincial water bodies. It also raises the possibility of conflict between water users for an increasingly scarce resource, of over-sizing irrigation perimeters, of over-exploitation of groundwater resources and of degradation of the aquatic ecosystem. If a comprehensive hydrological survey were to confirm these results, water could become the most important limiting environmental factor for the development of Thai Nguyen province.

#### 4.3.2 Water shortage state index

Selected index: number of months of water shortage with regard to the minimum flow.

##### 4.3.2.1 Description of results

###### a. Monthly flows of Song Cau and Song Cong

The flows of the Cau river and Cong river at the hydrological stations of Thac Bui and Tan Cuong are given in Table 60. The Tan Cuong station is located at the centre of the Song Cong watershed, and is believed to measure only part of the total drainage of the basin (see Map 8). For the purposes of this study, theoretical monthly flows of Song Cong at the catchment outlet (Cong equivalent) were calculated, based on the watershed total water flow and monthly percentages of flows measured at Tan Cuong. These theoretical flows also appear in table 60.

**Table 60 - Flows of Song Cau and Song Cong (M<sup>3</sup>/S)**

River	Period	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cau	1960-85	12.5	11	11.4	22.8	43.5	82.1	104	134	96.6	48.7	29	15.6
Cong	1961-76	2.92	3.15	3.5	8.7	14.8	23.4	25.8	39.2	31.2	17.7	8.65	3.86
Cong equivalent		5.43	5.85	6.51	16.18	27.52	43.52	47.98	72.91	58.03	32.92	16.08	7.17

###### b. Calculation of the minimum flow

The minimum flow must make it possible to respond to all the demands exerted on the water resource: irrigation, industrial development, human consumption, maintenance of aquatic life, waste purification, recharge of ground water, energy, transport and recreation (see Section 3.2.2).

*Agricultural minimum flow.* The construction standards for irrigation works in Vietnam stipulate that they must be able to provide a peak output of 0.8 l/s/ha to the plot for tillage before rice planting. A study of irrigation practices in the Red River Delta estimates the peak output necessary to be 0.63 l/s/ha for the winter/spring rice and to be 0.78 l/s/ha for the monsoon season rice (MOSTE/UNDP, 1995). For the province of Thai Nguyen, a peak output of 0.6 l/s/ha for the winter/spring rice is assumed. Given an assumed average effectiveness of irrigation of 70 per cent, this gives a total water demand of 0.86 l/ha/s for rice cultivation during the low dry season flow.

*Industrial and domestic minimum flow.* The preceding chapter estimated domestic water requirements to be 18,250,000 m<sup>3</sup>/an. The Provincial Department of the Environment estimates industrial water requirements to be 345,000,000 m<sup>3</sup>/an, most of it to meet the needs of Thai Nguyen city. As indicated, this high demand seems to be confirmed by the drinking water supply review in Thai Nguyen carried out by UNIDO and Safège. The industrial and domestic demands are considered to be stable throughout the year and were converted directly into l/s.

*Minimum flow for other freshwater services.* For the purpose of this purely indicative study, the minimum flow necessary to sustain all other freshwater services is assumed to be half the average low dry season flow. This minimum flow corresponds to a flow that could normally be met during a dry year.

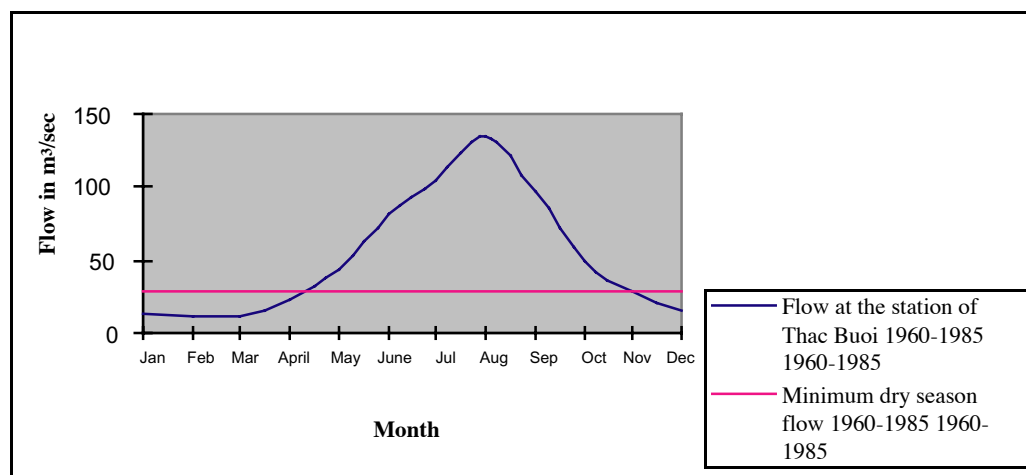
On the basis of these assumptions, the results in the Table 61 were obtained.

**Table 61 - Minimum flows for Song Cau and Song Cong**

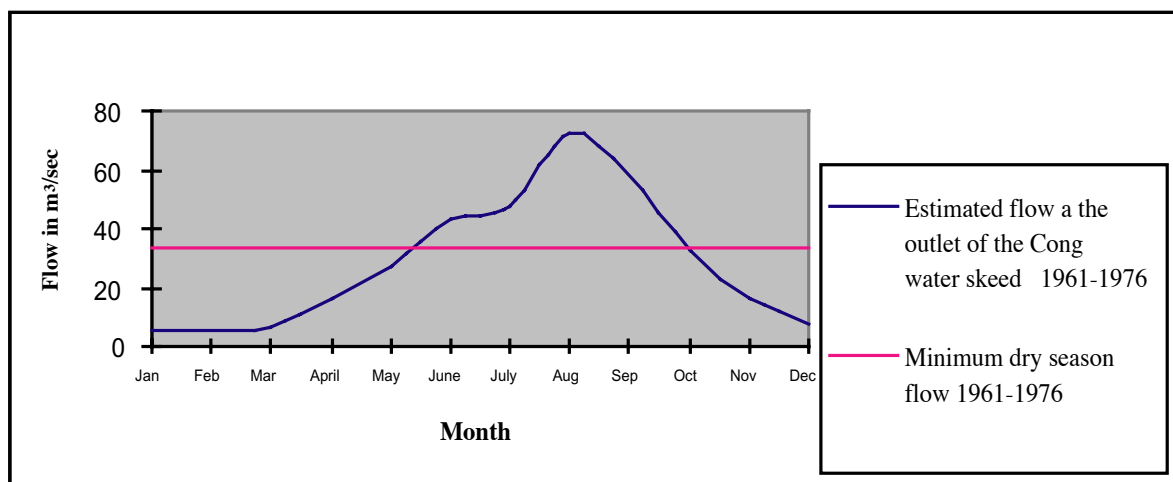
Watershed	Irrigated area (ha)	Peak output during the low dry season flow (l/ha/s)	Minimum flow for irrigation (l/s)	Minimum flow for industry (l/s)	Minimum flow for drinking water supply (l/s)	Other freshwater services	Total desirable minimum flow (l/s)
Cau	23,587	0.86	20,284	2,735	390	6,000	29,409
Cong	20,646	0.86	17,756	8,205	190	1,500	27,651
Bac Giang from Cong river	6,000	0.86	5,160	-	-	-	5,160
<b>Total</b>	<b>50,233</b>		<b>43,200</b>	<b>10,940</b>	<b>580</b>	<b>7,500</b>	<b>62,220</b>

These estimates provide the results shown in figures 21 and 22.

**Figure 21 : Importance of Water Shortage Periods of the Cau River**



**Figure - 22 Importance of Water Shortage Periods of the Cong River**



#### 4.3.2.2 Analysis of results

The analysis of the two minimum flow charts shows periods of water deficit of more than 5 months/year for Song Cong and of almost 4 months/year for Song Cau.

**Table 62 - Water Shortage State Index For The Cong and Cau Watersheds**

Watershed	Number of Months with deficit > 20% of desirable minimum flow	Index of status of duration and degree of water shortage
Cau	> 3 months	3
Cong	>5 months	5

It must be stressed that the deficits calculated here are purely theoretical, because they do not take into account the existing infrastructure for regulating flows in Thai Nguyen.

As indicated by the ombrothermic diagram (Figure 16), there is no month where crop production is limited by climatic conditions. The potential water shortage in Thai Nguyen Province reflects the strong dependence of the provincial farming system on irrigated rice cultivation. The next section discusses the importance of flow-regulating infrastructures to limit water shortages during the low dry season flow.

#### 4.3.3 Water shortage response index

Selected indicator: capacity to sustain the minimum flow.

##### 4.3.3.1 Description of results

a. *An estimate of the effective volume stored in the reservoirs of Thai Nguyen*

The statistics for water control in the province (see Insert 6) speaks of 270 small reservoirs irrigating 6,100 ha in addition to the Nui Coc and Thac Huong dams. It is assumed that the 1,514 temporary reservoirs, located by DART, are dry during the low flow period.

In the GIS database, “Dams” provide only the name and the geographical location of 38 reservoirs in Thai Nguyen Province. Information on the capacity of these dams is not included. This study therefore relies on the Ministry of Agriculture and Rural Development’s rural infrastructure database. That database records only the reservoirs that are directly supervised by DART given their size or their management complexity. It does, though, cover the whole of Vietnam. Based on DART’s database, Table 63 shows the effective volumes stored and the surfaces irrigated by 14 reservoirs in Thai Nguyen Province and Bac Can Province.

This list of rural water infrastructure provides an average volume stored per irrigated ha of 13,227 m<sup>3</sup> for Nui Coc dams, and of 7,464 m<sup>3</sup> for smaller reservoirs. By assuming an average of 7,500 m<sup>3</sup>/ha for the small reservoirs, and assuming that two thirds of them are located on the Cau watershed and one third in the Cong's watershed, the provincial storage capacity is estimated as follows.

$$\begin{aligned} \text{Cong Basin} &: 168,000,000 + (2,033 * 7,500) = 183,247,500 \text{ m}^3 \\ \text{Cau Basin} &: 6,466 * 7,500 = 48,495,000 \text{ m}^3 \end{aligned}$$

**Table 63 - Effective Storage Capacity of Reservoirs in Thai Nguyen and Bac Kan Provinces**

	Name of the reservoir	Irrigated land (Ha)	Volume (Million m <sup>3</sup> )	Total Volume (Million m <sup>3</sup> )
1	Nui Coc	11,500	168	224
2	Bao Linh	740	6.9	8
3	Phuong Hoang	270	2.15	2.3
4	Quan Che	360	2	2.5
5	Binh Son	359	2.4	2.7
6	Doan Uy	195	0.87	0.9
7	Ban Co	25	0.22	0.24
8	Khuon Nanh	30	0.79	0.8
9	Na Mat	85	0.8	0.85
10	Tan Kim	108	0.8	0.9
11	Tan Hoa	234	1.7	1.9
12	Phó Xuyen	222	1.2	1.3
13	Lang Gay	45	0.2	0.24
14	Cap Ke	84	0.55	0.58
Total		14,257	188.58	247.21

It is also assumed that stored volumes are released regularly during the five months of low water (December-April) to maintain the minimum level of low water flow desired. These results are detailed in Table 64.

**Table 64 - Water Shortage Response Index**

Basin	Volume of stored water (m <sup>3</sup> )	Volume that is necessary to maintain the adequate minimum water outflow	Maintaining Capacity of minimum outflow (%)	Maintaining Capacity Index of minimum outflow
<b>Cau</b>	48,495,000	189,950,000	25.5	4
<b>Cong</b>	183,247,500	381,687,000	48	3
<b>Thai Nguyen Province</b>	231,742,500	571,637,000	41	3

#### 4.3.3.2 Analysis of results

##### a. *Water, a factor limiting the development of Thai Nguyen?*

Existing reservoirs can provide only part of the water required to sustain the minimum flow necessary to preserve all the vital services provided by freshwater systems during the period of low dry season flow. The estimate of the minimum flow was based on the peak output necessary for irrigated rice cultivation. It is understood that rice planting can be spread out over several weeks in order to reduce the total peak output. Furthermore, stored water can also be restored gradually according to fluctuations in agricultural demand for water.

It would seem therefore that water volumes stored by existing reservoirs are neither sufficient to compensate for the seasonal variability in precipitation, nor to maintain the minimum flow necessary to preserve all of the vital functions of freshwater systems during the low flow period.

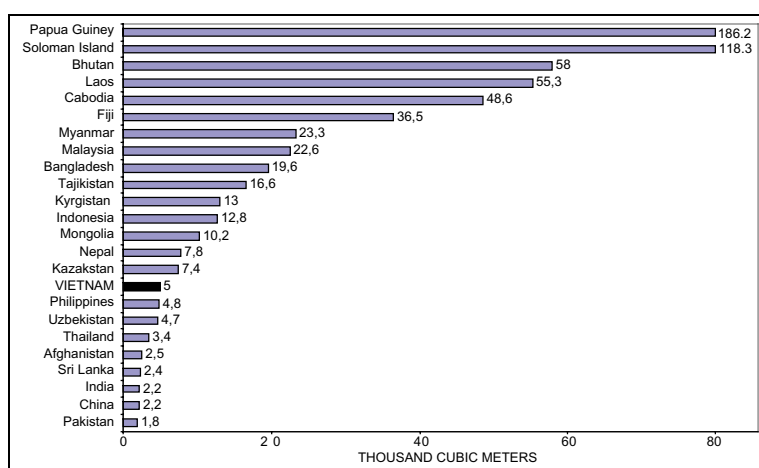
The results of the rudimentary simulation in the preceding section suggests that the province of Thai Nguyen uses almost all its water supply during the low flow period, and can irrigate only part of its rice production areas for the winter/spring crops. Water could therefore be the principal factor limiting agricultural production for the province. Reduced water resources could also constrain the province's industrial development.

These results are unexpected and do not fit with the traditional image of a monsoon country with abundant water resources. It will be recalled that on the basis of the climatic factors alone, there is no month in the year when vegetation growth is limited. The province's high water consumption is directly related to the significant water requirements for rice cultivation, which needs to be kept immersed most of the time for its growth. It should also be noted that the problem of insufficient water shortage, even in the northern areas of the province that benefit from heavy precipitation, was already indicated in a number of rural development studies as well as in some international water resource comparisons.

P. Lamballe (GRET, 1999) produced the following diagnosis of agricultural development in the district of Tam Dao (a section of Tam Dao located in the province of Phu Tho): "*The follow-up-diagnostic and the experiments on rice (densities, varieties, fertilisation) show that water constitutes the principal factor limiting production. For the rice of spring 1994 and 1996, framers had to wait two months before replanting. The diversification of our actions as from 1994 indicates that the problem of water remains as important for the winter dry season cultivation as it is in spring*".

On the same note, a comparison of the water resources carried out by the Asian Development Bank reveals that Vietnam has one of the lowest water resources per capita in Asia. This point is illustrated in Figure 23.

**Figure 23 - Annual Renewable Water Supply per capita ( x 1 000 m<sup>3</sup>)**



The Chairman of the Provincial People's Committee of Thai Nguyen Province initiated a consultation process with the provinces of Bac Can, Vin Phuc, Bac Giang, Bac Ninh and Hai Duong, through which 220 km of the Cau River flows, to establish a common strategy for the sustainable protection of water

and the environment. This initiative is justified by an increasing concern for the sustainability of the current management of this water resource (CNFMEE, 1999).

b. *The construction of reservoirs - a priority investment for the sustainable development of Vietnam?*

As discussed in Section 3.3.3, the regulation of seasonal hydrological flows is critical to reducing the frequency of floods and droughts, and to maintain a minimum flow to preserve the vital functions of freshwater ecosystems during the dry season in Vietnam. Given the crucial role that reservoirs can play to control seasonal flows and Vietnam's very low storage capacity, it would be tempting to recommend an acceleration of investments in water regulation infrastructure. The results provided by this study of the capacity to maintain a minimum flow in Thai Nguyen Province call nevertheless for certain prudence in this regard. Despite the construction of a high capacity reservoir at Nui Coc, it would seem that the most important water shortage risks are found in the Song Cong basin. Waters from Nui Coc seems to have been entirely absorbed by a corresponding increase in agricultural, domestic and industrial water demands. If this assumption were to be confirmed, the construction of a reservoir at Nui Coc would have resulted mainly in an increased pressure on water resources - but not in an increased maintenance capacity of minimum flow during low-flow periods.

c. *Need for a comprehensive analysis of water resources*

Because of data limitations, the results of this hydrological analysis are extremely tentative. Pressure on water resources and water shortages could be substantially over-estimated for the following reasons:

- Under-estimation of annual renewable water supply and of the flows of Cau and Cong rivers calculated based on fragmented hydrological data.
- Over-estimation of irrigated areas by remote sensing.
- Over-estimation of water demands for rice perimeters in the context of Vietnam's uplands using the software CROPWAT.
- Under-estimation of the percentage of agricultural, industrial and domestic water immediately returned to the hydrological system after use.
- Under-estimation of the number and the effective storage capacities of existing reservoirs.

However, it should be noted that water shortages could also have been under-estimated for the following reasons:

- Over-estimation of the effectiveness of irrigation systems in Thai Nguyen province.
- Under-estimation of the areas of Bac Giang irrigated from the Nui Coc reservoir and Son Cong.
- Recent increase in the seasonality of the hydrological cycle because of deforestation not reflected in available data.
- Reduction in storage capacity of reservoirs because of sedimentation.
- Insufficient maintenance of the reservoirs and progressive reduction in their storage capacity. Because of inadequate human and financial means to ensure effective maintenance of the infrastructure, many reservoirs in the rural areas are quickly degraded and store only a third or a half of their theoretical effective volume (M. Silver, 1999).

Conclusions reached through data analyses too often recommend additional studies to confirm or reject the results obtained and to further analyse several important issues. Because of the importance of water resources for sustainable development and of existing uncertainties concerning this resource, this study finds itself compelled to comply with this time-honoured practice, and to recommend a follow-up programme to assess water resources in these pilot provinces.

A good knowledge of water resources and of their uses in Thai Nguyen Province is essential for the controlled release of reservoir water in response to the fluctuations in agricultural demand. Improved sharing of this resource among the various users is also essential to avoid a significant degradation of

water quality, and of the diversity and productivity of freshwater ecosystems due to unsustainable abstraction rates.

Most environmental protection efforts in Thai Nguyen Province currently focus on soil erosion control, although the actual risk may be minimal. But the available data suggests that the importance of water resource conservation for the sustainable development of the province appears to be underestimated.

## 4.4 WATER POLLUTION INDICES

### 4.4.1 Water pollution risk index

Selected index: Faecal Waste Emissions

#### 4.4.1.1 Description of results

Map 41 shows the spatial distribution of the risk of faecal contamination, and was obtained by overlaying population density and sanitary practices. In accordance with the Drinking Water Supply and Sanitation review in Thai Nguyen Province led by DANIDA and CERPAD (1997), the following geographical distribution of sanitary practices was identified for the construction of the faecal contamination risk index:

- Double vault composting latrines and a small number of septic tanks in urban areas.
- One-vault latrines in rural plains and low hill areas.
- Open air defecation and a small number of latrines with a single pit in the Uplands.

#### 4.4.1.2 Analysis of results

*A moderate but not negligible risk of faecal contamination.* A moderate risk of faecal contamination exists along the entire length of the Cau river. This risk is strong to very strong in the districts of Thai Nguyen and Pho Yen. The mountainous zones seem relatively protected in spite of the prevalence of open air defecation, primarily as a result of the low population density.

*Importance of sustaining a minimum flow.* The flow of the Cau River exceeds 100 m<sup>3</sup>/s during the rainy season. It can reasonably be estimated that the waters of the Cau River<sup>15</sup> rapidly assimilate faecal emissions during this period. During the rainy season, the main precaution would be to avoid extracting water for human consumption directly from the high-risk river sections of Thai Nguyen, Dai Tu, Dinh Hoa and Pho Yen districts.

However, a strong risk of faecal and organic contamination could also exist during the dry season when the flow of the River Cau does not exceed 10 - 12 m<sup>3</sup>/s. In the absence of water treatment stations, the best protection will continue to consist of maintaining a minimum flow to preserve the natural purification capacity of surface water.

*Use of human excreta for agriculture.* Human excreta, or night soil, are commonly used as manure in northern Vietnam, particularly for market gardens. Night soil is covered with ash and soil to reduce the odour for a period of between 1 and 5 months. It is then spread immediately before sowing. Non-composted excreta are particularly dangerous for public health.

To reflect the impact of the spreading of non-composted night soil on the faecal contamination of water, this practice could be considered equivalent to open air defecation. An average to strong risk of faecal contamination would have been obtained in this case for the entire course of the Cau and Cong rivers. This issue is taken into account in the analysis of the state of water pollution below.

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<sup>15</sup> UNIDO/Safege estimate Thai Nguyen City's consumption at 7.2 m<sup>3</sup>/s (1994). Even if this amount is returned to the hydrological network with a BOD of 30 mg/l, the pollution load will be immediately reduced to 2-3 mg/l by dilution.

## 4.4.2 Water pollution risk index

### 4.4.2.1 Description of results

Table 65 provides the annual incidence of diarrhoea by district in Thai Nguyen Province between 1996 to 1998. In line with these results, Map 42 represents the state of faecal contamination in children less than five years old in Thai Nguyen Province. It was decided to show the incidence of diarrhoea in children less than five years old in Map 42, since this group is particularly sensitive to faecal contamination of water and therefore provides a precise proxy indicator. This allows a better spatial analysis of faecal contamination in the pilot province.

**Table 65 - Incidence of diarrhoea in Thai Nguyen from 1996 to 1998 in children under five years old, and over five years old (No/100 000 pop./an)**

District	Incidence rate 1996		Incidence rate 1997		Incidence rate 1998		Average incidence rate from 1996 to 1998		State index of faecal pollution	
	< 5 ans	> 5ans	< 5 ans	> 5ans	< 5 ans	> 5ans	< 5 ans	> 5ans	< 5 ans	> 5ans
Dai Tu	794	160	853	407	398	78	682	215	2	1
Dinh Hoa	439	206	717	142	586	216	581	188	2	1
Dong Hy	1,349	614	1,293	565	2,226	704	1,623	628	3	2
Pho Yen	2,377	561	1,750	478	1,906	6	2,011	348	4	1
Phu Binh	1,541	352	1,021	488	1,466	339	1,343	393	3	1
Phu Luong	889	395	1,015	465	877	487	927	449	2	1
TP Thai Nguyen	1,610	229	1,488	338	654	262	1,251	276	3	1
TX Song Cong	1,113	462	2,171	485	1,580	533	1,622	493	4	1
Vo Nhai	2,346	560	1,269	531	964	562	1,526	551	4	2
Total	1,351	358	1,179	397	1,127	393	1,211	383	3	1

Source: Provincial Health Department of Thai Nguyen (august 1999).

DANIDA and CERPAD refer to important differences in quality and reliability of the statistics of public health at the provincial level. To put these figures for diarrhoea into perspective, Map 43 shows the incidence of intestinal worms in Vietnam. These incidence rates were determined by a parasitologic study led by UNICEF and the National Institute of Nutrition (1995). The incidence of intestinal worms is directly related to sanitation practices and constitutes an excellent additional indicator of faecal contamination (RRDM, Public Health, 1995).

### 4.4.2.2 Analysis of results

*Contradictory results.* The average incidence of diarrhoea in Thai Nguyen Province from 1996 to 1998 was 1,211 per 100,000 inhabitants among children less than 5 years old; and 383 per 100,000 inhabitants for the rest of the population. This incidence rate for the rest of the population, which is substantially lower than the national average of 1,327 (1995), suggests a very low faecal contamination of water. This result would mean that the purification capacity of the Cau and Cong rivers is sufficiently strong, and that water supply and sanitation systems are sufficiently reliable to substantially reduce the impact of faecal contamination in high population density areas in Thai Nguyen Province.

This result differs significantly from the findings of the parasitologic study conducted by UNICEF and the National Institute of Nutrition (1995). That study found a rate of 80.6 per cent of hookworm present in a population test at Bac Thai (the former province combining the current provinces of Thai Nguyen and Bac Can). This is the second highest rate in Vietnam after the province of Ha Tinh. UNICEF and the

National Institute of Nutrition (1995) partly explain this very strong infection rate by the use of human excreta for agriculture in the north of Vietnam. That would argue for the incorporation of this factor in the aggregation of the index of risk of faecal contamination. On the basis of this parasitologic study, the faecal contamination of water in Thai Nguyen Province would in fact be very high (index 5) rather than very low (index 1).

*Correlation between risk and pollution status.* In agreement with the risk analysis of the faecal contamination of water, the highest rates of diarrhoea in children under 5 years old were encountered in the plains districts of Pho Yen, Song Cong and Phu Binh. An incidence of diarrhoea lower than expected for the urban district of Thai Nguyen should be noted. The incidence of diarrhoea in Thai Nguyen District fell quite significantly, from 1,610 cases per 100,000 inhabitants in 1996, to 654 cases in 1998. This result may be attributed to recent improvements in the city's water supply and sanitation system.

The incidence of diarrhoea in the district of Vo Nhai, meanwhile, was much higher than expected. In spite of a very low population density relative to the provincial average (70 against 300 hab. / km<sup>2</sup>), the rate infection reached 2,346 cases per 100,000 inhabitants in 1996. The abrupt fall of this rate to 964 cases per 100,000 inhabitants in 1998 makes a precise interpretation of the results very difficult. This rapid and substantial fall may come from a recent shift away from particularly hazardous sanitation practices, such as open air defecation near waterways or limited washing of the hands before meals.

*Improvement of the water quality monitoring system.* The absence of detailed information on water quality and on annual renewable water supply is compounded by the questionable reliability of public health statistics. This information void makes it difficult to analyse the root causes and the impact of faecal contamination, and is prejudicial to public health and water resource conservation. It might also lead to large investments to finance water treatment stations in localities where natural purification processes could have been shown to be sufficient. But it could also result in some sections of the population being exposed to high water pollution contamination not addressed by public investment plans.

#### **4.4.3 Water pollution response index**

##### 4.4.3.1 Description of results

Data for the percentage of the population having access to water supply and sanitation services (WSS) at the district level in the province of Thai Nguyen were not available for this study. The data available at the district-level for the WATSAN programme was therefore used as a proxy for this analysis. The results of the WATSAN programme for the province of Thai Nguyen are shown in Map 44.

##### 4.4.3.2 Analysis of results

*A very low coverage for WSS services.* The average WSS coverage rate in Vietnam is 35 per cent. This low figure is explained by the limited attention paid, until recently, to water quality in rural areas. About two thirds of WSS systems were set up at the initiative of private individuals. With a coverage of 31 per cent, Thai Nguyen province is within the national average. In line with the classification adopted for the determination of the index of response to faecal contamination in Section 3.4.3, Thai Nguyen province obtains a result of "3" for its response to water pollution.

*An aid programme based on socio-economic criteria.* The map of the response to faecal contamination is only marginally correlated to the map on the risk of faecal contamination. With the exception of Vo Nhai district, the WATSAN program seems to focus on districts facing the lowest risk of faecal contamination. This paradox may be explained by the selection of beneficiary districts by socio-economic criteria, in the absence of detailed water quality monitoring data.

## CONCLUSION

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This study strengthens and underlines the case for the used of environmental indicators as important information tools for the sustainable development of tropical uplands. They allow large amounts of biological, physical and socio-economic data to be analysed, prioritised and synthesised in a few maps and figures that are directly relevant and accessible to decision-making. Table 65 presents the results for the 12 selected STRESS indices in the pilot province of Thai Nguyen in Vietnam.

**Table 66 - Rating of the 12 STRESS Indicators**

<b>Environmental Indices</b>	<b>Pressure From very low (1) to very high (5)</b>	<b>State From very good (1) to very poor (5)</b>	<b>Response From very good (1) to very poor (5)</b>
Forest degradation	5	5	4
Soil erosion	3	2	2
Water shortage	3	3	3
Water pollution	2	1 or 5	3
Global Index	3	3 or 4	3

Following the conceptual STRESS framework, the construction of risk, state and response indices for each environmental sector allows a dynamic approach to an assessment of the state of the environment to be presented to decision makers. The indices underline the chain of causality that links the mechanisms of degradation and regeneration of tropical uplands, and raise decision makers' awareness and understanding of the vulnerability and developmental constraints of an ecosystem too often wrongly perceived as rich and under-exploited.

In their efforts to represent the entire system of environmental interactions, STRESS environmental indicators also provide a comprehensive analytical framework to utilise limited available information and data. By requiring environmental managers to collect and analyse a minimum set of key information on each environmental sector, its possible to mitigate the risk that a critical environmental problem is overlooked because of preconceived ideas as to its relative importance. Thus, possible water shortage problems highlighted by the water shortage index were relatively unexpected in the monsoonal country of Vietnam. These problems may have been overlooked by a less powerful method of data analysis.

The Thai Nguyen Province's case study also confirms the initial assumption of this work - the value of associating environmental indicators with a geographical database of natural resources to facilitate the communication of data to laymen decision-makers. Indeed, the association of these two tools allows:

1. A spatial representation of the state of environment to be provided to decision-makers. It is easier to communicate complex information using maps, than by tables or lists. Maps take advantage of our natural abilities to distinguish colours, patterns and spatial relationships. Moreover, decision-makers generally interpret maps more easily than numerical data, because they can "see" the spatial presentation.
2. The various assumptions used for the construction of environmental indicators is a transparent process. A modification of the aggregation assumptions will immediately be translated in the form of new spatial representations, which can be directly interpreted by decision-makers. These interactive opportunities are particularly adapted to the complexity of the decision-making processes.

3. A dialogue naturally takes place between decision-makers and analysts. Aggregated indicators have a strong appeal and can more easily attract the attention of decision makers than raw data. This appeal gives the analyst an opportunity to demonstrate the advantages of GIS to support decision-making.

The case study of Thai Nguyen Province also underlines the sensitivity of environmental indicators to the quality of the information base and to the selection of parameters that comprise them. Thus, the selection of the incidence of diarrhoea as indicator of the faecal contamination of water gives a water quality state index of "1", whereas an indicator of hookworms would have given a result of "5". These contradictory results are explained partly by the different procedures involved in the collection of data. In one case, data were collected and directly transmitted to supervisory administrations by local authorities, in the absence of an independent verification mechanism. In another case, they were obtained through a field monitoring programme conducted by independent organisations. Such substantial difference in results changes the final "rating" of the state of environment in Thai Nguyen from "3" in the first case, to "4" in the second case.

The absence of detailed information on some fundamental environmental sectors - such as biodiversity or water resources - is a major constraint for constructing sufficiently accurate environmental indicators to support policy decision-making in Thai Nguyen Province. As was stressed in three seminars organised by the Asian Bank of Development (ADB) in Shanghai, Dhaka and Manila in 1998 to evaluate the impact of its work on environmental indicators, this concern regarding the lack of adequate information seems to apply to many developing countries:

*"For most Asian countries, environmental information is generally lacking. When it does exist, it is often regarded as the property of individual government agencies, institutions and individuals".*

In the majority of OECD countries, debates on the validity of environmental indicators as instruments to support decision-making primarily have centred on the uncertainties and subjectivity associated with determining thresholds or reference values to assess environmental degradation and to weight the various parameters in the aggregation equations. It is interesting to note that discussions during the three ADB seminars focused, to the contrary, on the selection of indicators and on the availability of data necessary for their aggregation. The selection of environmental indicators commonly used in the OECD countries, such as power consumption and the use of manure per capita, to reflect the concerns of developing countries was thus disputed. Environmental indicators in tropical uplands will have to meet the specific needs of these ecosystems and take into account critical limitations in available information and data.

This information void will impact each environmental sector differently. Technological advances in remote sensing enables relatively reliable monitoring of vegetation changes and, consequently, the development of indicators of forest degradation that are sufficiently robust to support policy decision-making. The ability to calibrate soil erosion models using limited data sets, and to conduct complementary field surveys by experienced soil scientists, also allows an acceptable estimate of the risk and state of land degradation to be made. On the other hand, the construction of water degradation indicators depends essentially on the quality of the available hydrometeorological data and on national and local data disclosure policies. A comprehensive water resource assessment requires continued field programmes to monitor water flows and quality in a number of representative areas, using consistent approaches and methodologies that enable data comparison. Unfortunately, most of the existing data in tropical uplands are collected in an ad hoc manner to meet the needs of specific time-bound programmes in localised areas. Moreover, the monopoly in data collection of many hydrometeorological services in developing countries excludes any possibility of independent data verification.

In using the environmental indicators for tropical uplands suggested in this book, it is advisable to keep in mind the margin of error resulting from this quasi-information void. The inherent subjectivity associated with any selection and weighting of parameters to construct aggregated indicators will also have to be remembered. In view of these constraints, indicators should be regarded as only one tool for data analysis. They should be supplemented by other qualitative and scientific information to gain full relevance and to facilitate their scientific and policy-oriented interpretation.

Despite these constraints, the unquestionable advantages of indicators to communicate information and raise the awareness of decision-makers strongly advocates that this methodological work be further developed and extended to the other two pilot provinces in Vietnam. That extension will enable Vietnamese decision makers to compare the respective environmental performance of provincial authorities, and to identify and promote the most promising initiatives for sustainable development.

To facilitate this extension of the work, additional surveys on biodiversity and water quality in the pilot provinces are recommended. These complementary studies will allow direct assessments to be made of biodiversity rather than having to rely on the percentage of non-disturbed forest cover as a proxy indicator for biodiversity. Specific measurements of faecal coliforms or biological oxygen demand in the principal rivers of the pilot provinces during high and low flow periods will put into further perspective the information derived from proxy indicators of water quality.

Lastly, a medium-term extension of this work for the construction of environmental indicators could include a monetary quantification of the degradation of tropical uplands. While environmental managers usually deal with physical units, policy decision makers work primarily with monetary units. That approach, moreover, would make it possible to partly address the “statistical bias” associated with existing macro-economic indicators such as GNP.

## Appendix 1 : Maps

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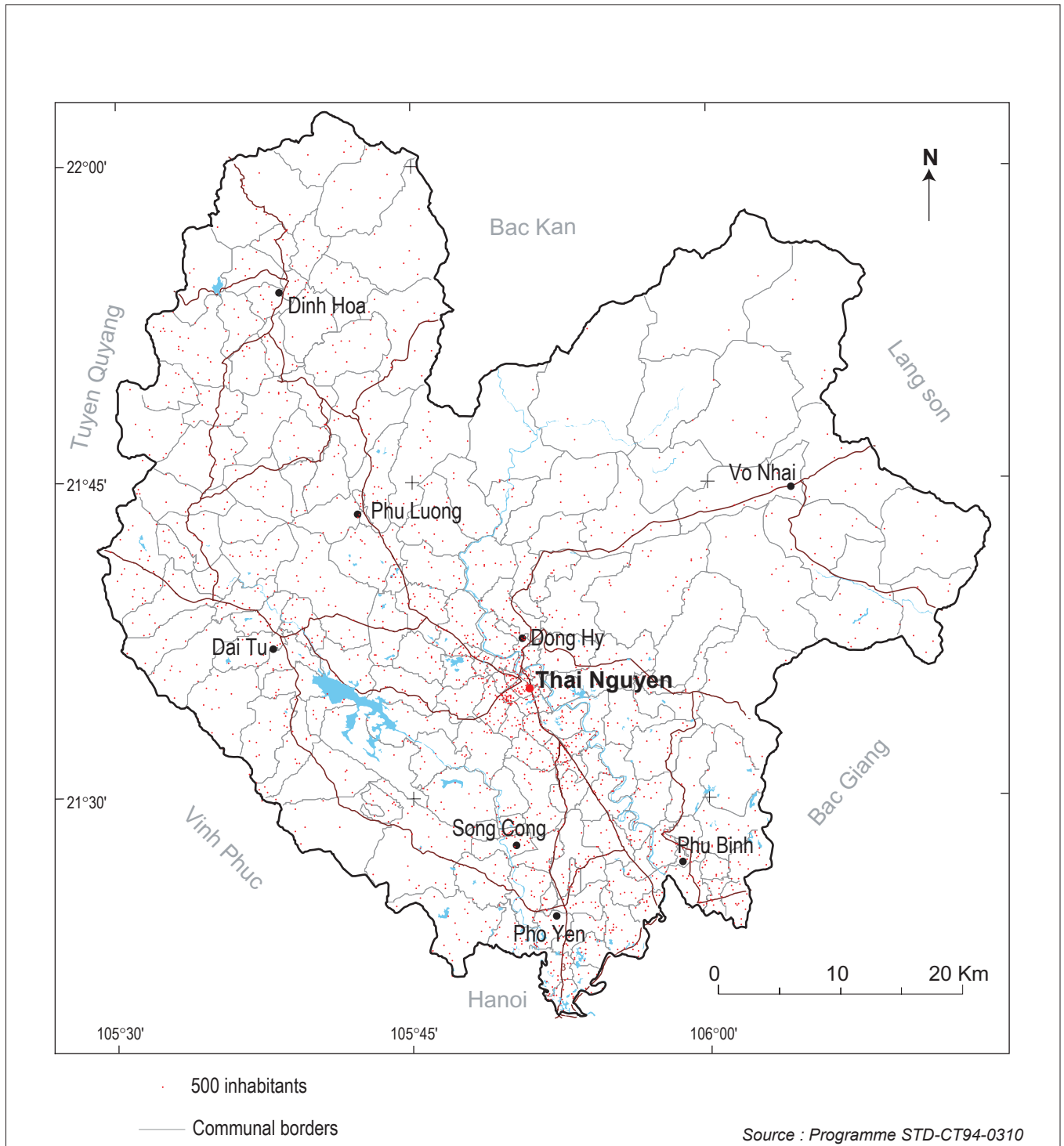
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**Map 1 : The Pilot Province  
of Thai Nguyen**

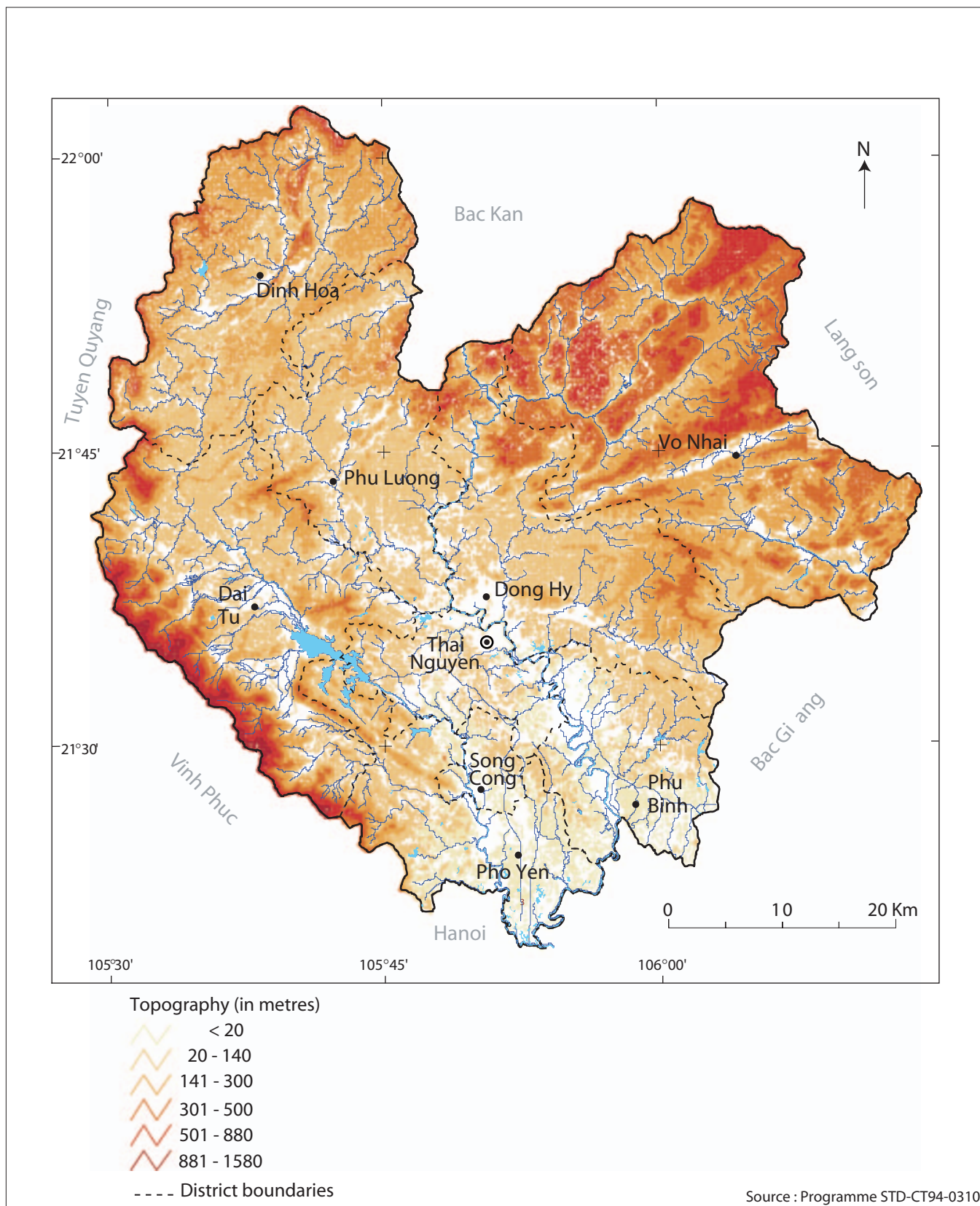


Sources : after Brabant and al. 1997

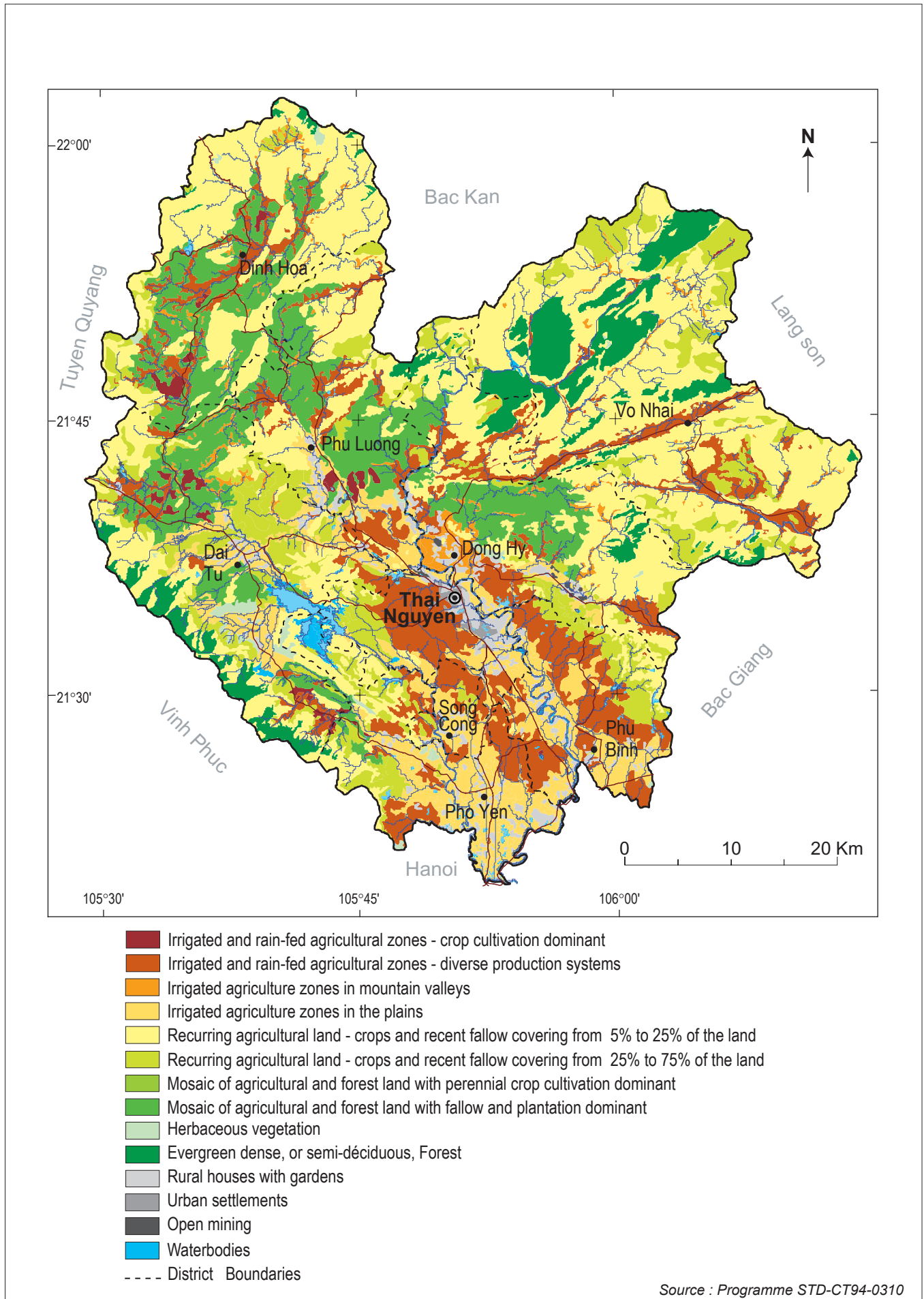
**Map 2 : Population Distribution in Thai Nguyen**



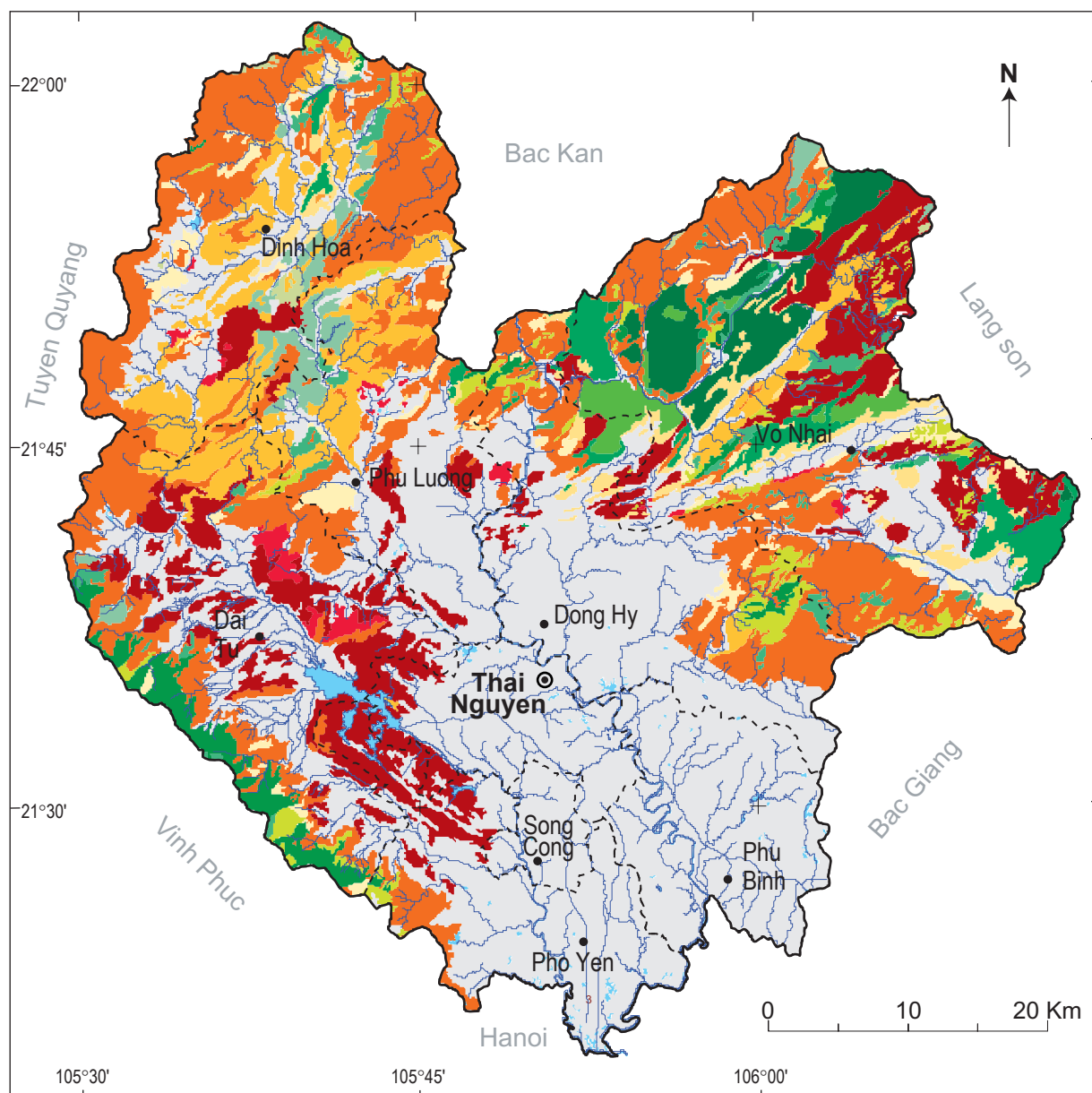
**Map3 : Topography of Thai Nguyen**



**Map 4 : Land Cover of Thai Nguyen**



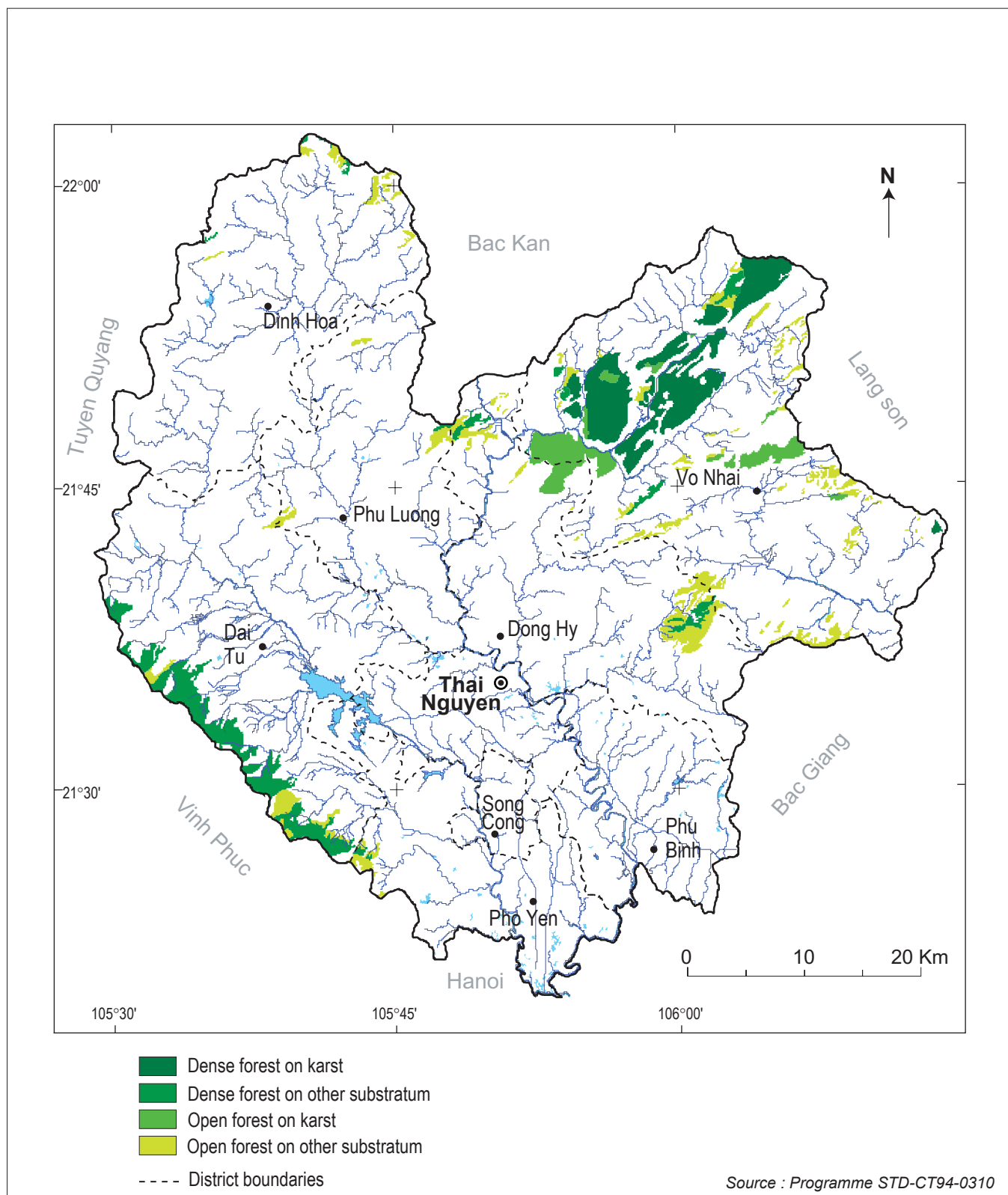
**Map 5 : Distribution of Main Vegetation Types of Thai Nguyen**



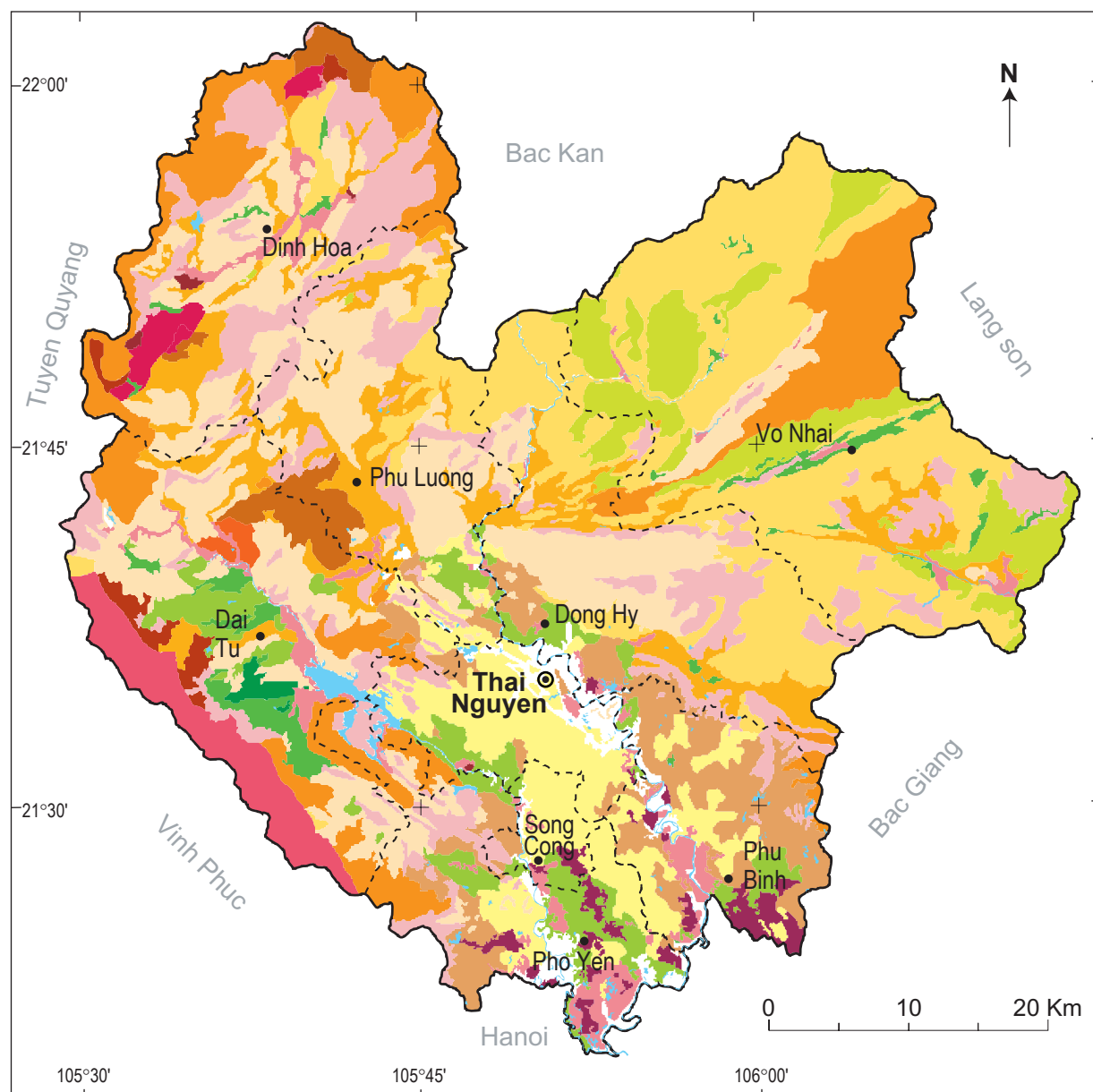
- Agricultural land
- Dense forest
- Dense forest on karst
- Open forest
- Open forest on karst
- Open forest and woody bush
- Open forest and woody bush on karst
- Open forest and woody bush with mosaic of plantations
- Open forest with mosaic of plantations
- Plantation
- Woody bush and shrub
- Woody bush and shrub on karst
- Woody bush and shrub with mosaic of plantations
- Shrub on karst
- Shrub and bush
- Shrub and bush with mosaic of plantations
- - - - District boundaries

Source : Programme STD-CT94-0310

**Map 6 : Marginally - or undisturbed Forests of Thai Nguyen**



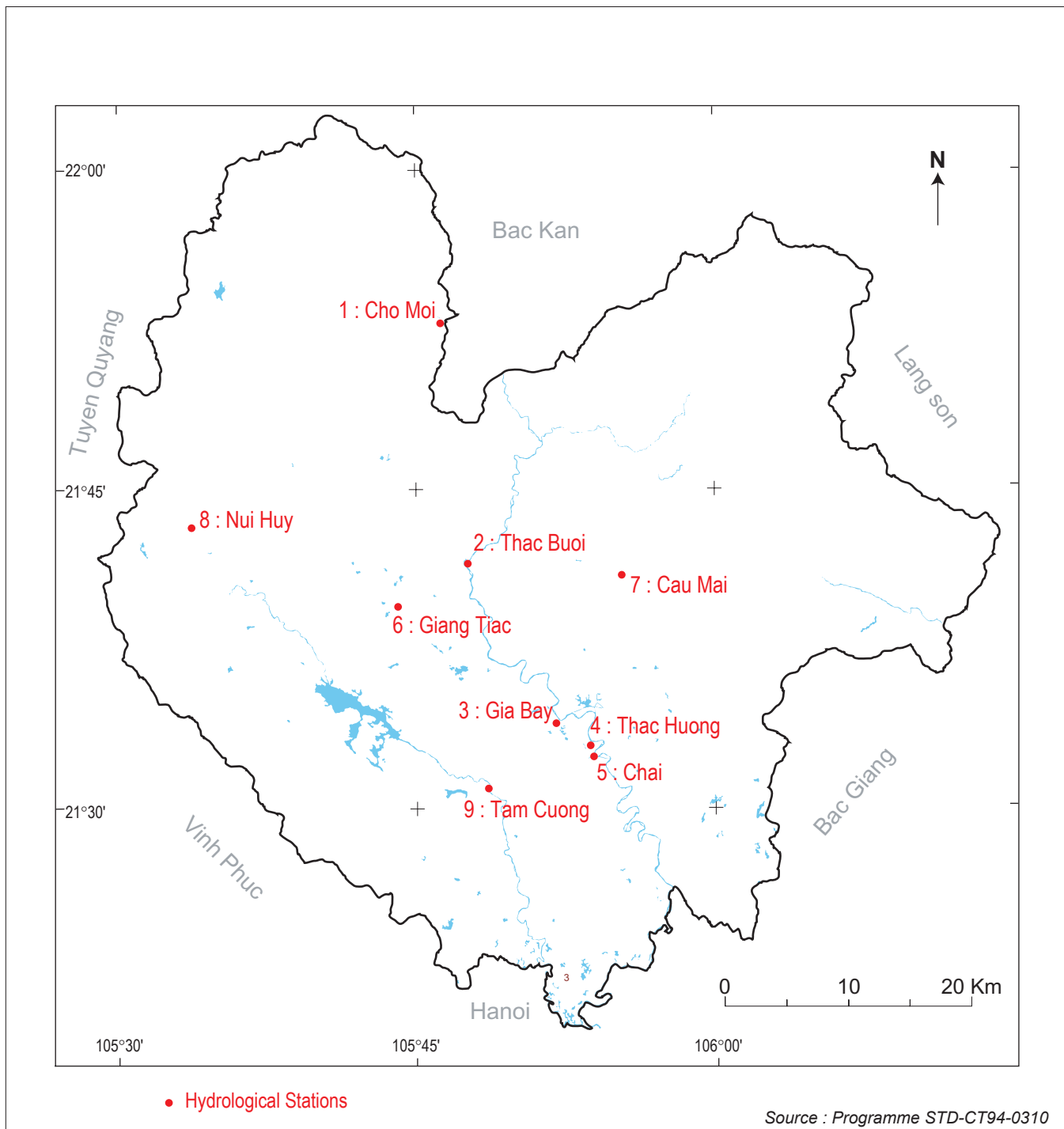
Map 7 : Soil distribution of Thai Nguyen (from the morpho-pedology map)



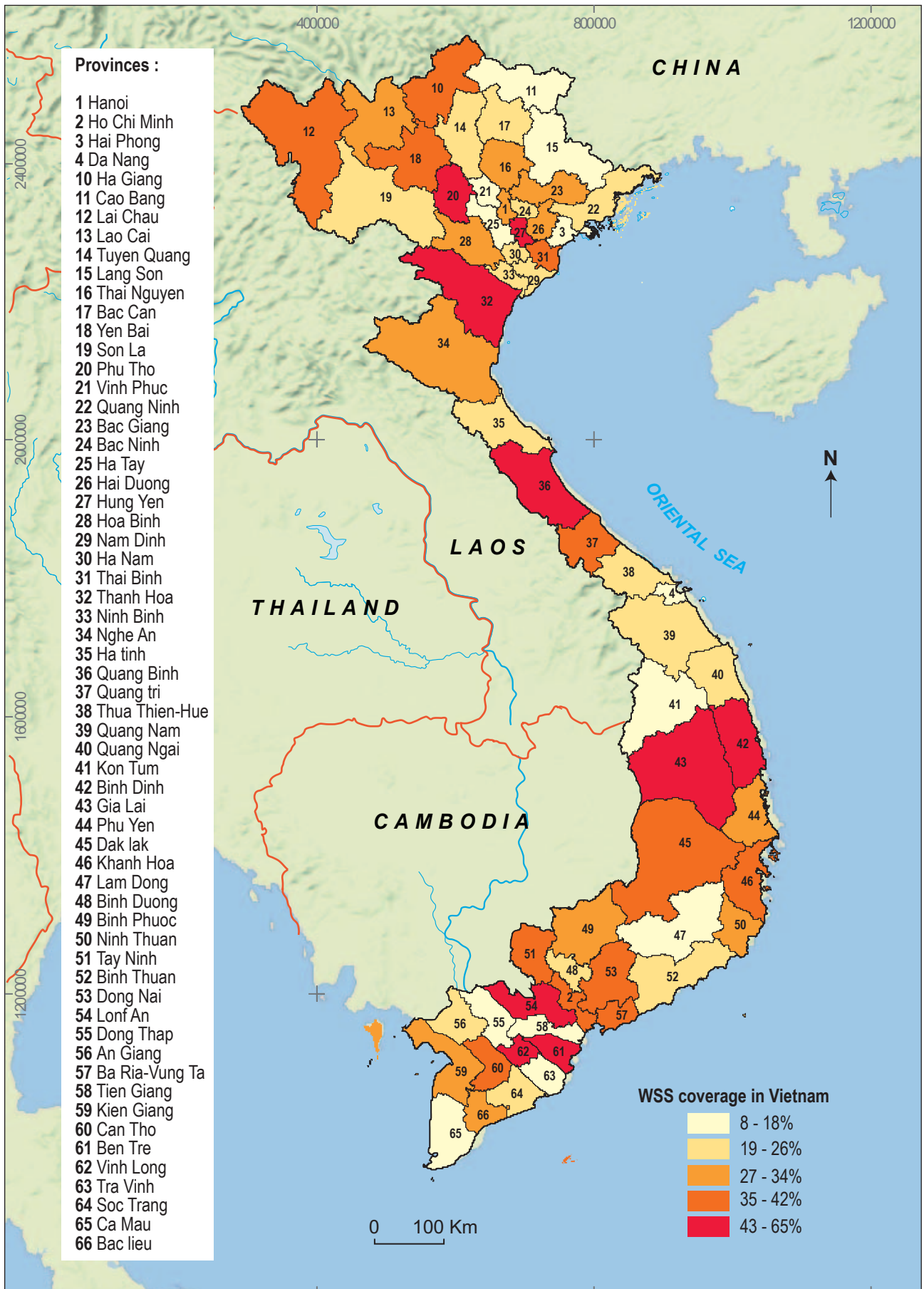
- Anthrosols cumuliques, fluvisols eutriques
- Acrisols hapliques, ferralsols xanthiques, cambisols dystriques
- Hills : Acrisols hapliques, cambisols dystriques. Low ground : fluvisols eutriques
- Hills : Cambisols dystriques, acrisols hapliques. Low ground : fluvisols eutriques
- Hills : Cambisols dystriques, leptosols dystriques, acrisols hapliques
- Hills : Cambisols dystriques, leptosols dystriques. Low ground : fluvisols eutriques
- Hills : Cambisols dystriques, alisols ferriques. Low ground : luvisols eutriques
- Hills : Acrisols ferriques and hapliques, leptosols dystriques. Low ground : luvisols eutriques
- Hills : Cambisols ferraliques, acrisols hapliques. Low ground : fluvisols eutriques
- Hills : Ferralsols hapliques, acrisols hapliques. Low ground : fluvisols eutriques
- Hills : Leptosols dystriques, acrisols ferriques and hapliques. Low ground : fluvisols eutriques
- Fluvisols eutriques
- Leptosols dystriques, cambisols humiques, cambisols ferraliques, cambisols dystriques
- Leptosols dystriques, leptosols umbriques
- Leptosols dystriques, cambisols ferraliques, alisols hapliques, phaeozems hapliques, lithosols
- Lithosols, phaeozems calcaires, lxisols hapliques
- Régosols eutriques, cambisols dystriques
- Cambisols ferraliques
- Cambisols ferraliques, boulders
- - - - District boundaries

Source : Programme SDT-CT94-0310

**Map 8 : Hydrological stations of Thai Nguyen**

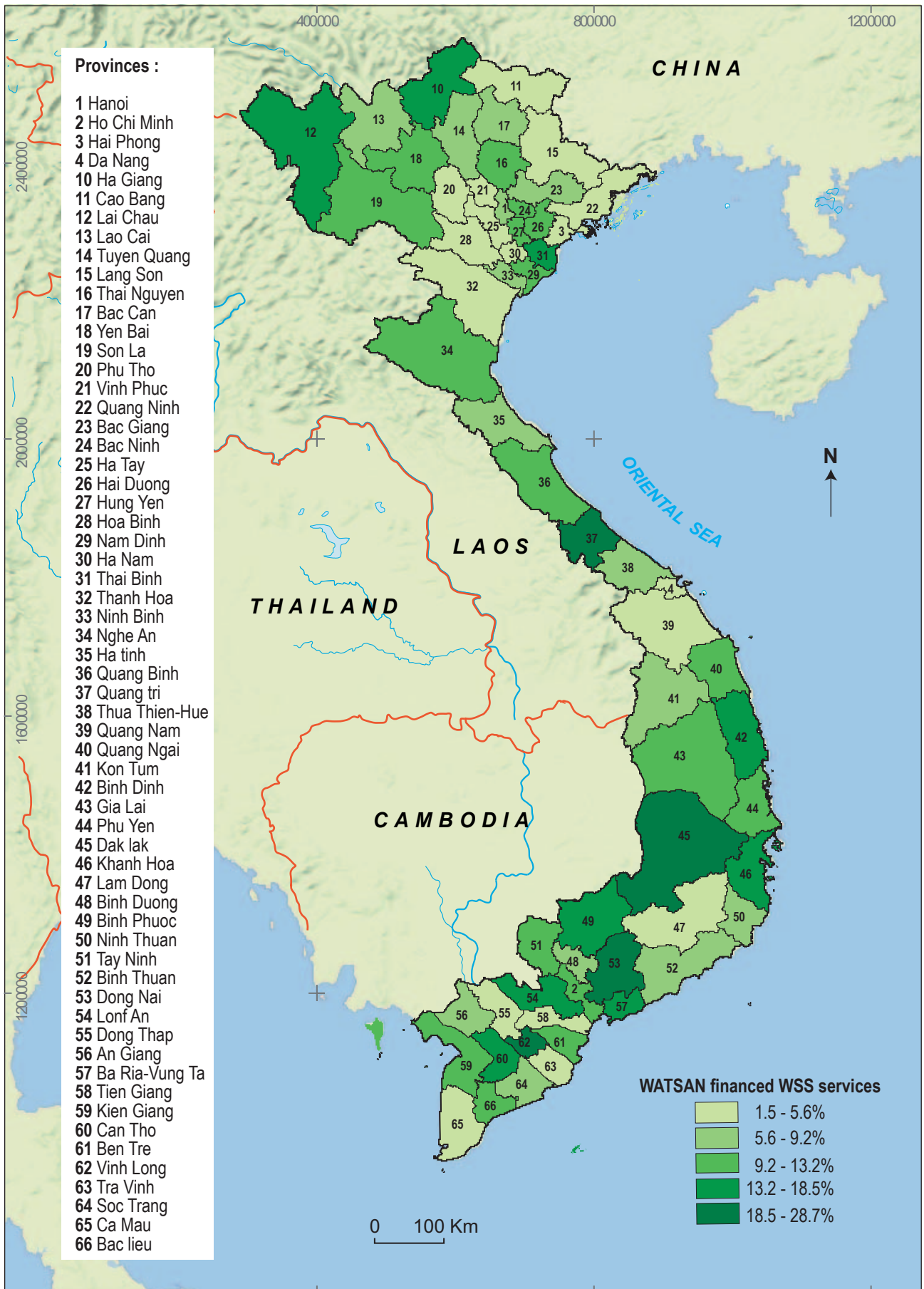


**Map 9 : Water Supply and Sanitation Services  
in Vietnam**



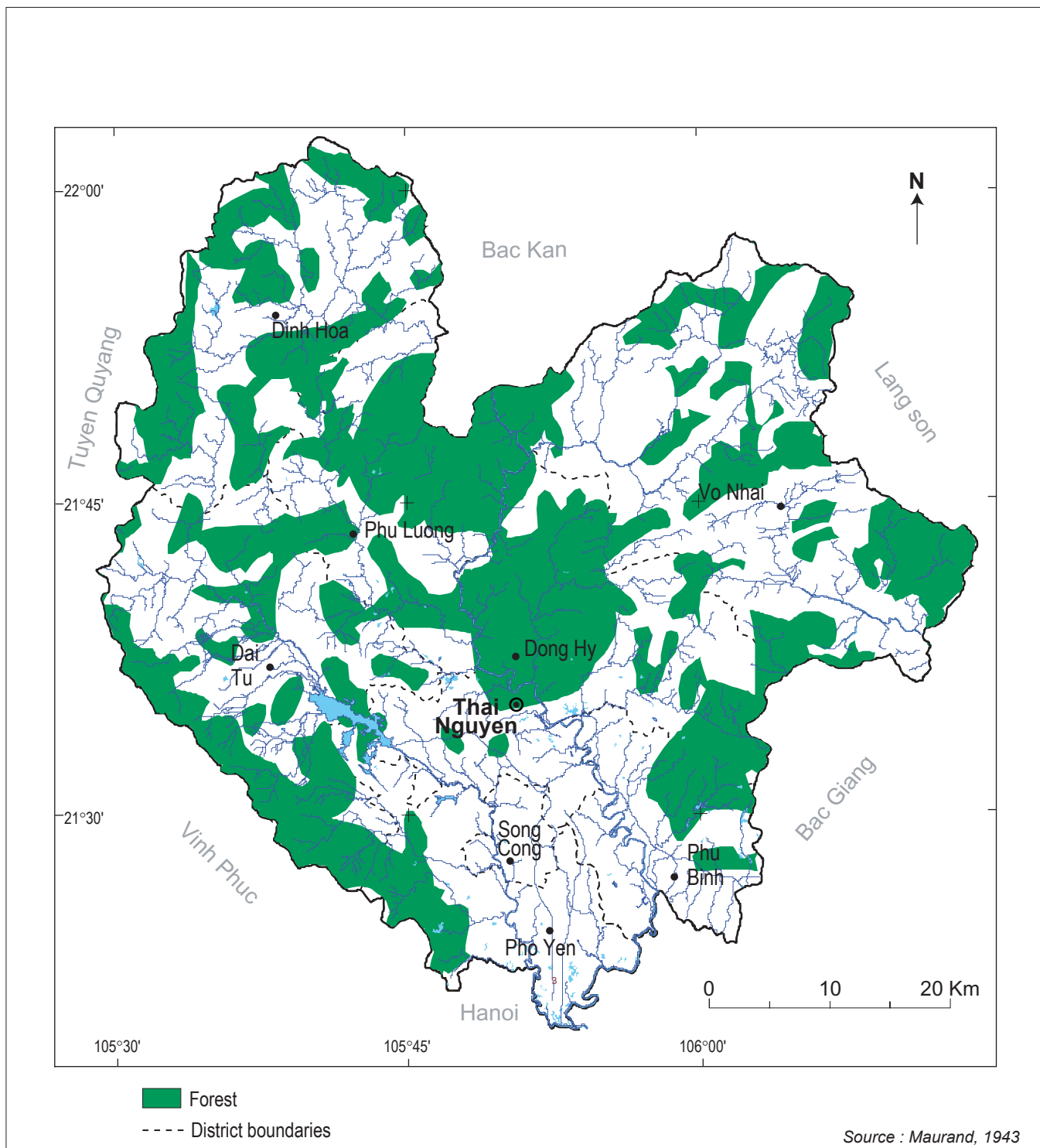
Source : UNICEF - 1999

**Map 10 : WATSAN-financed WSS Services  
in Vietnam**

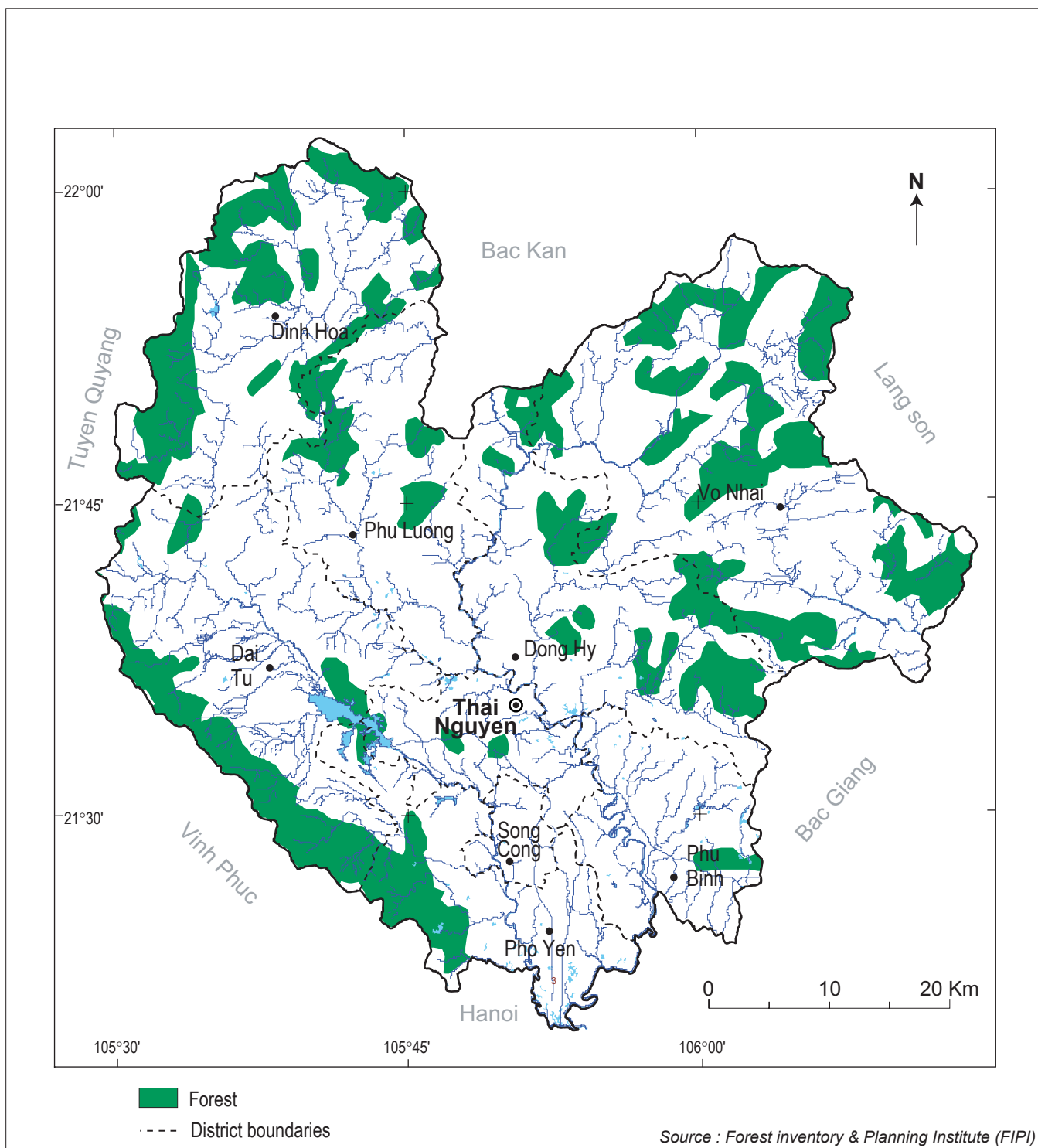


Source : UNICEF - 1999

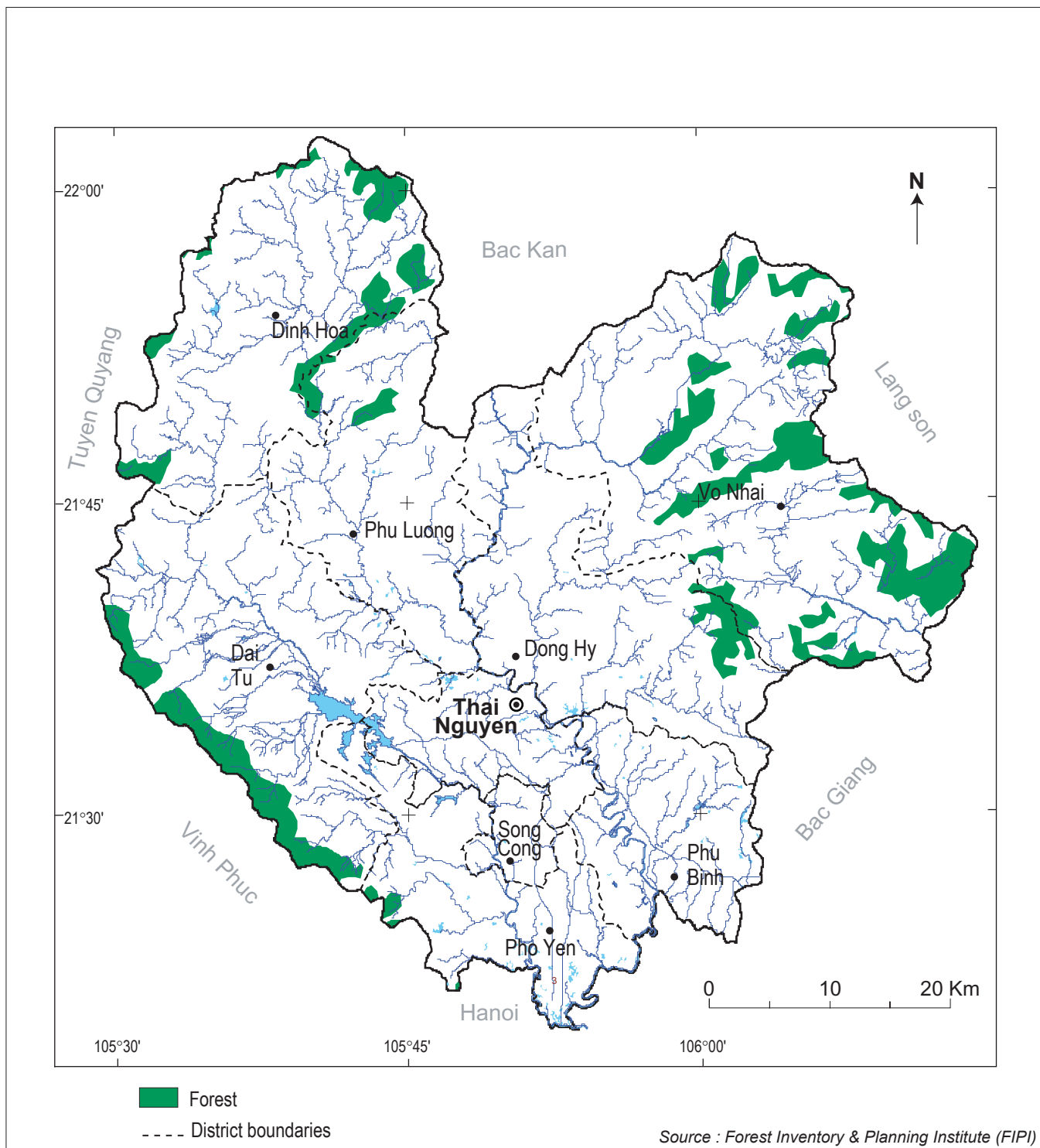
Map 11 : Forest Cover in 1943



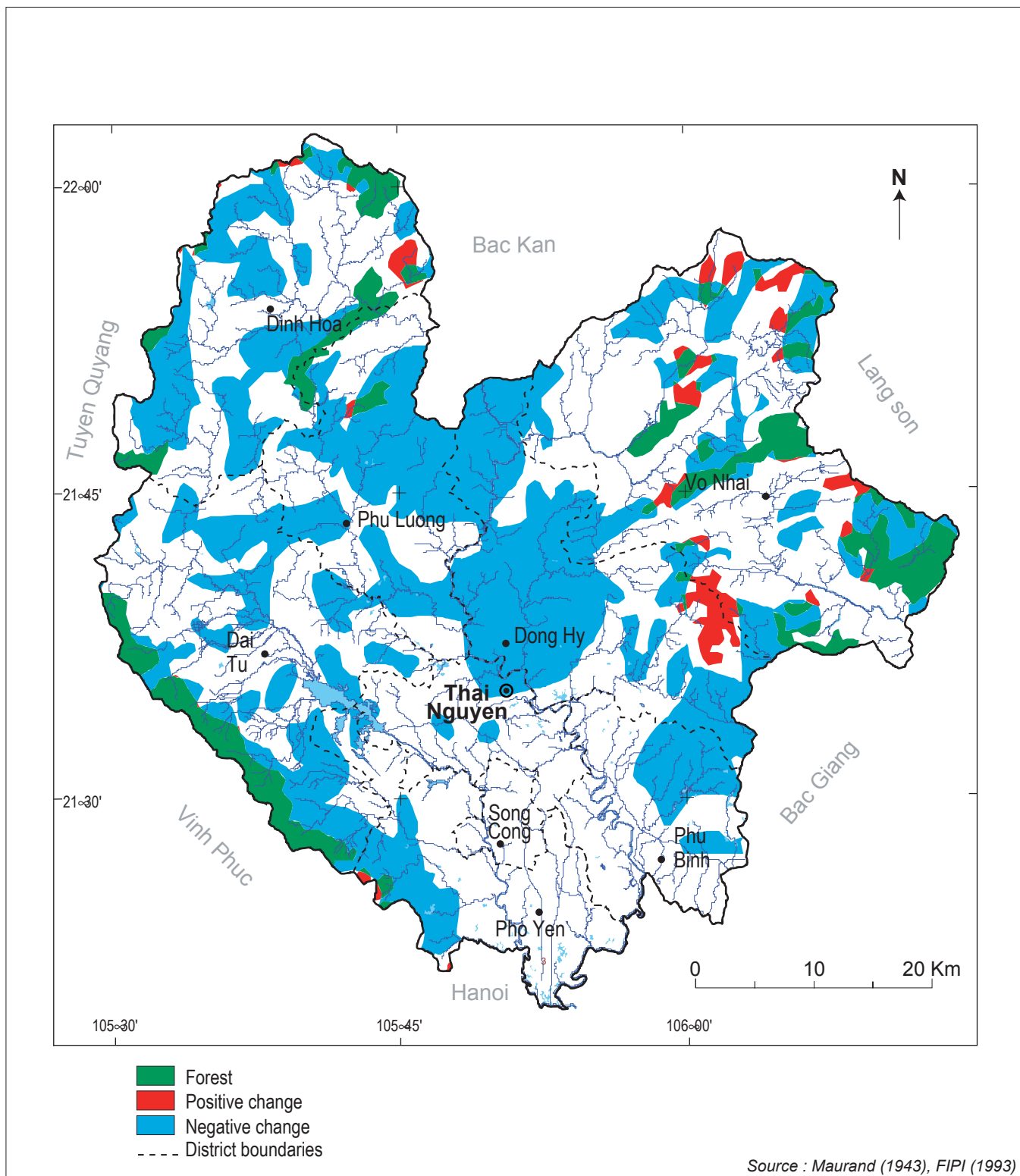
Map 12 : Forest Cover in 1983



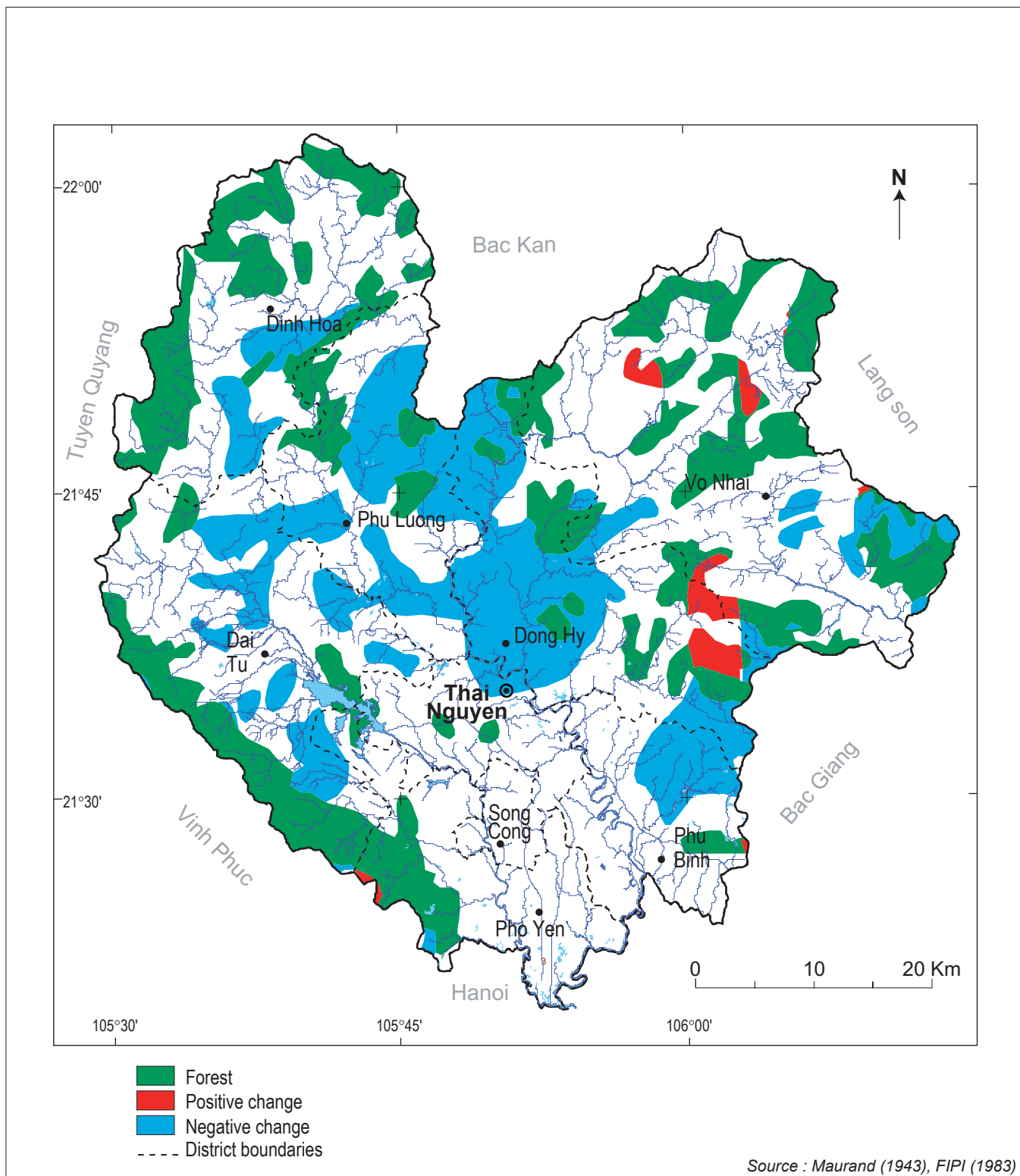
**Map 13 : Changes in Forest Cover in 1993**



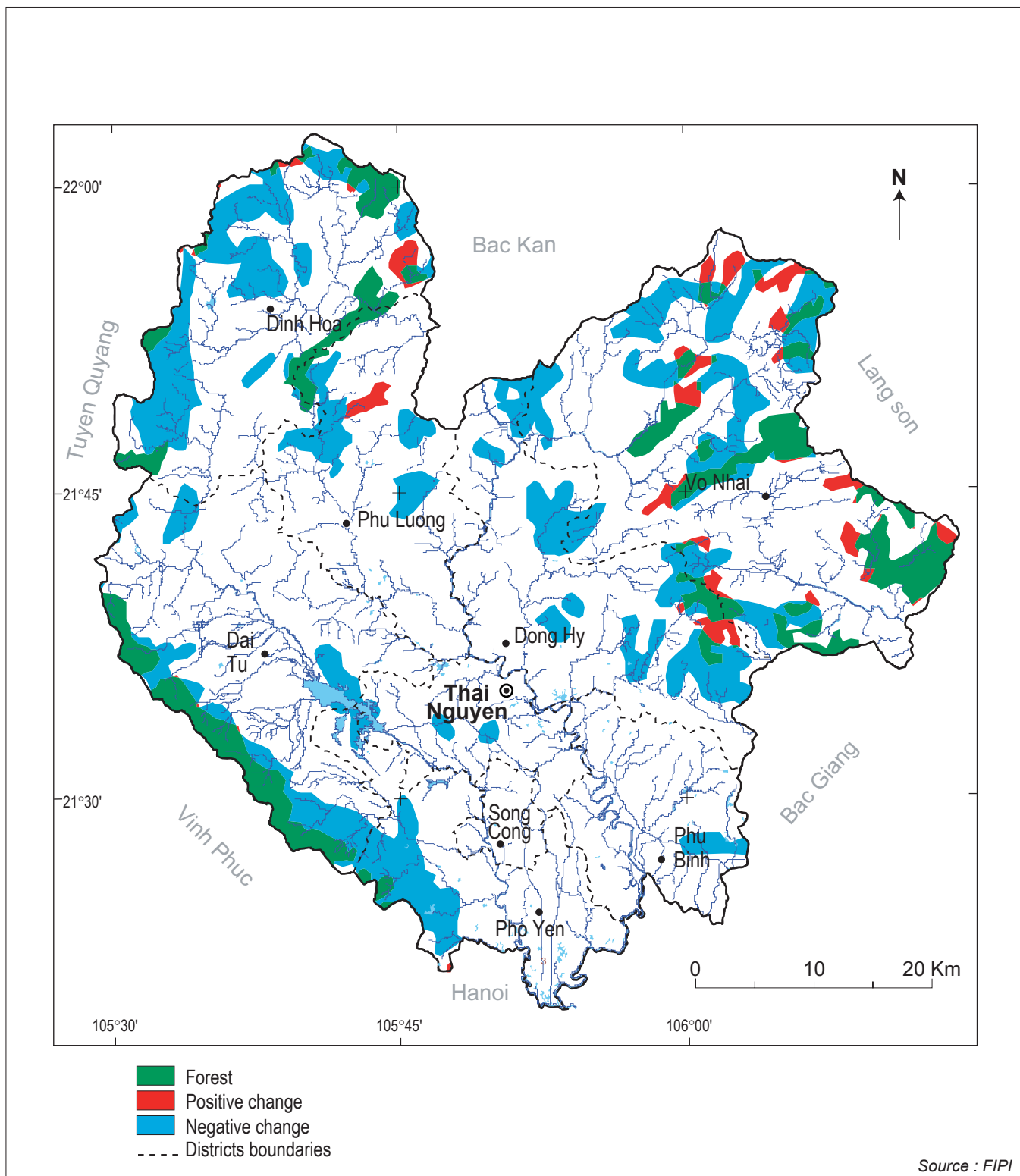
**Map 14 : Changes in Forest Cover 1943-1993**



**Map 15 : Changes in Forest Cover 1943-1983**

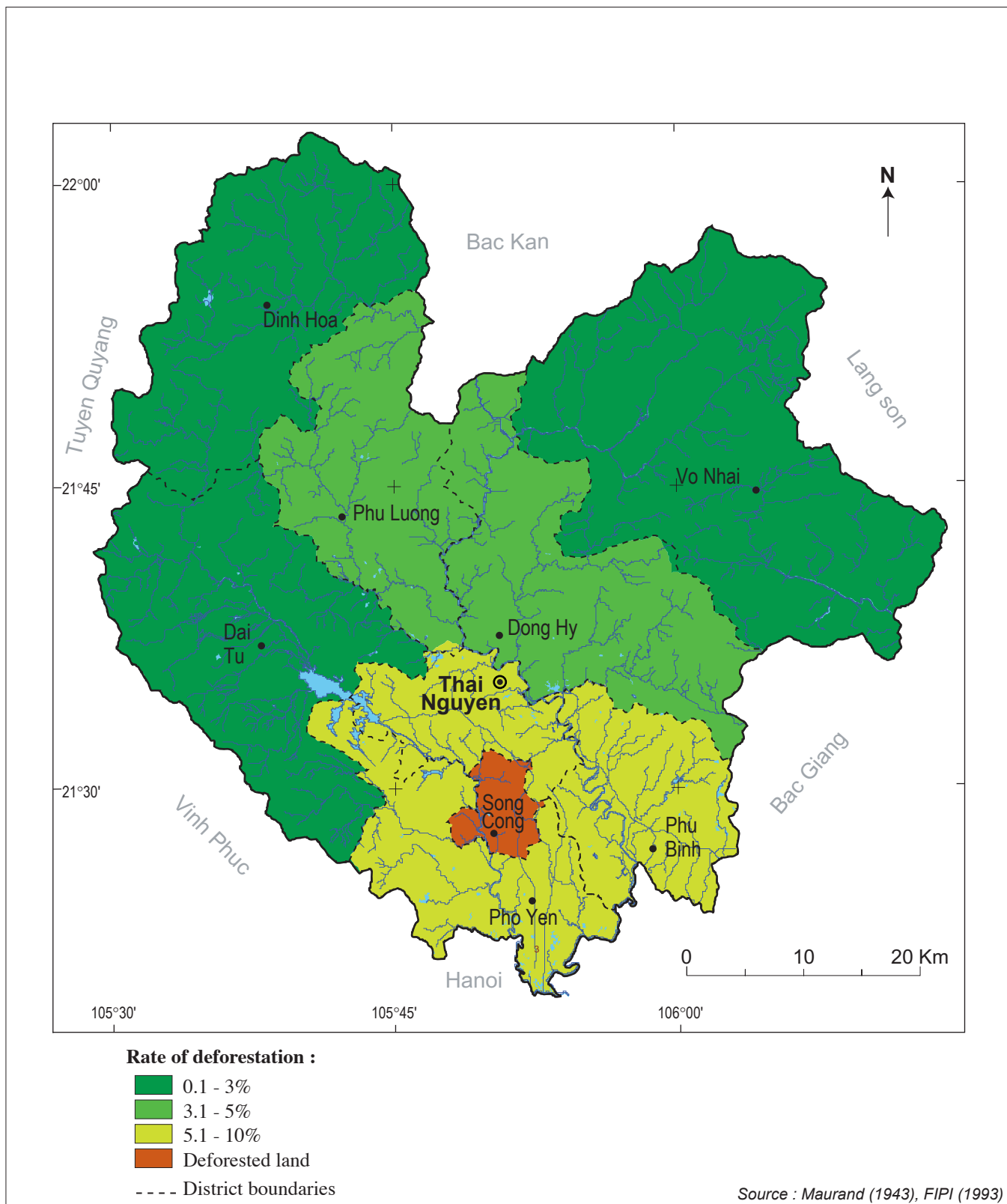


**Map 16 : Changes in Forest Cover 1983-1993**

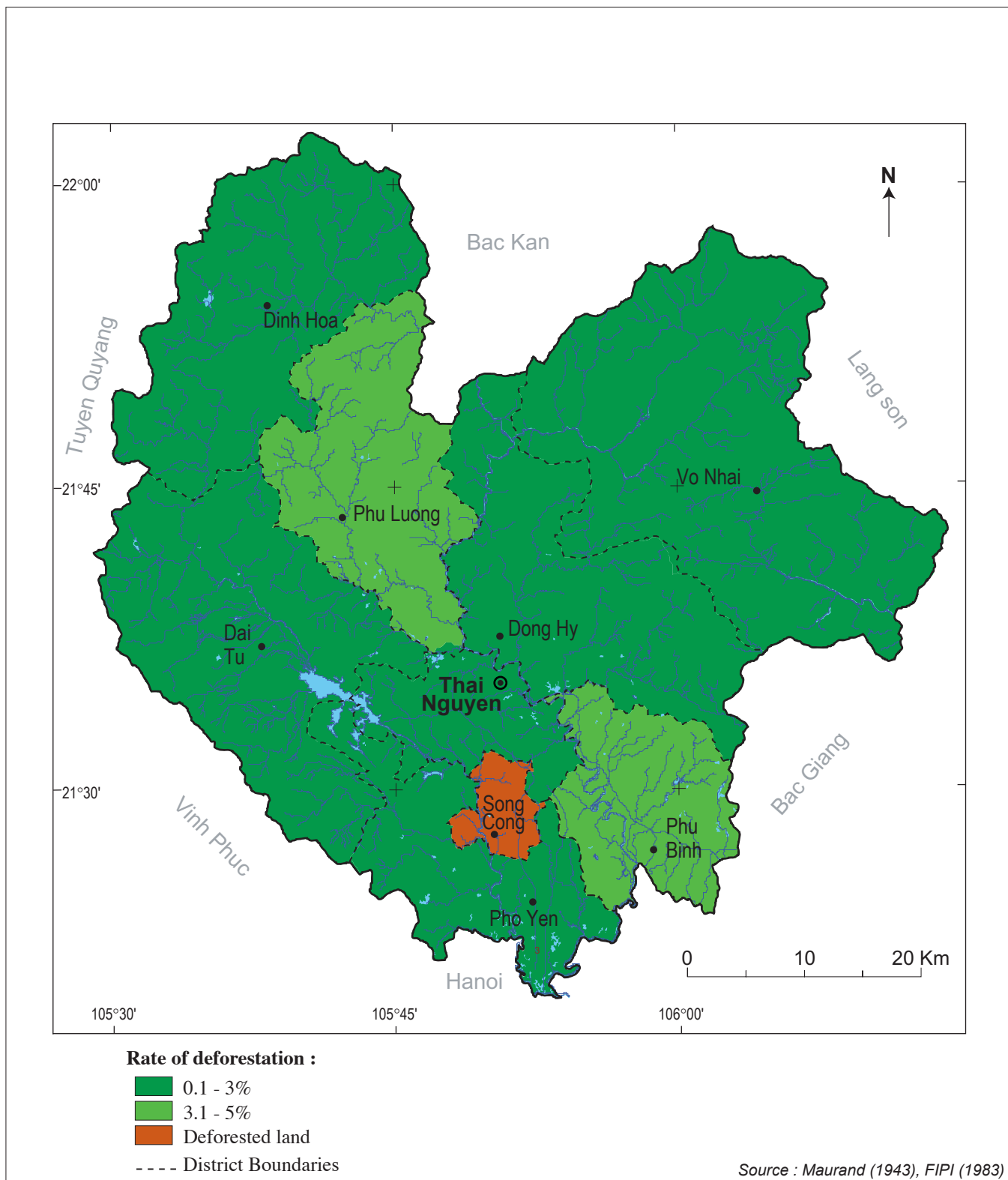


Source : FIPI

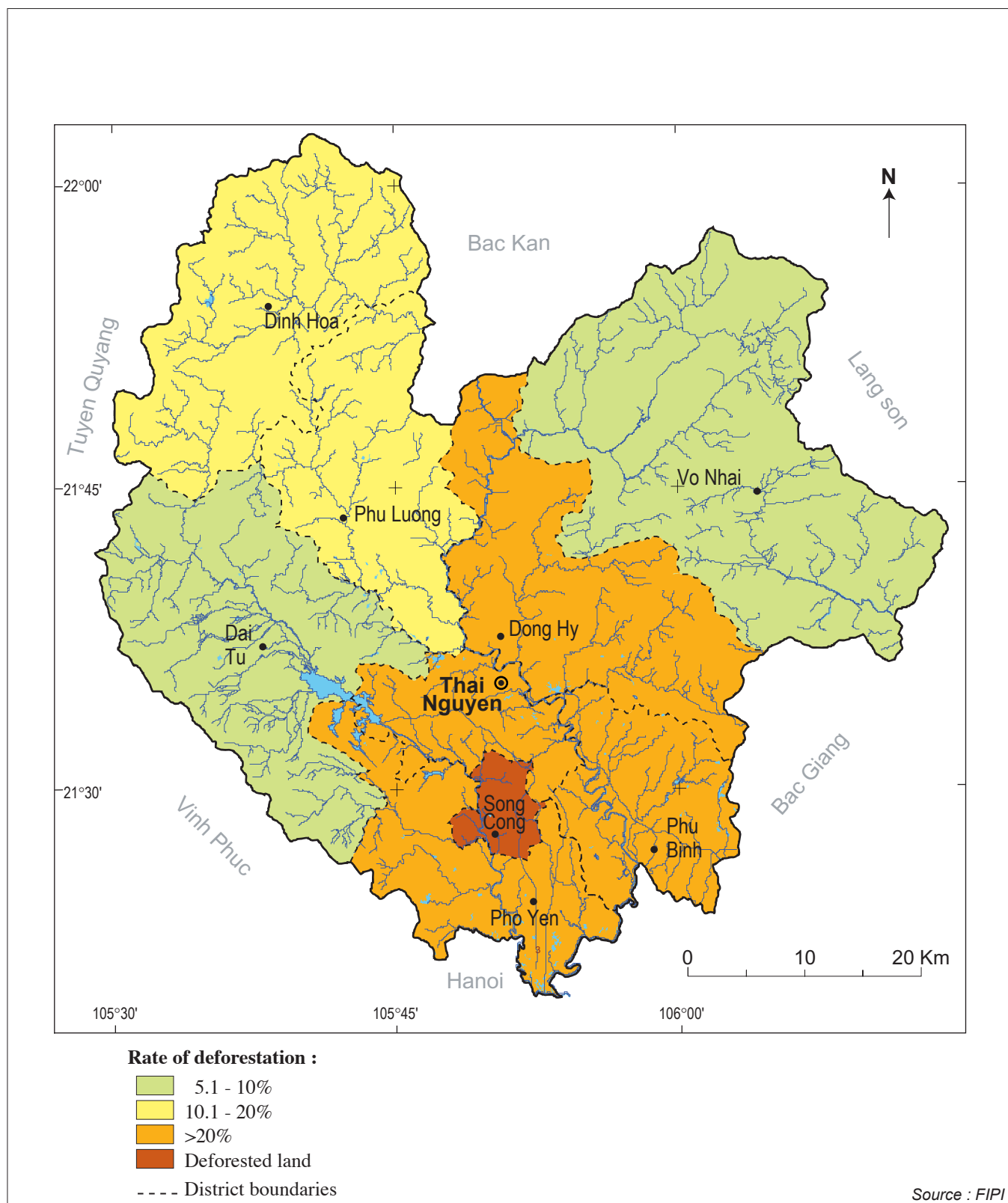
Map 17 : Annual Deforestation Rate by District, 1943 to 1993



Map 18 : Annual Deforestation Rate by District, 1943 to 1983

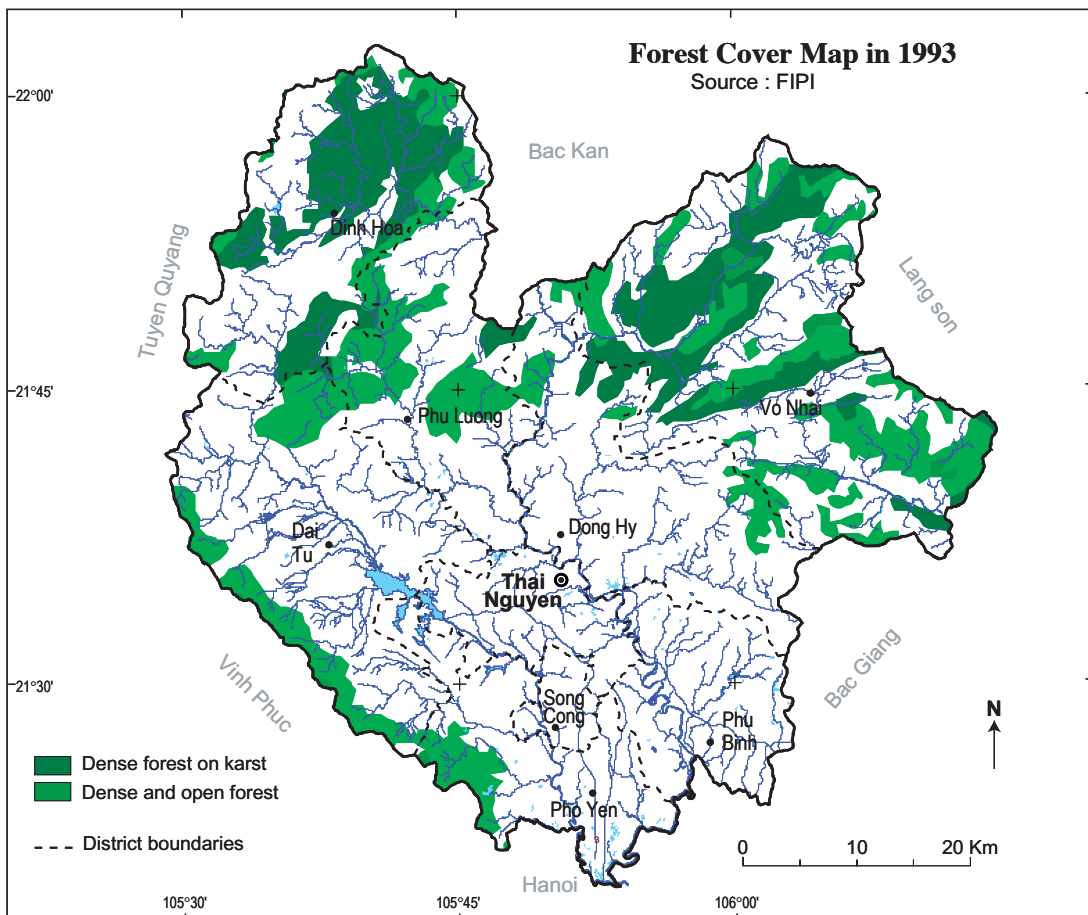
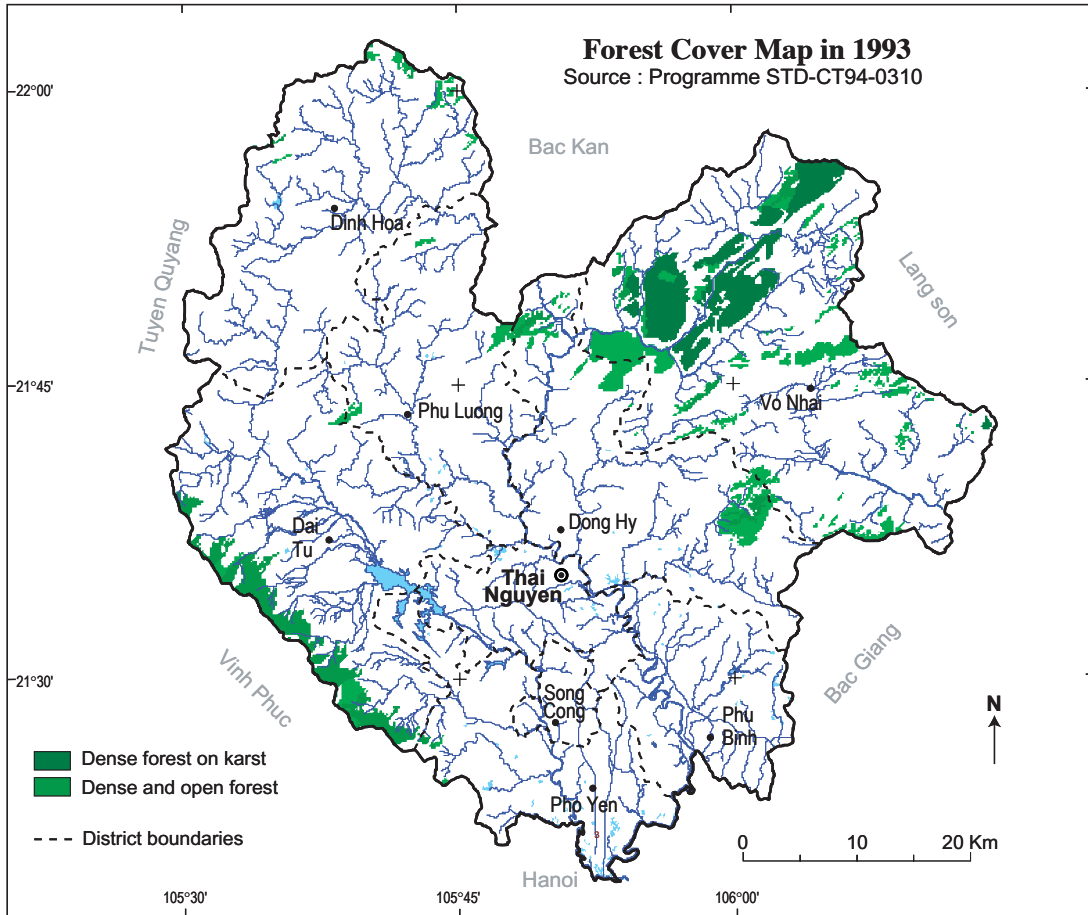


**Map 19 : Annual Deforestation Rate by District, 1983 to 1993**

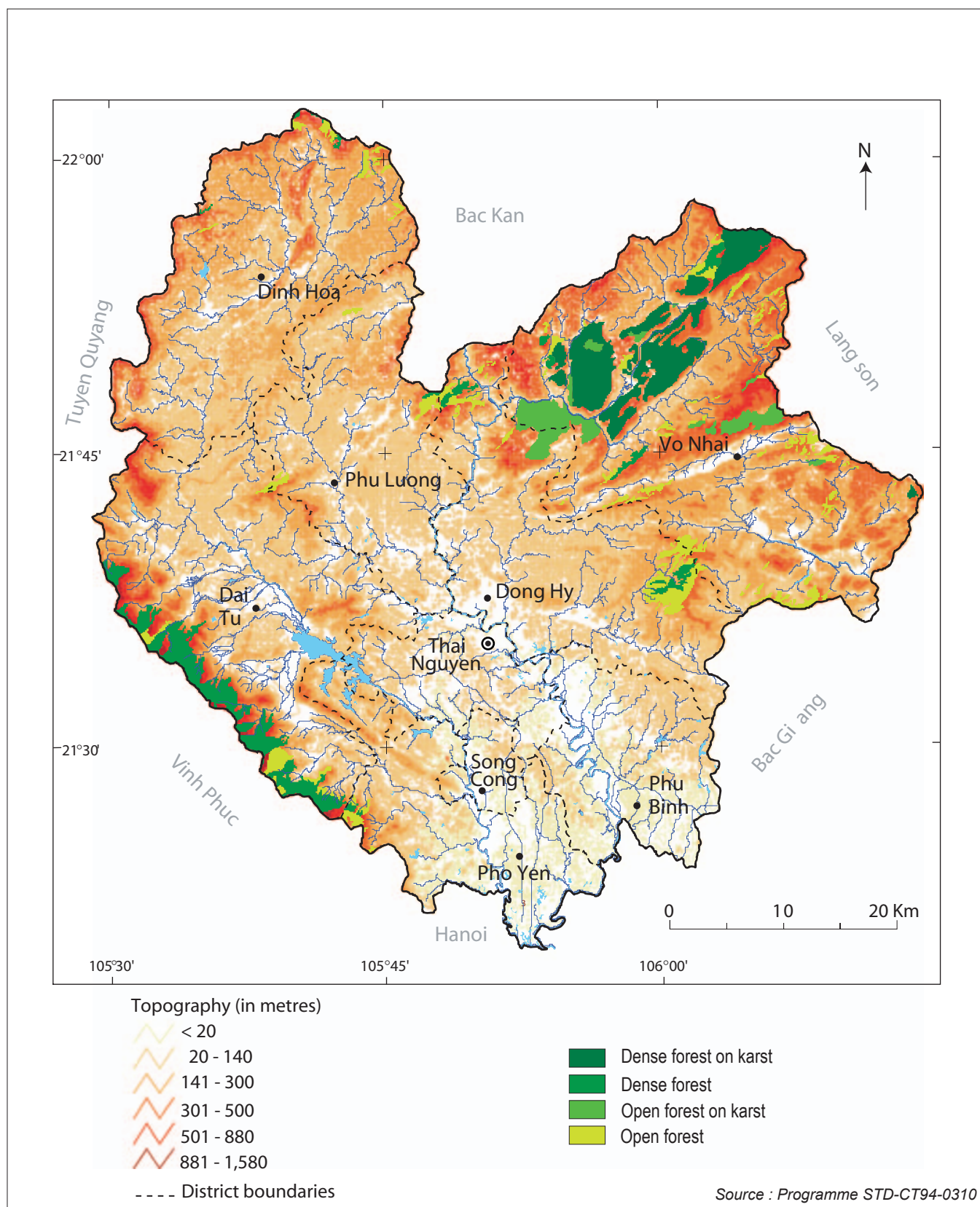


Source : FIPI

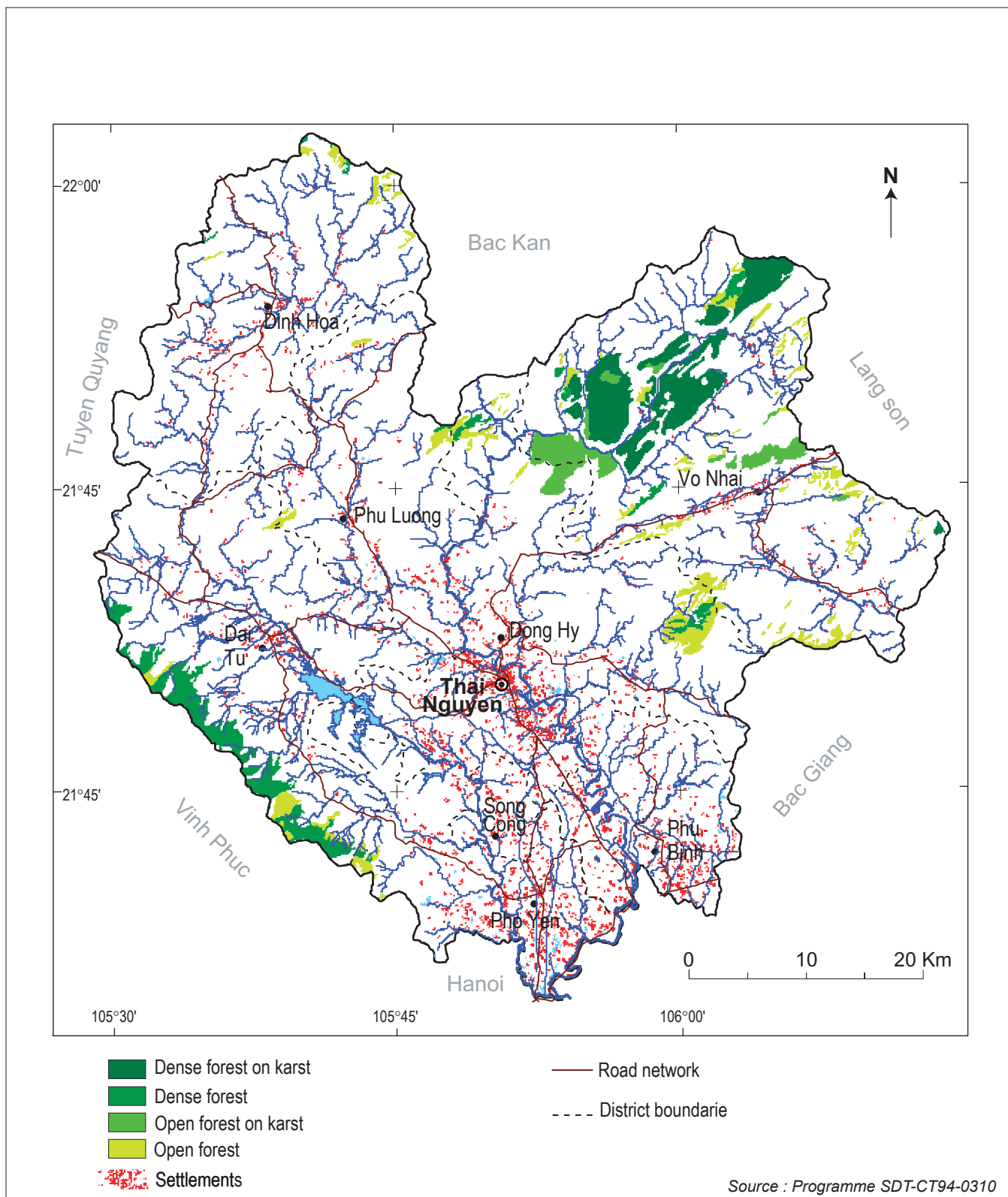
**Map 20 : Comparison of STD3 and FIPI Forest Cover Maps**



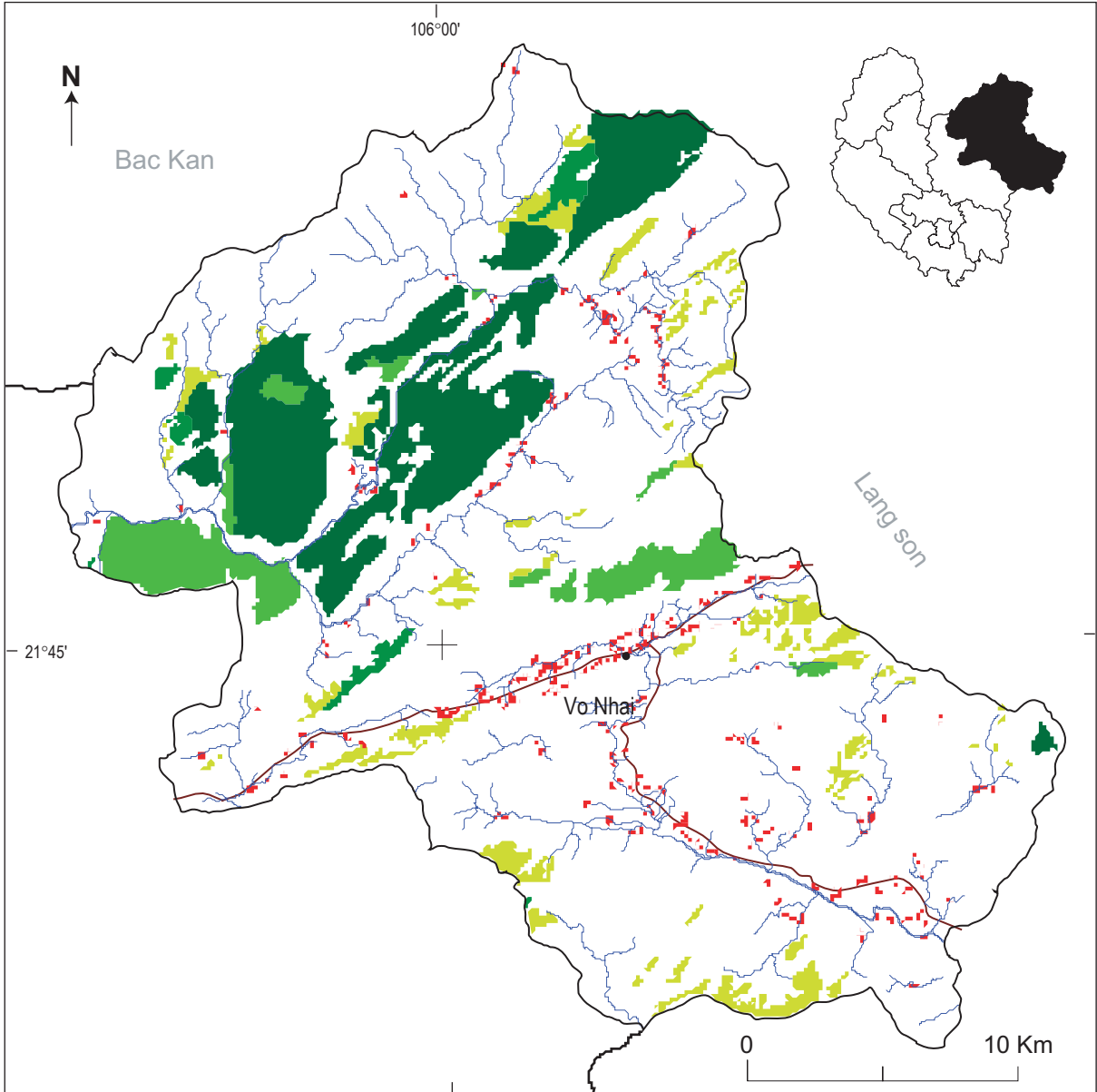
**Map 21 - Topography and Forest Cover**



**Map 22 - Deforestation, Road and Hydrological Network, and Settlements in Thai Nguyen**



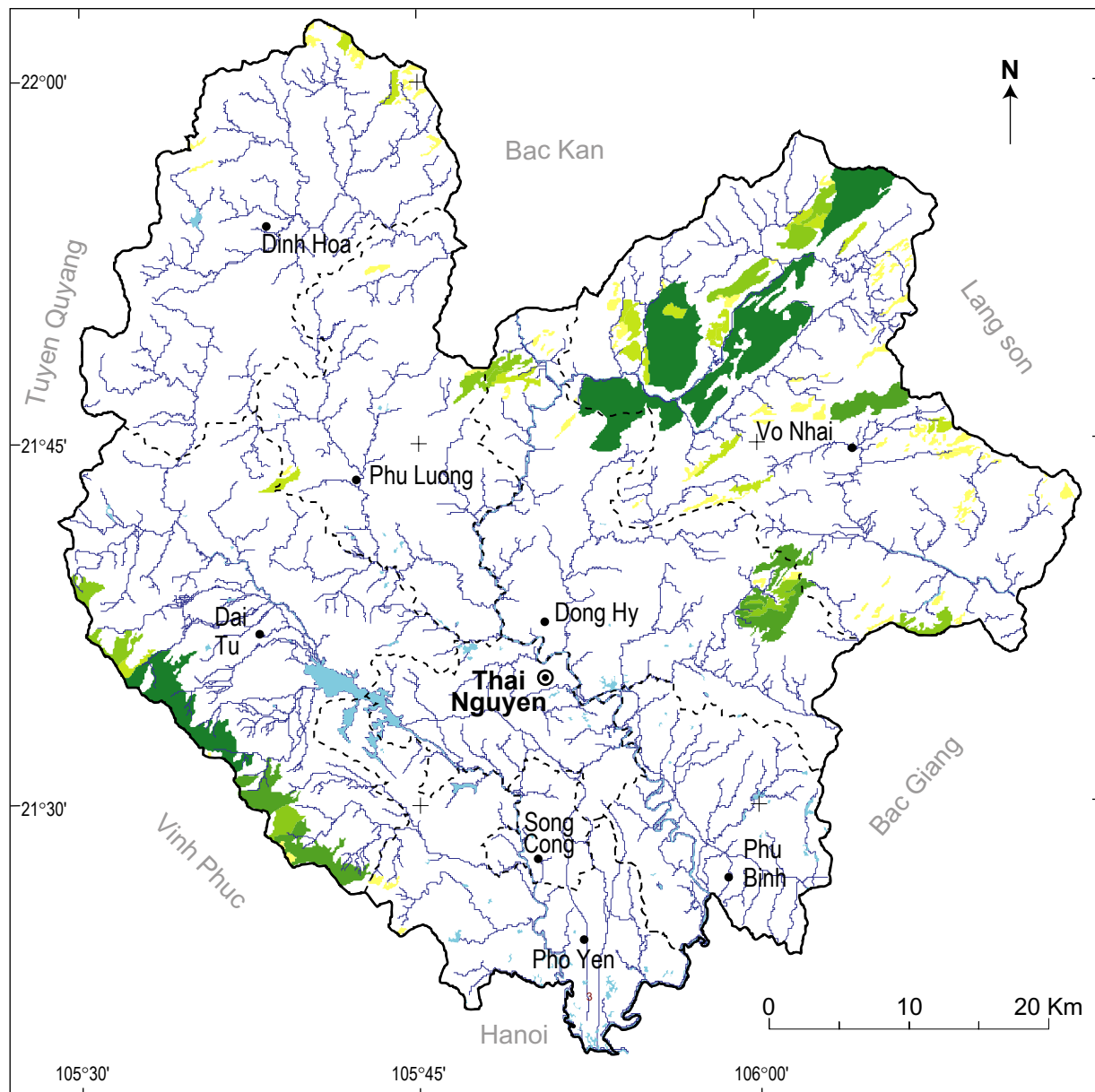
**Map 23 : Deforestation, Road and Hydrological Network, and Settlements in Vo Nhai**



- |   |   |
|---|---|
|  Dense forest on karst |  Road network        |
|  Dense forest          |  District boundaries |
|  Open forest on karst  |   |
|  Open forest           |   |
|  Settlements           |   |

Source : Programme SDT-CT94-0310

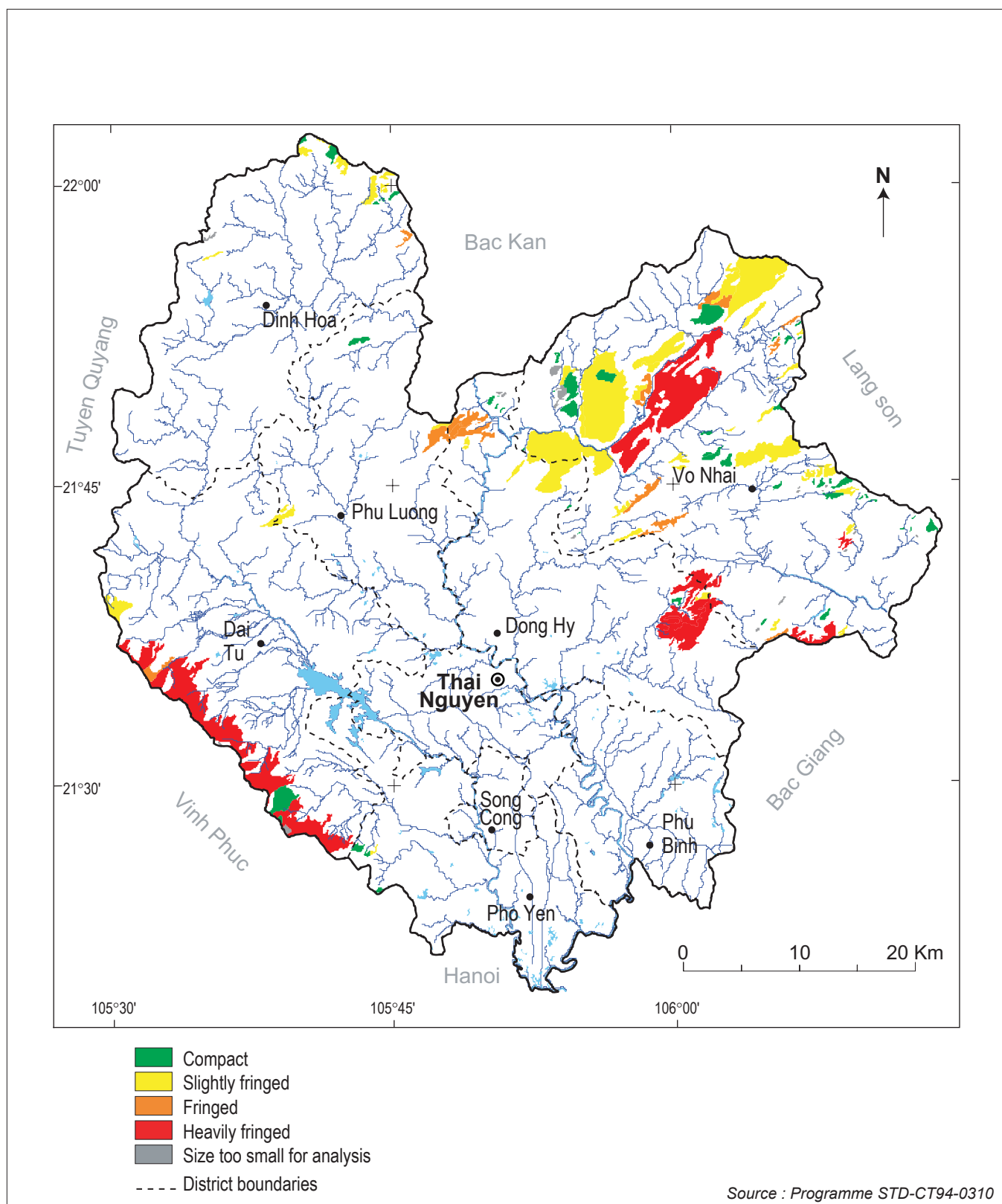
**Map 24 : Index of Forest Fragments Size**



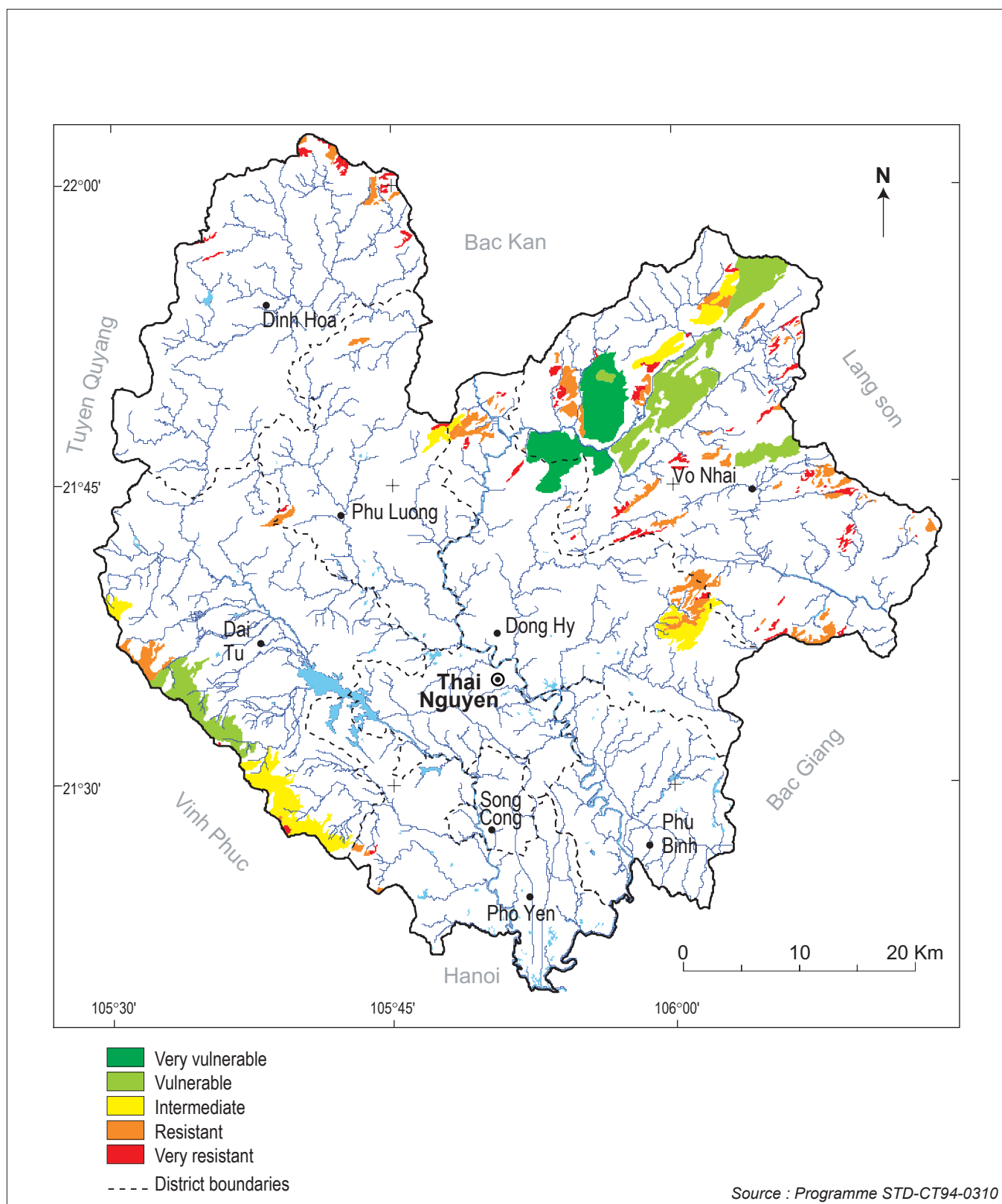
- Larger than 1,651 ha.
- Between 551 and 1,650 ha.
- Between 251 and 550 ha.
- Between 101 and 250 ha.
- Less than 100 ha.
- District boundaries

Source : Programme STD-CT94-0310

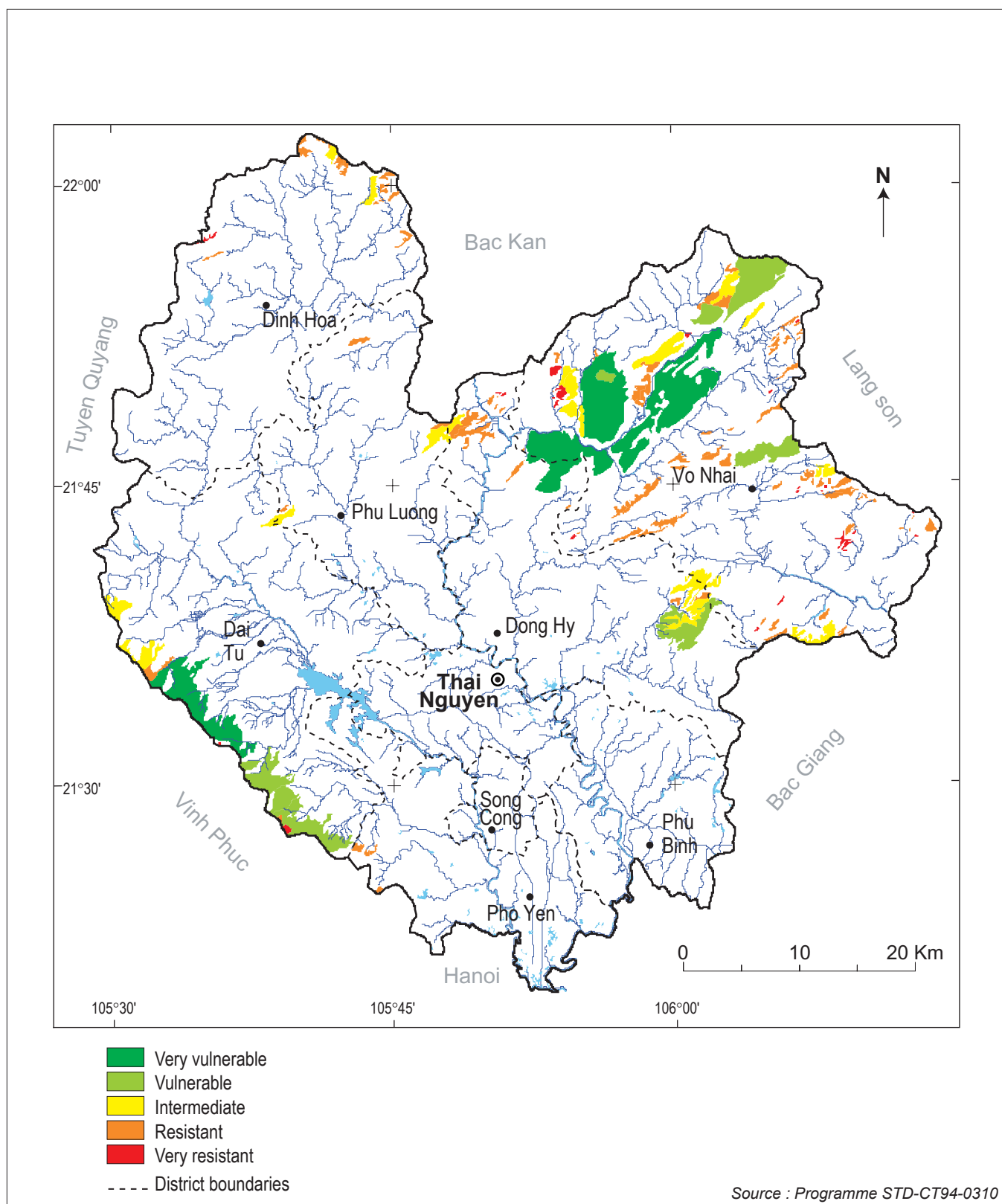
**Map 25 : Index of Forest Fragments Compactness**



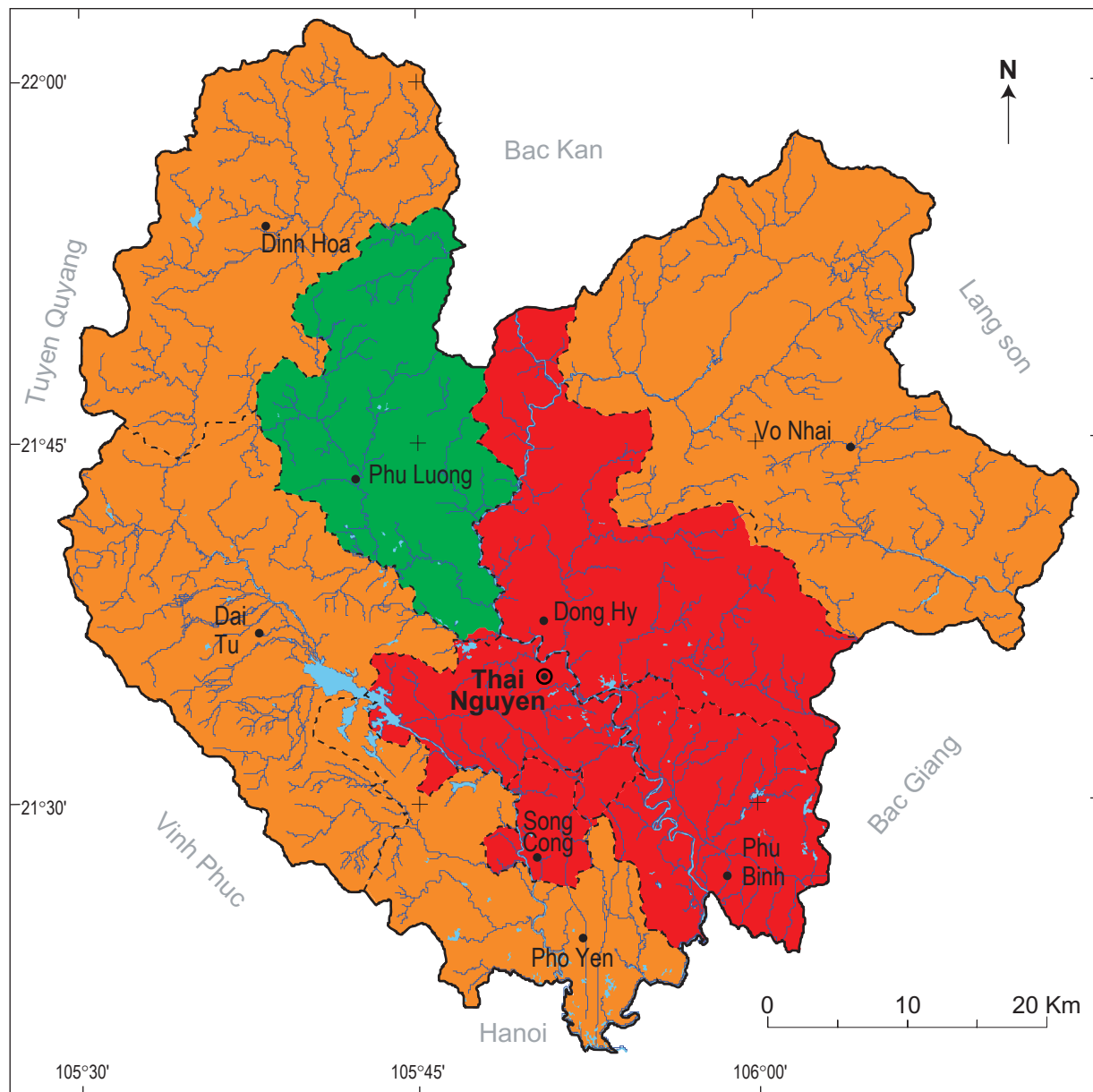
**Map 26 : Forest Vulnerability Status Index (Compactness : 3)**



**Map 27 : Forest Vulnerability Status Index (Compactness : 4)**



**Map 28 : Afforestation by district, 1993**

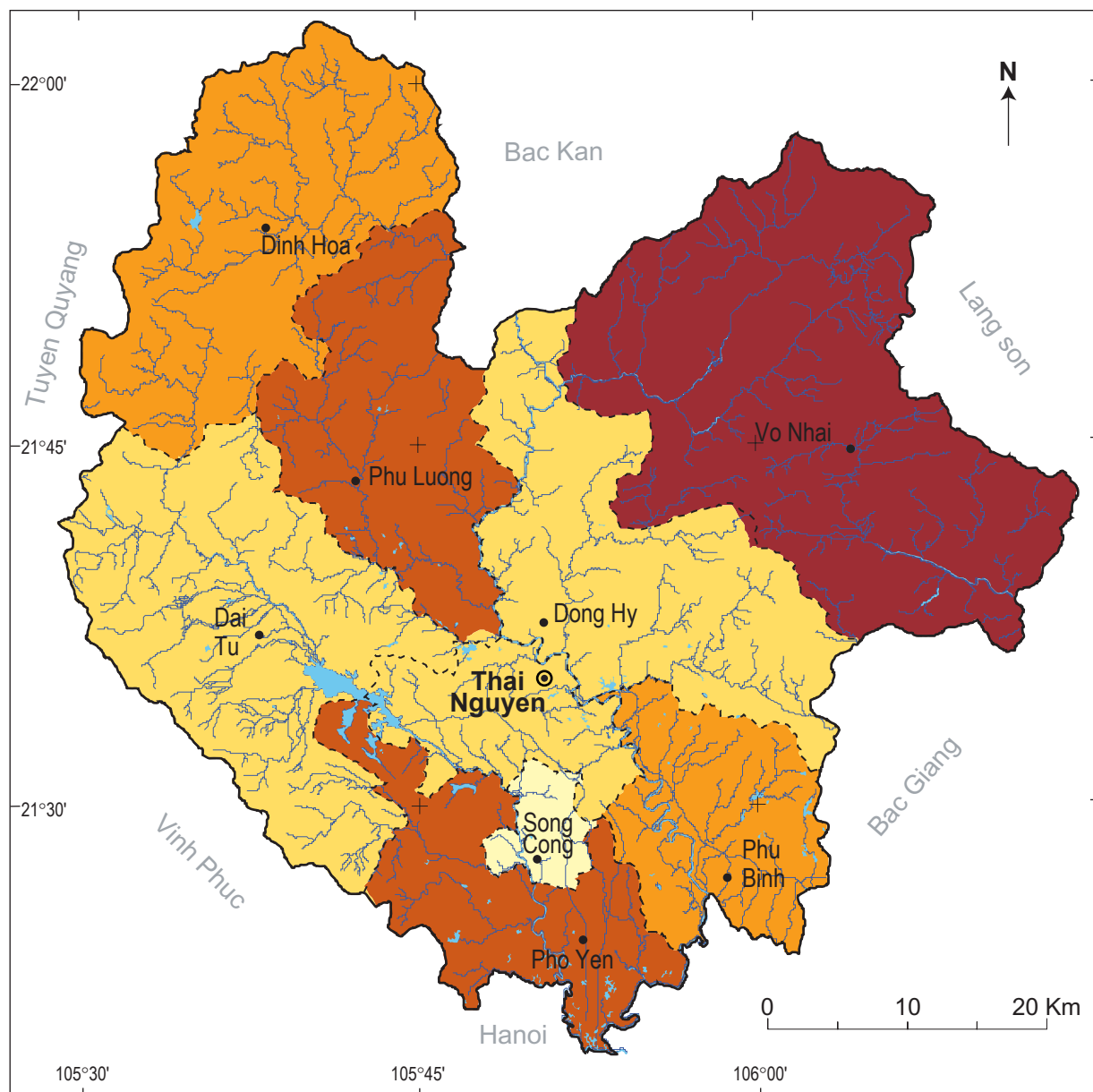


**Afforestation as a percentage of the total district area**

- More than 2%
- Between 1 and 2%
- Less than 1%
- District boundaries

Source : FIPI (1993)

**Map 29 : Reforestation by District, 1993**



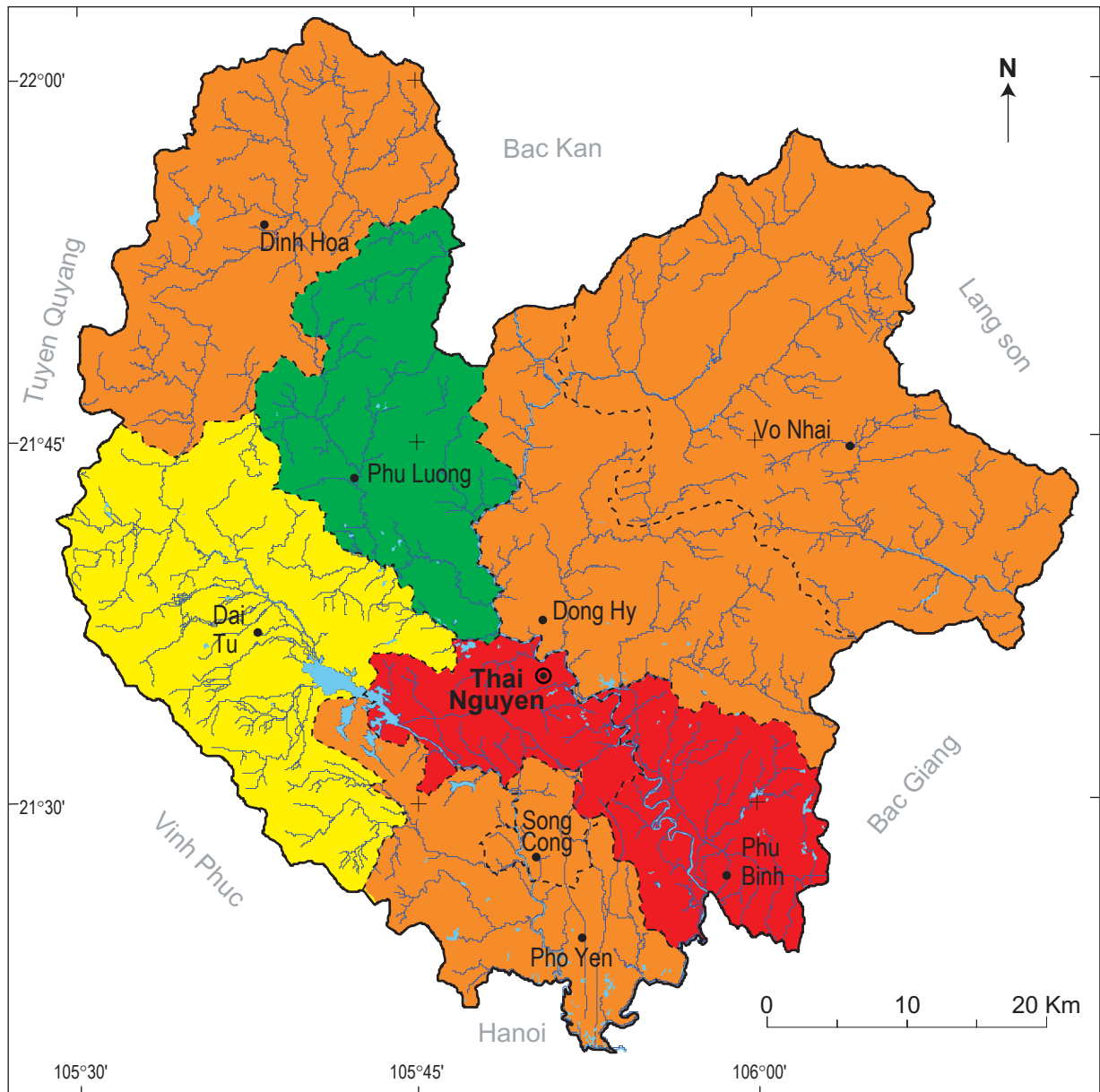
**Reforested land as a percentage of the total district area :**

- More than 1.2%
- Between 0.9 and 1.2%
- Between 0.6 and 0.9%
- Between 0.3 and 0.6%
- Less than 0.3%

--- District Boundaries

Source : FIPI (1993)

**Map 30 : Reforestation Index in 1993, by District**



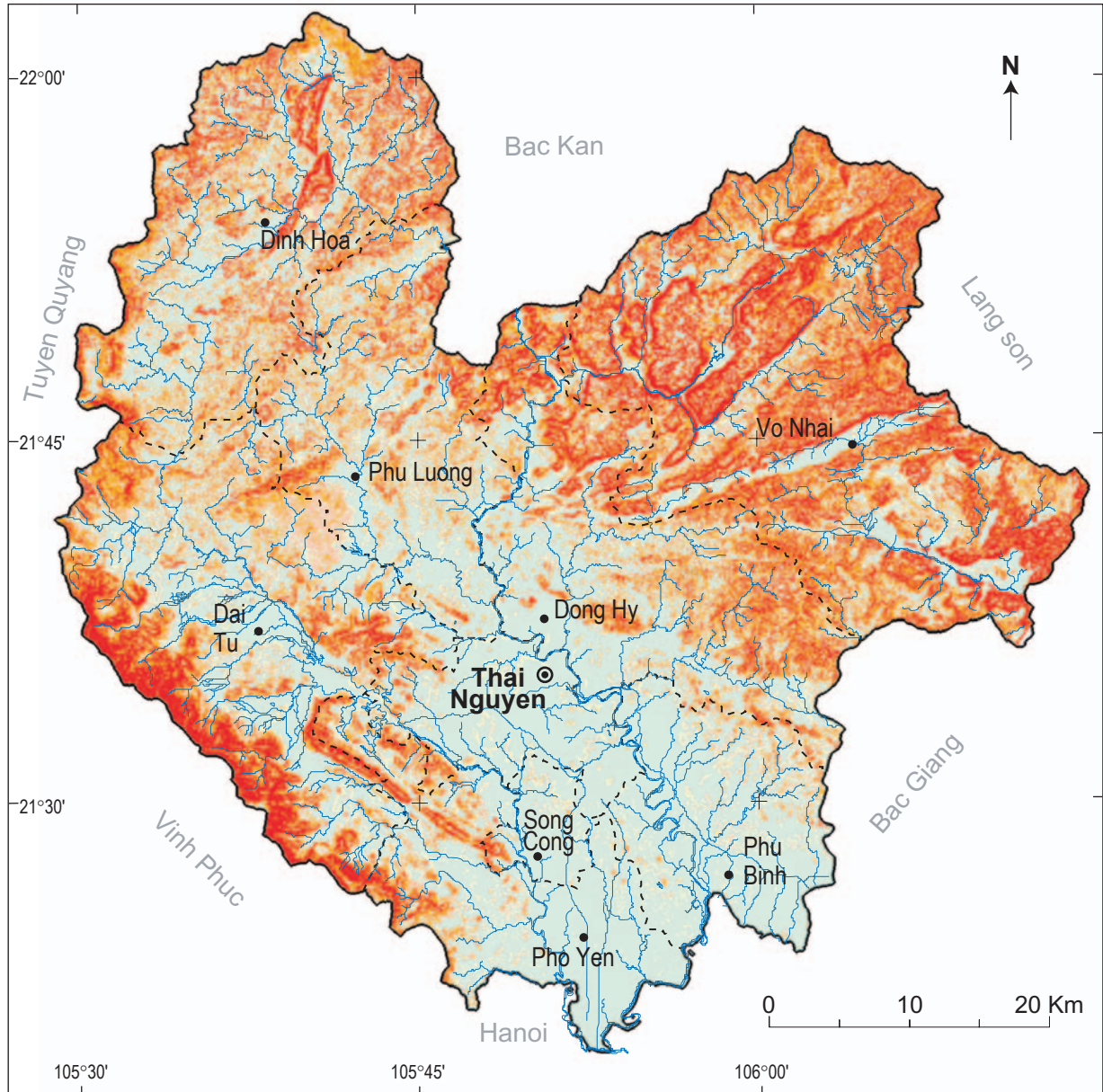
**Reforestation index in 1993**

- More than 3%
- Between 2 and 3%
- Between 1 and 2%
- Less than 1%

---- District boundaries

Source : FIPI (1994)

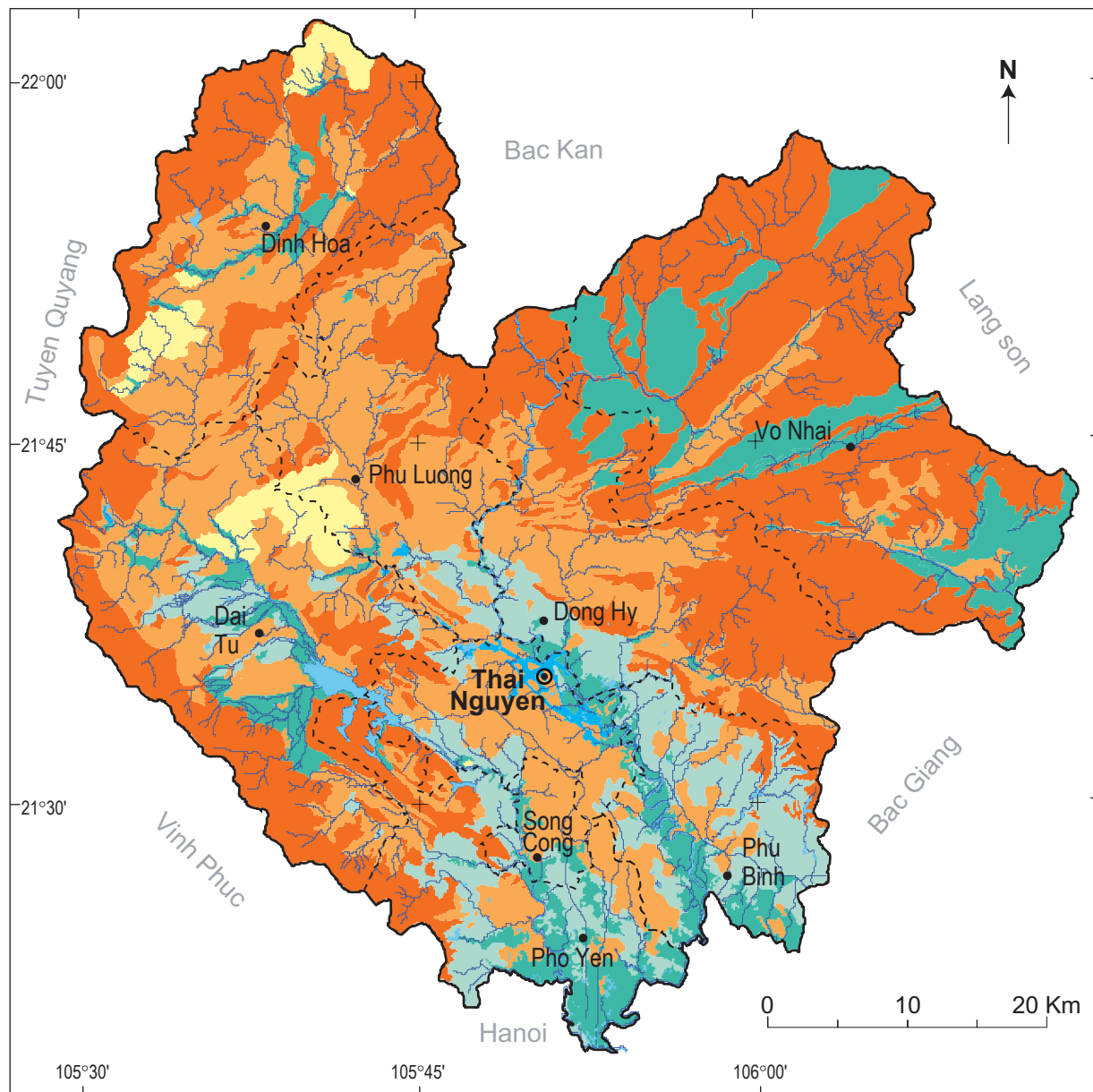
**Map 31 : Influence of Slope on Soil Erosion**



- Slope**
- 1. Less than 3%
  - 2. Between 4% and 8%
  - 3. Between 9% and 15%
  - 4. Between 16% and 40%
  - 5. More than 40%
- District boundaries

Source : Programme STD-CT94-0310

**Map 32 : Influence of Morpho-pedology on Soil Erosion**

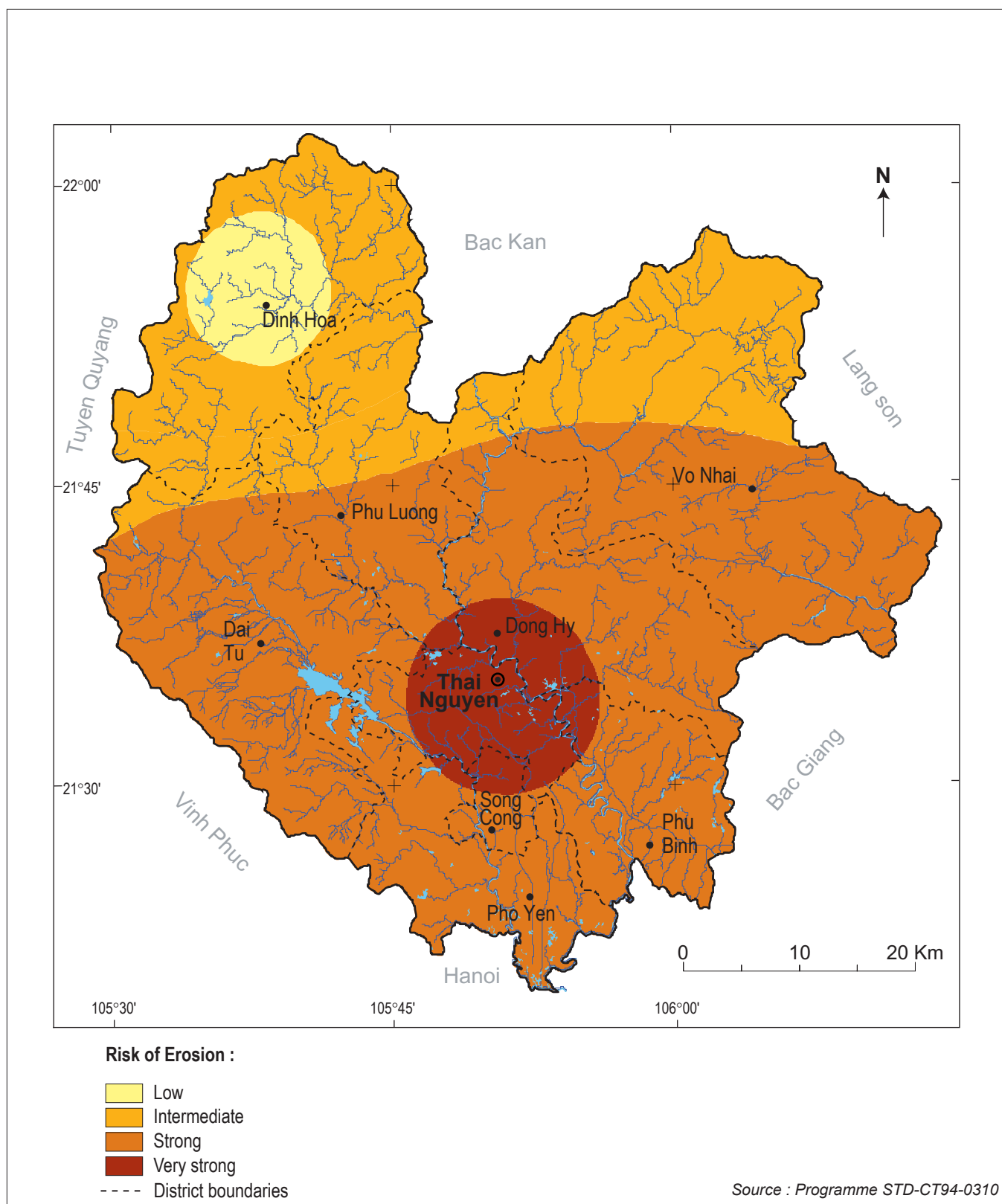


**Vulnerability to Erosion :**

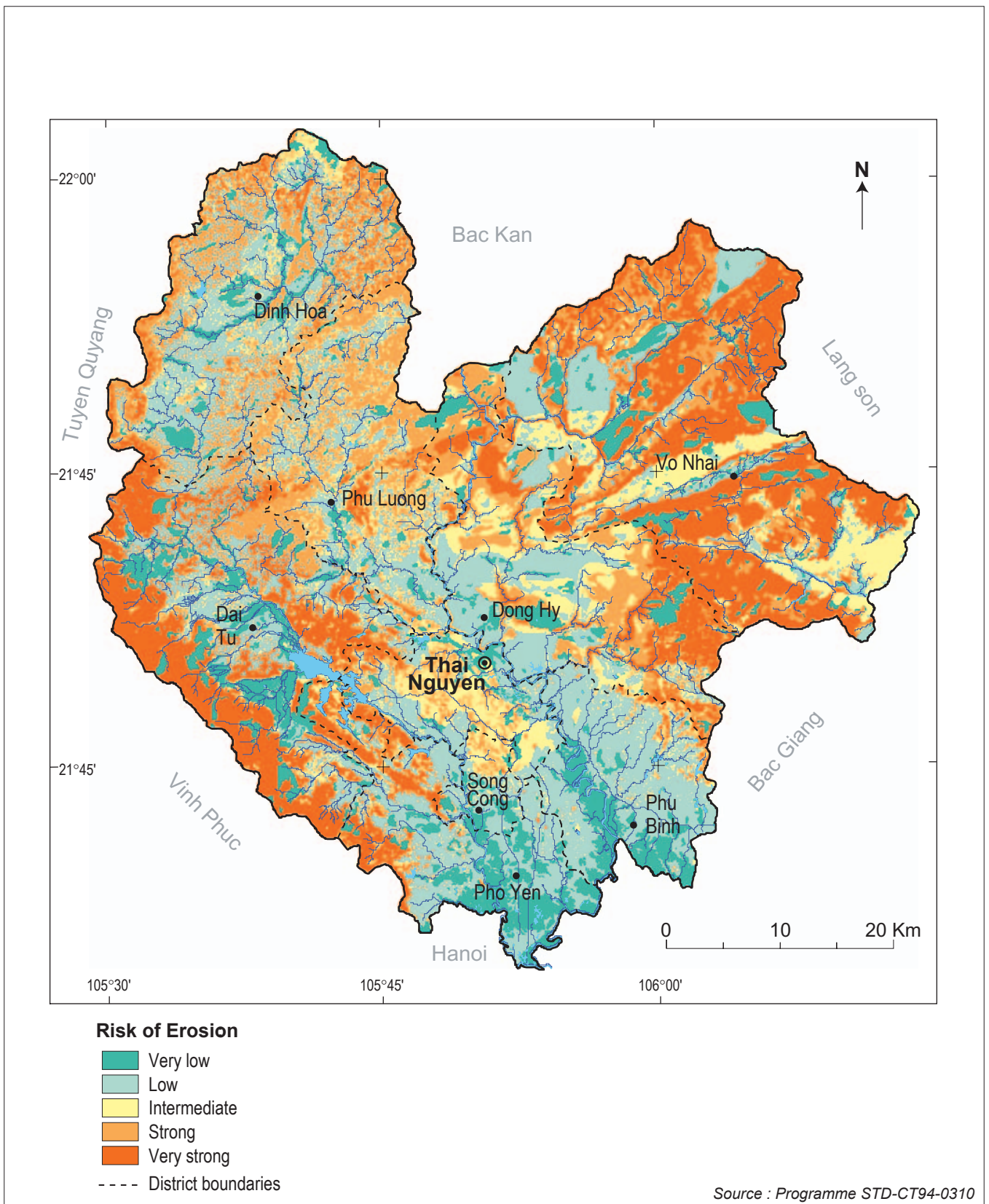
- Very resistant
- Resistant
- Intermediate
- Vulnerable
- Very vulnerable
- District boundaries

Source : Programme STD-CT94-0310

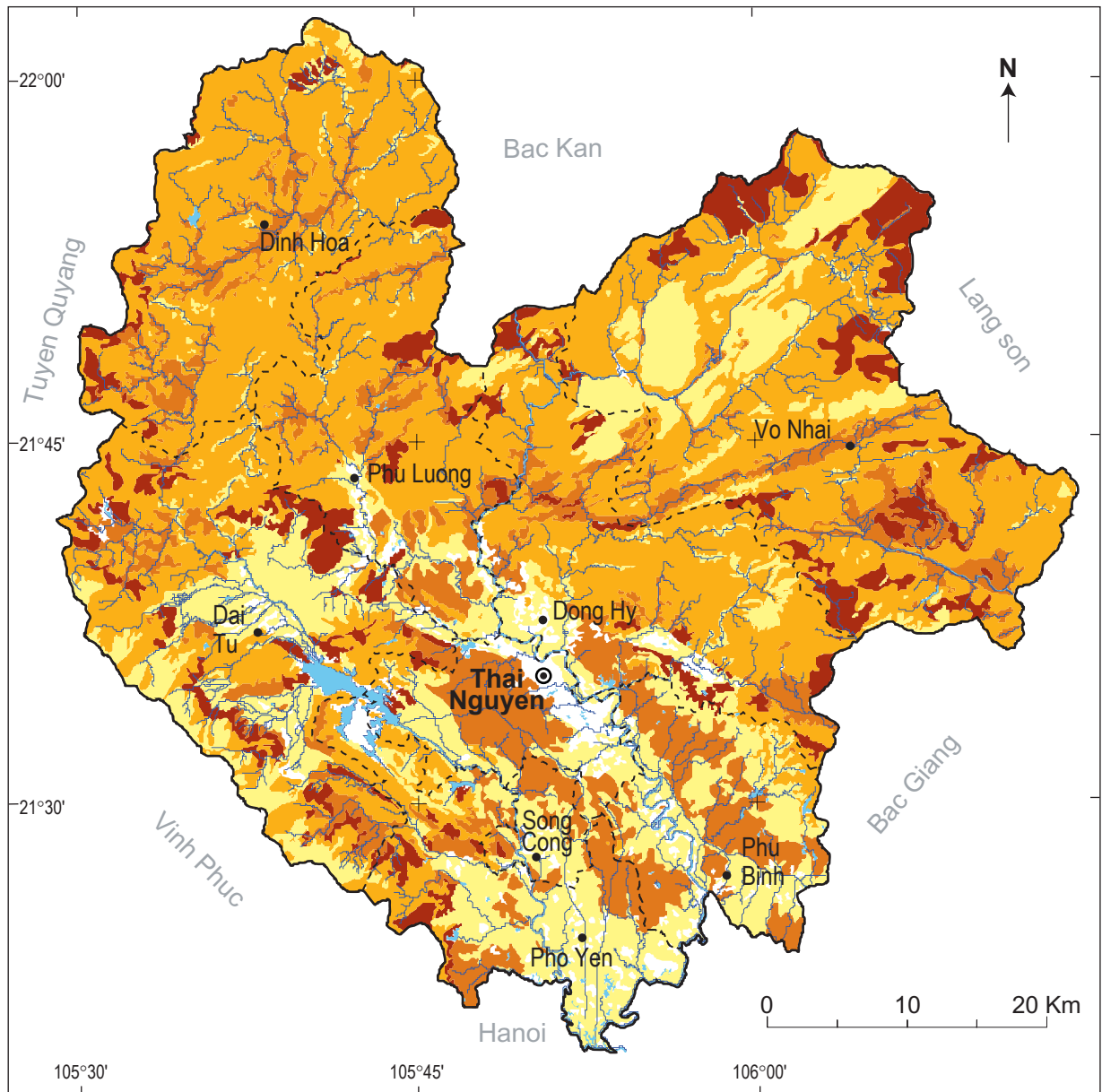
**Map 33 : Influence of Rainfall on Risk of Soil Erosion**



**Map 34 : Inherent Vulnerability of Soils to Erosion**



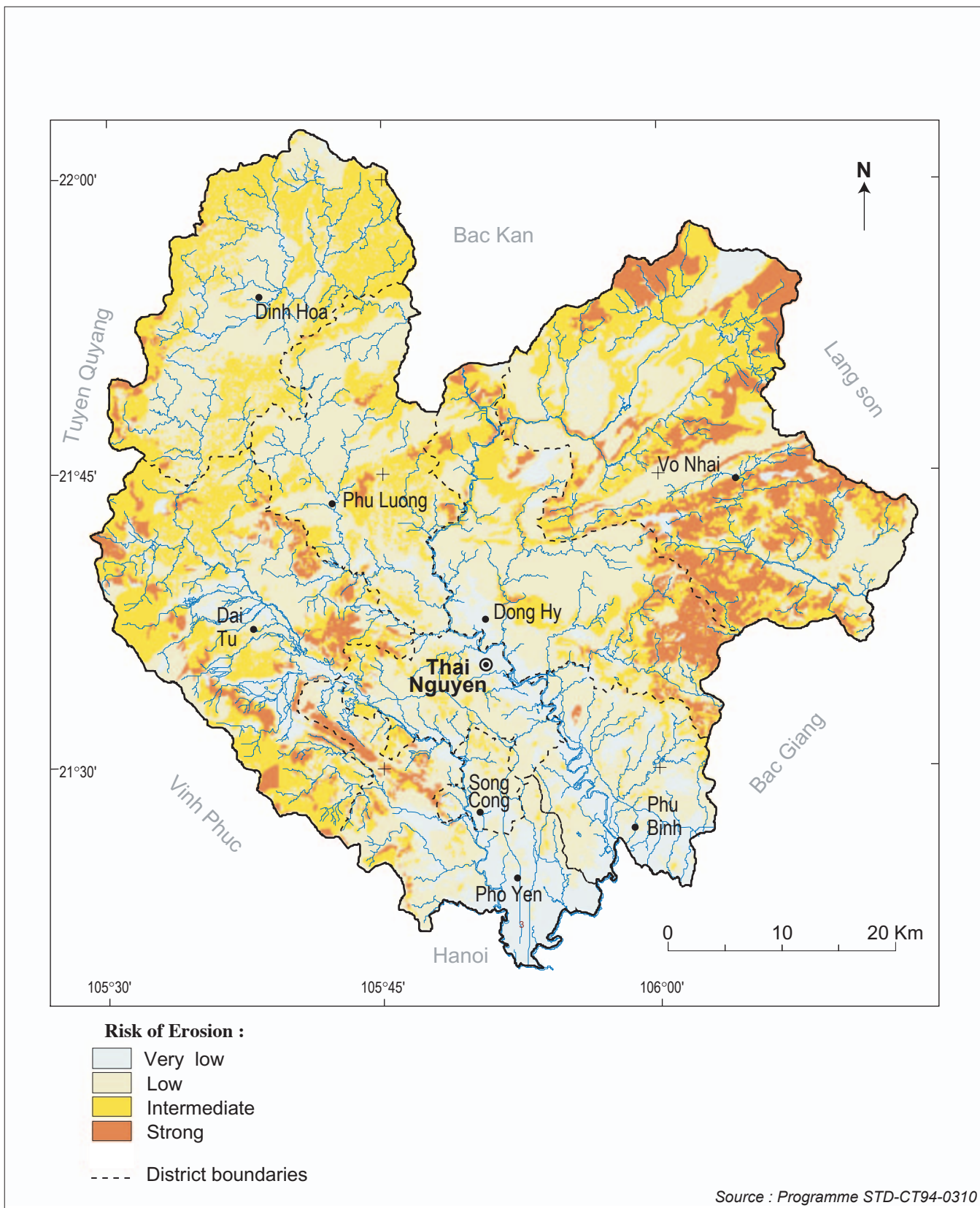
**Map 35 : Influence of Land Cover on Soil Erosion**



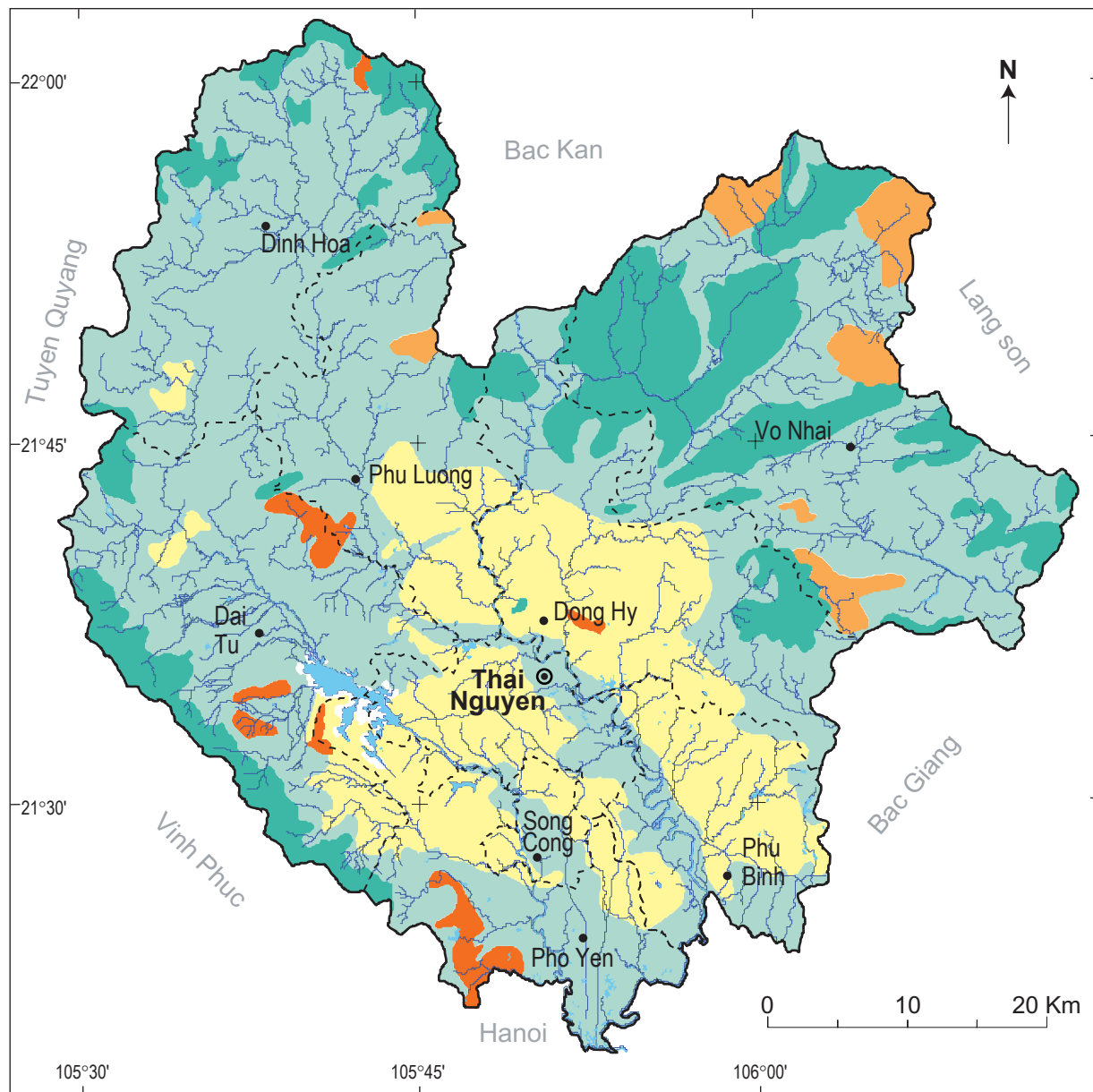
- Very low
- Low
- Low to intermediate
- Intermediate to strong
- District boundaries

Source : Programme STD-CT94-0310

**Map 36 : Soil Erosion Risk Index**



**Map 37 : Soil Erosion Status Index**

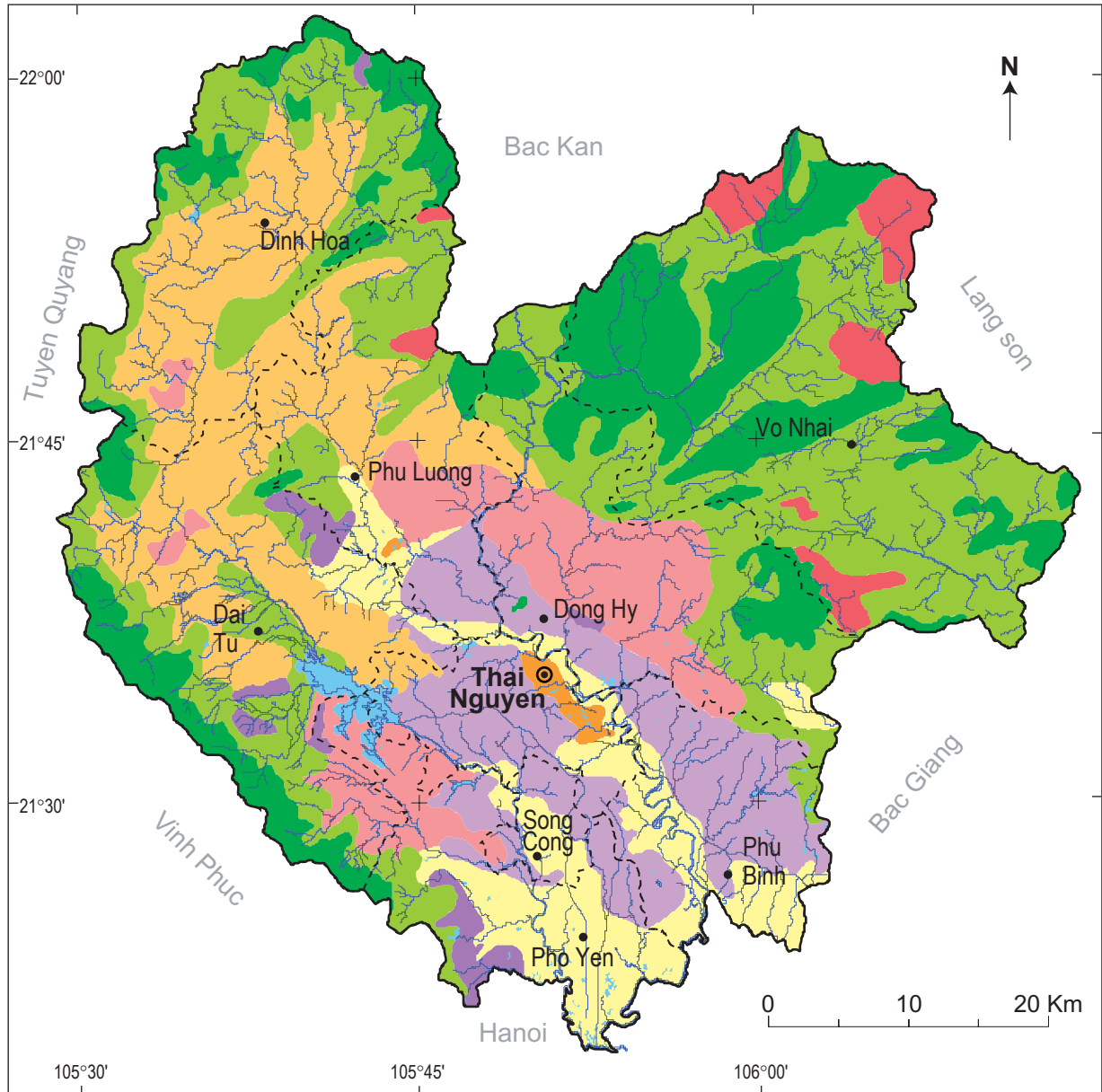


**Erosion status :**

- Very low
- Low
- Intermediate
- Strong
- Very strong
- District boundaries

Source : P. Brabant (1999)

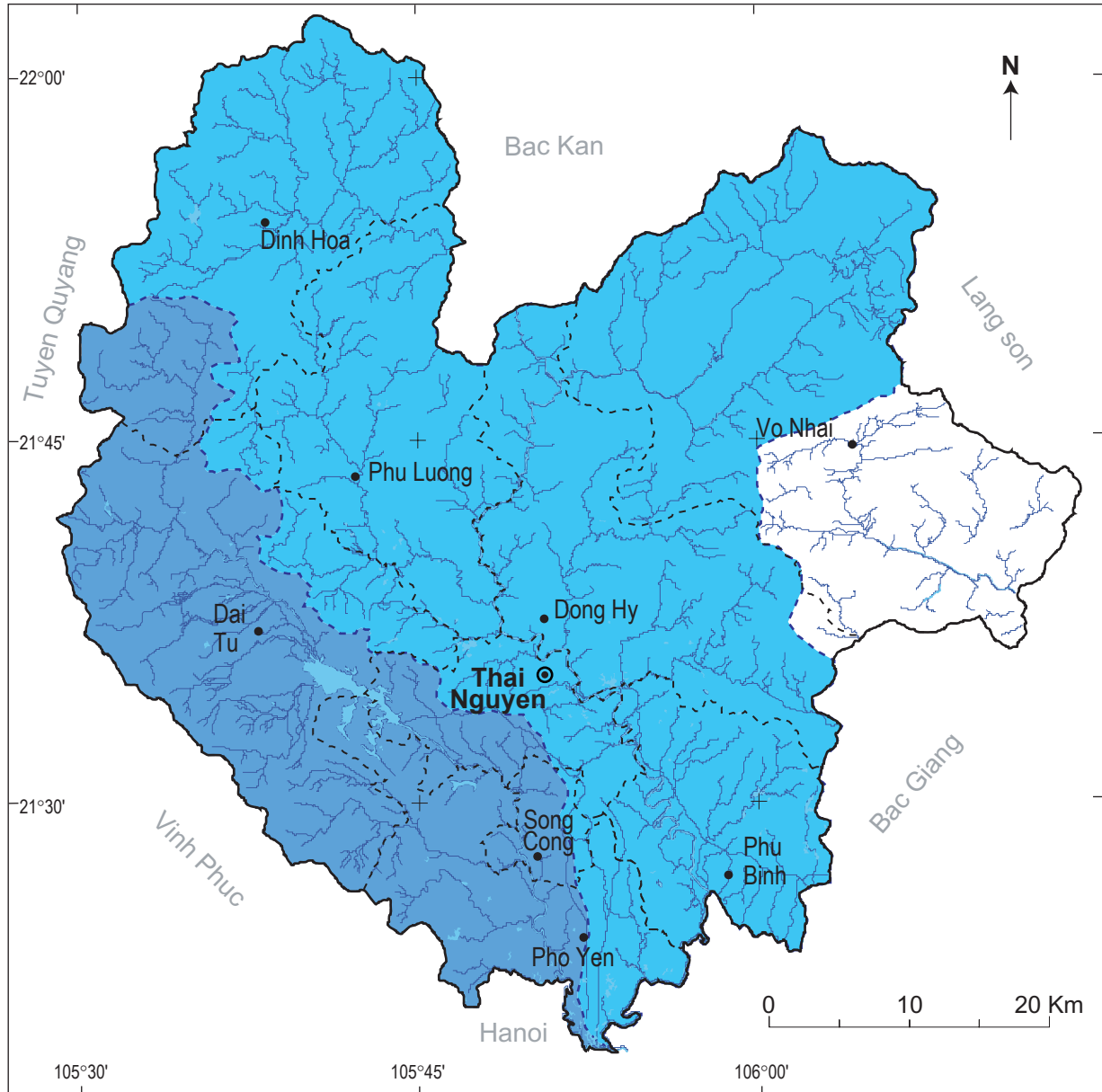
**Map 38 : Soil degradation Status Index**  
(water erosion and/or in situ degradation)



- Soil degradation status**
- 1 - Very low erosion
  - 2 - Low erosion
  - 3 - Intermediate degradation *in situ*
  - 3 - Intermediate erosion
  - 3 - Intermediate erosion and degradation *in situ*
  - 4 - Strong erosion
  - 4 - Strong erosion and degradation *in situ*
  - 5 - Very strong erosion
  - 5 - Very strong erosion and degradation *in situ*
  - District boundaries

Source : P. Brabant (1999)

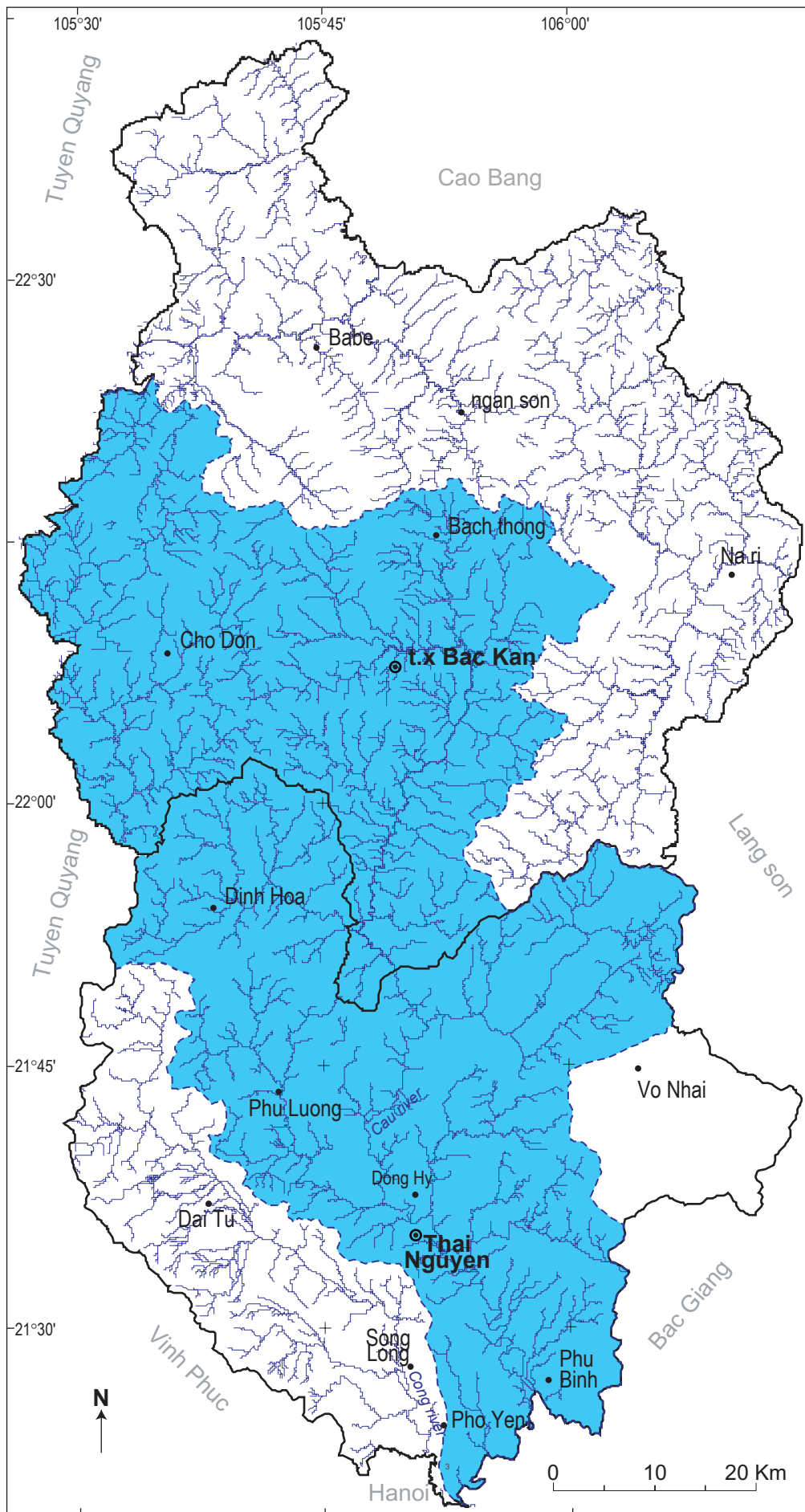
**Map 39 : Water Basins of the Cau and Cong Rivers**



- The Cong River Water Basin
- The Cau River Water Basin
- - - - District boundaries

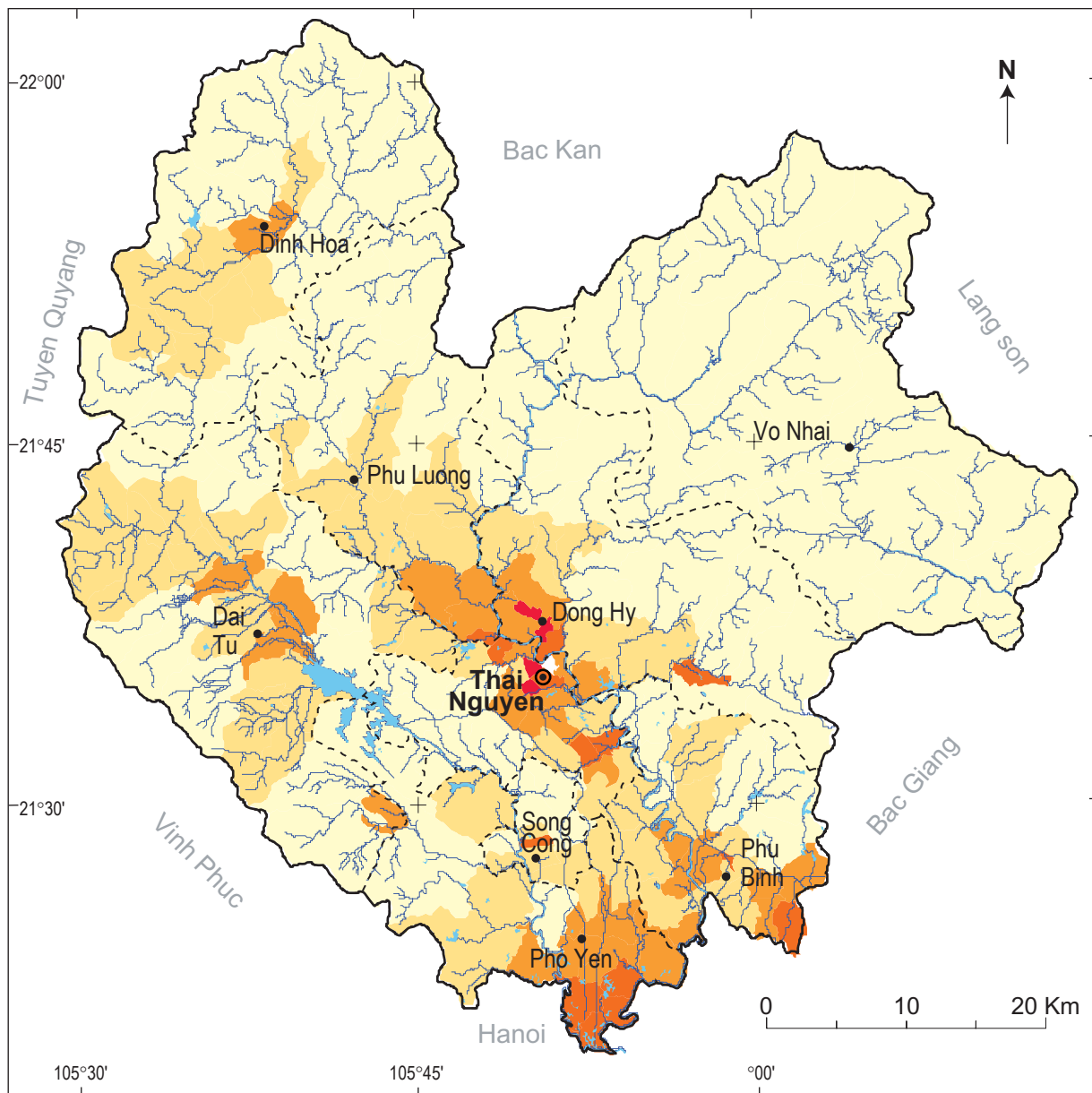
Source : Programme STD-CT94-0310

Map 40 : Water Basin of the Cau River in Thai Nguyen and Bac Kan Provinces



Basin of the Cau River

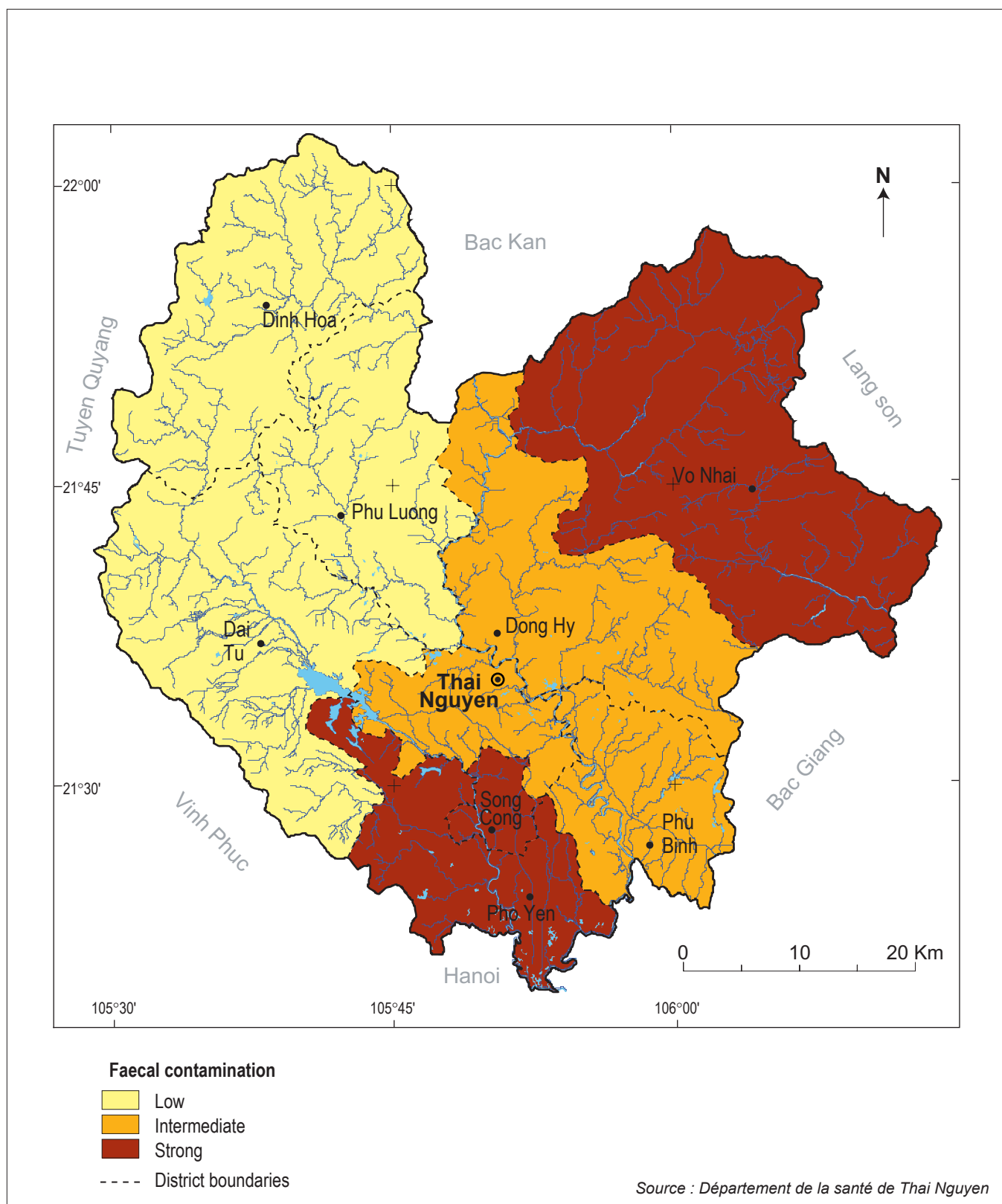
**Map 41 : Faecal Contamination Risk Index**



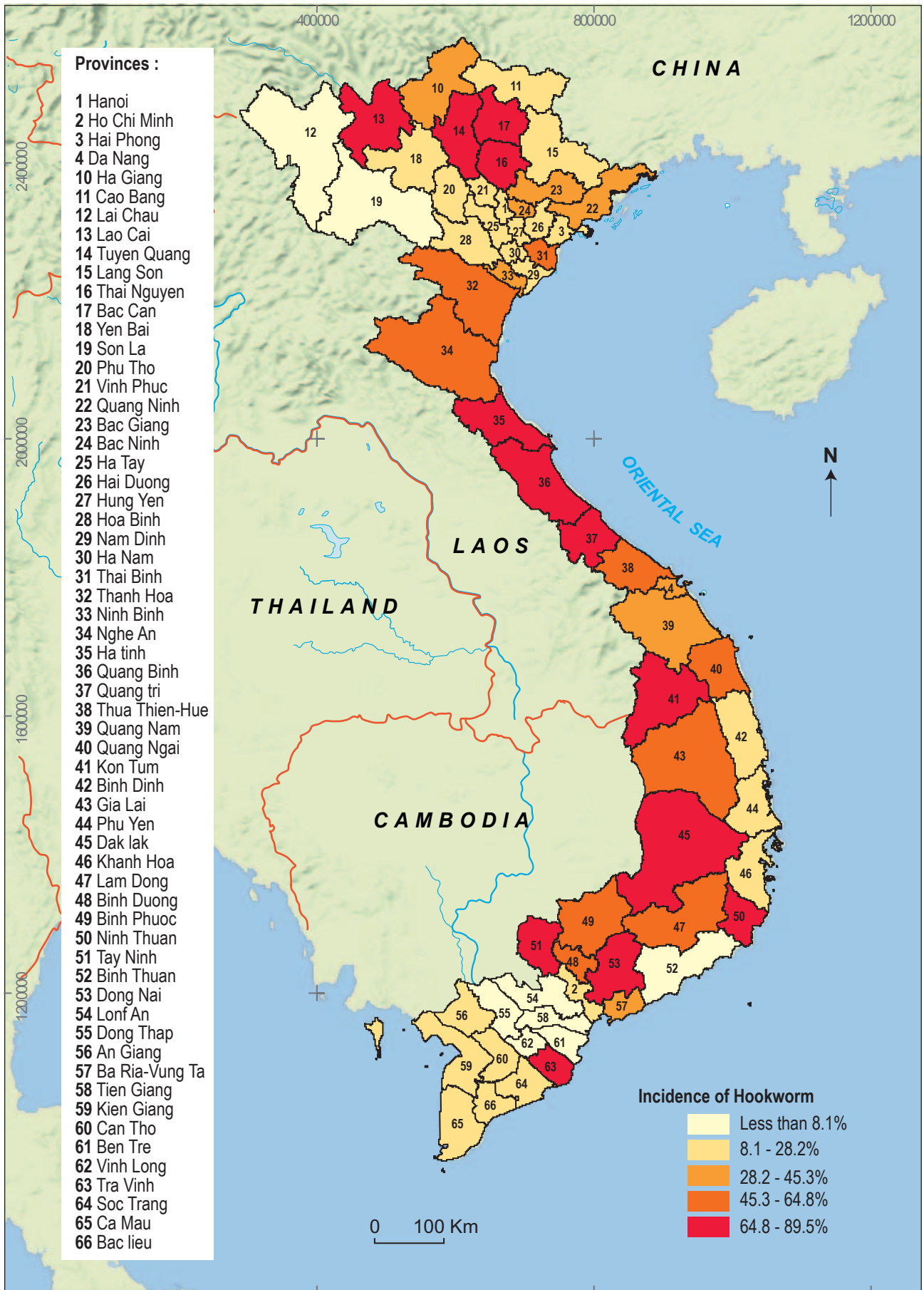
- Very low
- Low
- Intermediate
- Strong
- Very strong
- District boundaries

Source : Programme STD-CT94-0310

**Map 42 : Faecal Contamination Status Index, by District**

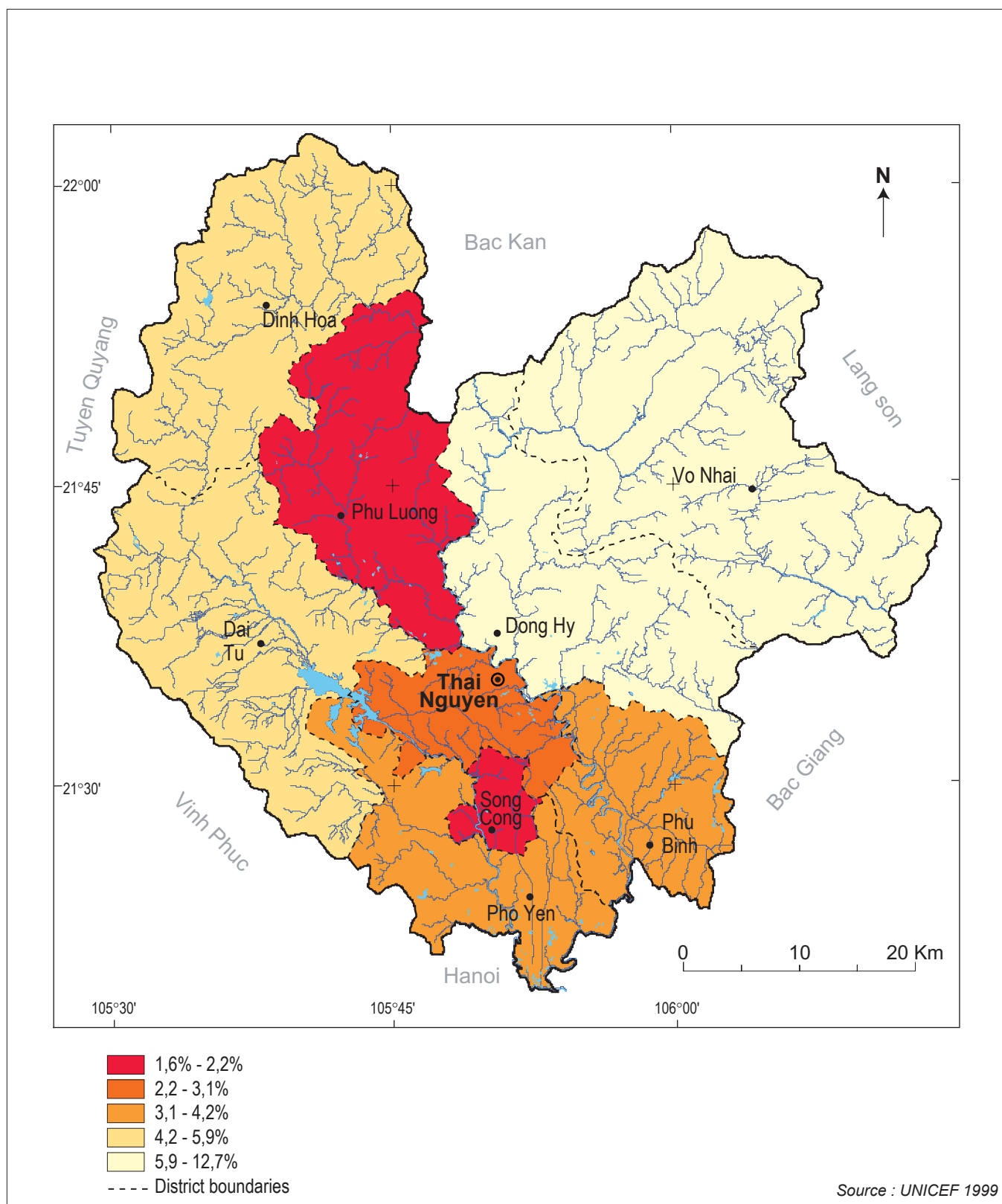


**Map 43 : Incidence of Hookworm in Vietnam**



Source : UNICEF / Institut national de nutrition (1995)

**Map 44 : Faecal Contamination Response Index**



## Appendix II - Photographs : landscapes, soils, forests, rivers in Thai Nguyen Province



P. Brabant

*Transition zone between lowland irrigated rice areas  
and the lower hills*



P. Brabant

*Steeply sloped uplands on schist*



P. Brabant

*A lower hills landscape*



P. Brabant

*Schist landscape with narrow valley  
irrigated rice cultivation*



P. Brabant

*A higher hills landscape*



P. Brabant

*Karstic landscape, with limestone substratum*

P. Brabant



*The Cau River, upstream of Thai Nguyen City*

P. Brabant



*Dense scrub covers post-deforestation fallow, and protect against soil erosion <sup>2</sup>*

B. Moeremans



*The Cong River at low flow*

P. Brabant



*Dense forest*

P. Brabant



*Upland soils on schist (acrisol) <sup>1</sup>*

P. Brabant



*Deforested land, abandoned after cultivation*

<sup>1</sup> The soil depth in the Uplands is, on average, 1.5 metres. It can be deeper than 2 metres, but is rarely less than 0.5 metre in steeply sloped land.

<sup>2</sup> Nevertheless, the erosion risk is high when the soil is not protected against erosion by vegetation or cultivation. This insert shows an example of strong erosion in a widely spaced eucalyptus plantation.

## **Appendix III : Main initiatives to establish integrated environmental and economic accounting systems**

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The importance of incorporating the environmental dimension into National Accounting Systems (SNA) was emphasised by the United Nations Conference for Environment and Development, held in Rio de Janeiro in 1992. Its message is clear: “*a programme to develop national systems of integrated environmental and economic accounting is proposed*” (Agenda 21, Chapter 8).

Although many experiments are being conducted, no country has yet established such a system. Henri M. Persin and Ernst Lutz (1993) have compared the various environmental accounting approaches implemented in seven industrialized countries - Germany, Canada, the United States, France, Japan, Netherlands and Norway. Their study concludes that while approaches differ substantially from one country to another, none stands out as significantly superior.

This diversity comes from the two distinct goals that environmental accounting can pursue – improved assessment of economic performance, and a better decision-making support system. At this stage, this diversity is hardly prejudicial, for the collected data are similar and the only difference lies in systems of interpretation. Environmental accounting efforts seem to progress in four major directions: integration of environmental damages and services, and changes in the stocks of natural capital into existing national accounts; construction of satellite, or parallel, accounts of the environment; development of natural resources accounts; and construction of patrimony accounts.

### **1.1 Expanded national accounts**

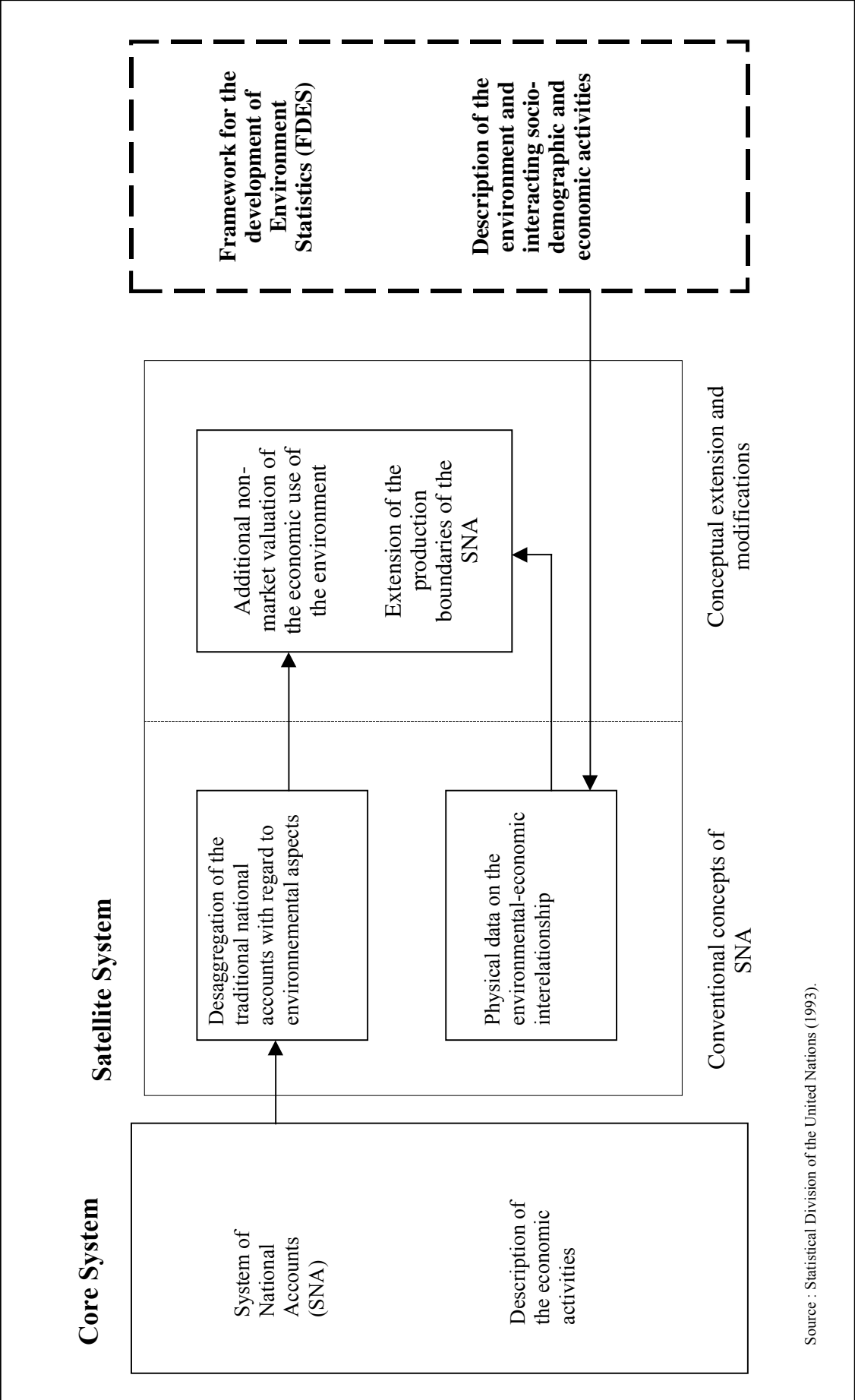
This approach, notably used by Canada (A. Comolet and R. Perelman, 1991), aims to incorporate environmental damage and services, and changes in the stocks of natural capital, into existing national accounts. Proponents of this approach stress that only a monetary quantification of environmental damage into rational economic accounting systems will ensure an incorporation of the environment into decision-making processes. But putting this approach into action is proving problematic because of difficulties in valuing the services provided by the environment. Estimating the value of non-renewable resources requires many assumptions as to the future value of these resources. To date, no agreement exists on a common methodology to quantify, in monetary terms, the environment’s life support functions.

Canada’s approach concentrates on the costs of pollution and natural resource depletion. However, it does not take into account environmental services such as waste purification.

### **1.2 Satellite accounts**

One alternative to modifying national accounts to include environment is to establish separate “satellite accounts”. This is the approach that the United Nations Systems and the EC’s EUROSTAT have adopted. The objective of satellite (or parallel) accounts is to link environmental datasets to unmodified national accounts. A figure 24 illustrates this approach, which was published by the United Nations Statistical Office (1993). Satellite accounts are designed to extend the statistical field in three directions – disaggregating of SNA monetary flows according to environmentally relevant criteria; identification of additional flows and stocks required to take into account the environmental aspects, which will be described in physical units; and development of additional monetary data on natural resource depletion and environmental damage.

Figure 24 : SNA (Satellite) System for Integrating Environmental and Economic Accounting (SEEA)



Source : Statistical Division of the United Nations (1993).

The information integrated in the satellite accounts provides the foundation for the construction of specific indicators that will supplement traditional macro-economic indicators. One of the principal applications of satellite accounts is thus to adjust the Gross National Product (GNP) and to make it possible to construct a “green GNP” with which to better assess the true economic performance of a country.

### 1.3 Natural resource accounts

This approach was developed by Norway, and presents a number of points that are common to the satellite accounts. It aims to improve natural capital stock management by supplementing the economic information provided by national accounts with an autonomous natural resource accounting system. This system distinguishes four categories of natural resources: mineral, biological, renewable and environmental. The term “environmental resources” includes those environmental elements that perform services rather than material factors to social production.

The fundamental principle of natural resource accounting is that goods and services are extracted from nature, used for social production and finally returned to nature having undergone modification during the production and consumption processes. This fundamental principle is reflected in the four types of information collected for each category: stocks, transformations by human activities, services rendered by resources and impact of human activities on natural resources. Figure 25, from the Economic and Social Council of the United Nations (1991), illustrates this concept.

**Figure 25 : General Measurement Concepts in Norwegian Resource Accounting**

<b>Resource classes (physical classes)/ Structure of resource accounting</b>	<b>Mineral Resources</b>	<b>Biological resources</b>	<b>Inflowing Resources</b>	<b>Status Resources</b>
Stocks and equivalents	Economically recoverable reserves	Populations	Generally not applicable	Availability and quality
Transformation by human activities	Extraction of materials	Active harvesting	Active and passive Harvesting	Direct Use
Services rendered by resources	Material input into production and consumption	Material input into production and consumption: direct amenities	Life-sustaining functions	Activity bases; Life-sustaining functions; direct amenities
impact of human activities on natural resources	Change in reserve bases	Population dynamics	Generally not applicable	Quality changes (including residuals disposal)

Sources: A. Kahnert, *Natural Resource Statistics- An Overview*. In : *Bulletin of the International Statistics Institute, Proceedings of the 44<sup>th</sup> Session, Madrid, 1983. Volume L. Book 2, Page 1303.*

This approach is concentrated on the natural resources cycle, and aims to optimise the use of those resources. It thus differs fundamentally from the approach that classifies natural resource use by economic objectives. Natural resource accounts do not claim to be comprehensive and do not aim to better measure economic performance or to adjust GNP. They are essentially used by the Norwegian government to facilitate the sustainable management of critical natural resources.

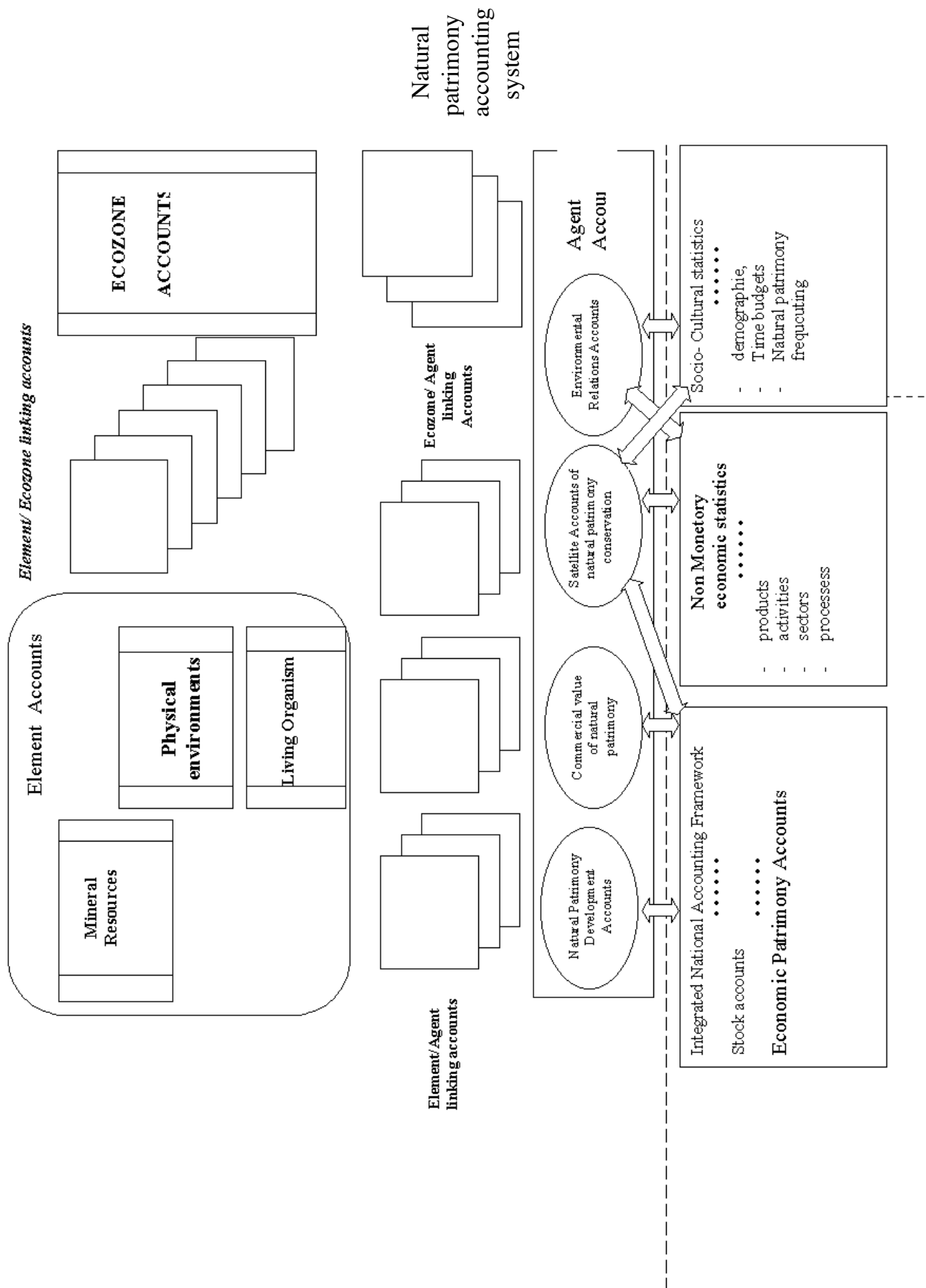
#### 1.4 Patrimony accounts

Patrimony accounts were developed in France, and show some similarities with the Norwegian natural resource accounts. They are, however, more ambitious insofar as they aim to cover simultaneously the economic, social and ecological aspects of the environment. The patrimony value of a resource considers not only its economic value, but its ecological and social value. M. Toulemon (1987) notes that an undisturbed natural area will see its economic and commercial value increase if it is cultivated, but its ecological or aesthetic value will not necessarily also increase.

Patrimony accounts try to capture these dimensions by using three types of accounts: (i) accounts of elements which analyses the increasing/decreasing trends of the various patrimony elements; (ii) the ecozone accounts which measure some of the relationships between patrimony elements within an ecosystem and aim primarily to describe ecozone health status; and (iii) agent accounts, which are designed to clarify the human influence on the natural patrimony. As specified in *Le Dossier* (1987) “agent accounts can be established in physical or monetary units. Accounts in physical units translate the pressure on the natural environment and the use of the element. Accounts in monetary units reflect the economic value of the patrimony or its management costs. They are linked to the national economic accounts”. Figure 26, produced by INSEE, shows the relationships between these accounts.

Because they are so ambitious, patrimony accounts have so far only been completed for some sectors, such as for freshwater. For the most part, existing patrimony accounts concentrate on natural resource accounts similar to the Norwegian accounts (E Lutz, 1993).

Figure 26 : Natural patrimony accounting system



## Appendix IV : Indicators suggested by the UN Commission for Sustainable Development

CHAPTERS OF AGENDA 21	DRIVING FORCE INDICATORS	STATE INDICATORS	RESPONSE INDICATORS
<b>CATEGORY - SOCIAL</b>			
Chapter 3 - Combating poverty	- Unemployment rate	- Head count index of poverty - Poverty gap index - Squared poverty gap index - Gini index of income inequality - Ratio of average female wage to male wage	
Chapter 5 - Demographic dynamics and sustainability	- Population growth rate - Net migration rate - Total fertility rate	- Population density	
Chapter 36 - Promoting education, public awareness and training	- Rate of change of school-age population - Primary school enrolment ratio (gross and net) - Secondary school enrolment ratio (gross and net) - Adult literacy rate	- Children reaching grade 5 of primary education - School life expectancy - Difference between male and female school enrolment ratios - Women per hundred men in the labour force	- GDP spent on education
Chapter 6 - Protecting and promoting human health		Basic sanitation: Per cent of population with adequate excreta disposal facilities - Access to safe drinking water - Life expectancy at birth - Adequate birth weight - Infant mortality rate - Maternal mortality rate - Nutritional status of children	- Immunization against infectious childhood diseases - Contraceptive prevalence - Proportion of potentially hazardous chemicals monitored in food - National health expenditure devoted to local health care - Total national health expenditure related to GNP
Chapter 7 - Promoting sustainable human settlement development	- Rate of growth of urban population - Per capita consumption of fossil fuel by motor vehicle transport - Human and Economic loss due to natural disasters	- Per cent of population in urban areas - Area and population of urban formal and informal settlements - Floor area per person - House price to income ratio	- Infrastructure expenditure per capita
<b>CATEGORY - ECONOMIC</b>			
Chapter 2 - International cooperation to accelerate sustainable development in countries and related domestic policies  Chapter 4 - Changing consumption patterns	- GDP per capita - Net investment share in GDP - Sum of exports and imports as a per cent of GDP  - Annual energy consumption - Share of natural-resource intensive industries in manufacturing value-added	- Environmentally adjusted Net Domestic Product - Share of manufactured goods in total merchandise exports  - Proven mineral reserves - Proven fossil fuel energy reserves - Lifetime of proven energy reserves - Intensity of material use - Share of manufacturing value-added in GDP - Share of consumption of renewable energy resources	
Chapter 33 - Financial resources and mechanisms	- Net resources transfer / NGP - Total ODA given or received as a percentage of GNP	- Debt / GNP - Debt service / export	- Environment protection expenditures as a per cent of GDP - Amount of new or additional funding for sustainable development

<b>CHAPTERS OF AGENDA 21</b>	<b>DRIVING FORCE INDICATORS</b>	<b>STATE INDICATORS</b>	<b>RESPONSE INDICATORS</b>
Chapter 34 - Transfer of environmentally sound technology, cooperation and capacity-building	- Capital goods imports - Foreign direct investments	- Share of environmentally sound capital goods imports	- Amount of new or additional funding for sustainable development - Technical cooperation grants
<b>CATEGORY - ENVIRONMENT</b>			
Chapter 18: Protection of the quality and supply of freshwater resources	- Annual withdrawals of ground and surface water - Domestic consumption of water per capita	- Groundwater reserves - Concentration of faecal coliform in freshwater - Biochemical oxygen demand in water bodies	- Waste-water treatment coverage - Density of hydrological networks
Chapter 17 - Protection of the oceans, all kinds of seas and coastal areas	- Population growth in coastal areas - Discharges of oil into coastal waters - Releases of nitrogen and phosphorus to coastal waters	- Maximum sustained yield for fisheries - Algae index	
Chapter 10 - Integrated approach to the planning and management of land resources	- Land use change	- Changes in land condition	- Decentralized local-level natural resource management
Chapter 12 - Managing fragile ecosystems: combating desertification and drought	- Population living below poverty line in dryland areas	- National monthly rainfall index - Satellite derived vegetation index - Land affected by desertification	
Chapter 13 - Managing fragile ecosystems: sustainable mountain development	- Population change in mountain areas	- Sustainable use of natural resources in mountain areas - Welfare of mountain populations	
Chapter 14 - Promoting sustainable agriculture and rural development	- Use of agricultural pesticides - Use of fertilizers - Irrigation per cent of arable land - Energy use in agriculture	- Arable land per capita - Area affected by salinization and waterlogging	- Agricultural education
Chapter 11 - Combating deforestation	- Wood harvesting intensity	- Forest area change	- Managed forest area ratio - Protected forest area as a per cent of total forest area
Chapter 15 - Conservation of biological diversity		- Threatened species as a per cent of total native species	- Protected area as a per cent of total area
Chapter 16 - Environmentally sound management of biotechnology			- R&D expenditure for biotechnology - Existence of national biosafety regulations or guidelines
Chapter 9 - Protection of the atmosphere	- Emissions of greenhouse gases - Emissions of sulphur oxides - Emissions on nitrogen oxides - Consumption of ozone depleting substances	- Ambient concentrations of pollutants in urban areas	- Expenditure on air pollution abatement
Chapter 21 - Environmentally sound management of solid wastes and sewage-related issues	- Generation of industrial and municipal solid waste - Household waste disposed per capita		- Expenditure on waste management - Waste recycling and reuse - Municipal waste disposal

<b>CHAPTERS OF AGENDA 21</b>	<b>DRIVING FORCE INDICATORS</b>	<b>STATE INDICATORS</b>	<b>RESPONSE INDICATORS</b>
Chapter 19 - Environmentally sound management of toxic chemicals		- Chemically induced acute poisonings	- Number of chemicals banned or severely restricted
Chapter 20 - Environmentally sound management of hazardous wastes	- Generation of hazardous wastes - Imports and exports of hazardous wastes	- Area of land contaminated by hazardous wastes	- Expenditure on hazardous waste treatment
Chapter 22 - Safe and environmentally sound management of radioactive waste	- Generation of radioactive wastes	- Area of land contaminated by hazardous wastes	- Expenditure on hazardous waste treatment
<b>CATEGORY: INSTITUTIONAL</b>			
Chapter 8 - Integrating environment and development in decision-making			- Sustainable development strategies - Programme of integrated environmental and economic accounting - Mandated Environmental Impact Assessment - National councils for sustainable development
Chapter 35 - Science for sustainable development		- Potential scientists and engineers per million population	- Scientists and engineers engaged in R&D per million population - Expenditure on R&D as a percent of GDP
Chapter 37 - National mechanisms and international cooperation for capacity-building in developing countries			
Chapter 38 - International institutional arrangements			
Chapter 39 - International legal instruments and mechanisms			- Ratification of global agreements - Implementation of ratified global agreements
Chapter 40 - Information for decision-making		- Main telephone lines per 100 inhabitants	- Programmes for national environmental statistics
Chapter 23-32 - Strengthening the role of major groups			- Representation of major groups in national councils for sustainable development - Representatives of ethnic minorities and indigenous people in national councils for sustainable development - Contribution of NGOs to sustainable development

## Appendix V : Analysis of the Cau River's available water quality data

Vietnam is still to develop overall assessment guidelines for the quality of river water. To illustrate the type of data required, Table 67 compares the water quality data available for the Cau River with the assessment grid used by the Watershed Agency ADOUR-GARONNE in France.

**Table 67 - Cau River Water Quality: An Evaluation Using the Adour - Garonne Assessment Grid**

Parameters	1A	1B	2	3	Cau River	
					Thac Buoi	Gia Bay
Conductivity _S/cm to 20 _C	400	400 to 750	750 to 1500	1500 to 3000		
Temperature	20	20 to 22	22 to 25	25 to 30	23,8	24,6
PH	6,5 to 8,5	6,5 to 8,5	6 to 9	5,5 to 9,5	7,1	7,2
Suspended Solid (mg.l <sup>-1</sup> )	30	30	30	30 to 70	245	
Dissolved O <sub>2</sub> (mg.l <sup>-1</sup> )	7	5 to 7	3 to 5	MAMP		
Dissolved O <sub>2</sub> i n % de saturation	90%	70 to 90	50 to 70	MAMP <sup>1</sup>		
BOD <sub>5</sub> (mg.l <sup>-1</sup> )	3	3 to 5	5 to 10	10 to 25		
Oxydability (mg.l <sup>-1</sup> )	3	3 to 5	5 to 8		1,29	1,84
COD (mg.l <sup>-1</sup> )	20	20 to 25	25 to 40	40 to 80		
NH <sub>4</sub> (mg.l <sup>-1</sup> )	0,1	0,1 to 0,5	0,5 to 2	2 to 8		
NO <sub>3</sub> (mg.l <sup>-1</sup> )			_44	44 to 100		
N total (Kjeldahl)	1	1 to 2	2 to 3			
Fe (mg.l <sup>-1</sup> )	0,5	0,5 to 1	1 to 1,5		0,44	0,28
Mn (mg.l <sup>-1</sup> )	0,1	0,1 to 0,25	0,25 to 0,50			
F (mg.l <sup>-1</sup> )	0,7	0,7 to 1,7	0,7 to 1,7	1,7		
Cu (mg.l <sup>-1</sup> )	0,02	0,02 to 0,05	0,05 to 1	1		
Zn (mg.l <sup>-1</sup> )	0,5	0,5 to 1	1 to 5	5		
As (mg.l <sup>-1</sup> )	0,01	0,01	0,01 to 0,05	0,05		
Cd (mg.l <sup>-1</sup> )	0,001	0,001	0,001	0,001		
Cr (mg.l <sup>-1</sup> )	0,05	0,05	0,05	0,05		
CN (mg.l <sup>-1</sup> )	0,05	0,05	0,05	0,05		
Pb (mg.l <sup>-1</sup> )	0,05	0,05	0,05	0,05		
Se (mg.l <sup>-1</sup> )	0,01	0,01	0,01	0,01		
Hg (mg.l <sup>-1</sup> )	0,0005	0,0005	0,0005	0,0005		
Phenols (mg.l <sup>-1</sup> )		0,001	0,001 to 0,05	0,05 to 0,5		
Détergents (mg.l <sup>-1</sup> )	0,2	0,2	0,2 to 0,5	0,5		
S.E.C (mg.l <sup>-1</sup> )	_0,2	0,2 to 0,5	0,5 to 1	1		
Coliforms (Num.100ml)	50	50 to 5000	5000-50000			
<i>Esch. coli</i> (Num.100ml)	20	20 to 2000	2000-20000			
Fec. strep. (Num.100ml)	_20	20 to 1000	1000-10000			
Diff. Between biotic index and standard index	1	2 ou 3	4 ou 5	6 ou 7		

(Grid used by the Water Basin Agency ADOUR-GARONNE, after Degremont, 1989)

The classes of water quality identified by the Adour-Garonne grid are:

- Class 1A. Water considered as pollution free, which satisfies the most quality demanding uses.
- Class 1B. Water of a slightly lower quality – this water can nevertheless satisfy all uses.
- Class 2. “Passable” quality: sufficient for irrigation, industrial uses, and drinking water supply after thorough treatment. Watering of animals is generally tolerated. Fish live in this water normally, but its breeding can be uncertain. Recreation activities related to water are possible when only exceptional contact with the water is involved.
- Class 3. “Poor” quality: only suited to irrigation, cooling and transport. This water can support pisciculture, but the survival of the fish is uncertain in periods of low flow or of high temperature, for example.
- Off class. Waters exceeding the tolerable maximum (class 3) value for one or more parameters. This water is inappropriate for most uses and can pose a threat to public health and to the environment.

The hydrological stations of Thac Buoi and of Gia Bay also measure some physico-chemical parameters related to the natural composition of water. These parameters are general monitored for the use of water for drinking water supply.

Table 68 compares the results obtained for these parameters with the EC and WHO drinking water quality norms:

**Table 68 - Evaluation of the Cau river’s for drinking water quality**

Parameters	EEC circular 80/779/EEC		WHO Guidelines (1986)	Cau River	
	Recommended concentration	Maximum tolerable concentration		Thac Buoi	Gia Bay
Magnesium - Mg (mg.l <sup>-1</sup> )	30	50	50	5,3	5,7
Calcium - Ca (mg.l <sup>-1</sup> )	100	-	-	25,4	23,1
Sodium - Na (mg.l <sup>-1</sup> )	20	150	200	15,5 (Na et K)	9,03 (Na et K)
Potassium - K (mg.l <sup>-1</sup> )	10	12	-		
Silice - SiO <sub>2</sub> (mg.l <sup>-1</sup> )	-	-	-	14,9	14,7
Chlorure - Cl (mg.l <sup>-1</sup> )	25		250	4,82	3,69
Sulfate - SO <sub>4</sub> (mg.l <sup>-1</sup> )	25	-	400	6,81	5,62

The quality of water is usually defined by the least favourable parameter measured (Degrémont, 1989). Given the very high concentration of suspended solids (SS), this approach would result in grading the waters of the Cau river as “off class”. Of course, the assessment criteria for Adour-Garonne were developed to meet the needs of temperate areas, and the recommended SS concentration is poorly adapted to the very high SS rates common in tropical areas. If the SS criteria and the average water temperature specific to tropical areas are ignored, the other available physicochemical parameters seem to indicate a good water quality of the river Cau. This water appears free from pollution, and able to satisfy the most quality demanding uses.

In reality, the lack of data makes it extremely difficult to evaluate the water quality of the Cau River. Only a very limited number of parameters (pH, COD, cations, anions) is indeed covered. And apart from the COD, they do not include fundamental water quality parameters like BOD, heavy metals, total coliforms or persistent organic pollutants.

These analytical constraints are compounded by the absence of recent and disaggregated data. Available averaged data provided by the National Hydrometeorological Service (HMS) sometimes cover periods of more than 20 years. Thus, chemical composition averages relate to the period 1964-1985 in Thac Buoi and to 1972-85 in Gia Bay. The average SS concentration at Thac Buoi covers the period 1961-80. Lastly, the average temperatures provided in Table 66 relate to the period 1962-85 in Thac Buoi, and to the years 1962/69/85 in Gia Bay.

A set of water analyses carried out in eight rural locations in Thai Nguyen province, and in three sites in Thai Nguyen city, by HMS in November 1995 provide something of an opportunity to put the data provided by the stations of Thac Buoi and of Gia Bay into perspective. The 1995 analyses include measurements of biological oxygen demand and dissolved oxygen, as well as the main heavy metals. The results of these analyses are given in Tables 69 and 70. They seem to suggest a very good quality of water in the province. On the basis of those analyses, the water in Thai Nguyen was almost free of organic pollution and of heavy metals at the sites tested in November 1995. These analyses do not, unfortunately, include measurements of faecal coliforms and cannot provide further information on faecal contamination in these sites at that time.

**Table 69 - Results of water samples from 8 rural sites in November 1995**

River	District	pH	BOD mg/l	DO mg/l	Fe Fe3 mg/l	SO mg/l	NH mg/l	NO Mg/l	PO mg/l	F mg/l	Mn mg/l	Zn mg/l	Cd mg/l	Pb mg/l	Hg mg/l	As mg/l	CN mg/l	Ph nol mg/l	Tong Do c mg mg/l	Can Lo l mg mg/l
Song Cong	Dac son	7.6	2.8	9.0	0.250	14.3	0.120	0.01	0.32	0.0015	0.141	0.03	0.0003	0.00127	0.0003	0.009	0.0008	0.0090	0.48	12.81
Ho nni Cee	Nha nghi	7.7	1.8	8.6	0.335	6.20	0.097	0.01	0.41	0.0040	0.082	0.02	0.0004	0.01800	0.0004	0.007	0.0041	0.0075	0.44	8.52
Kenh Chinh	Tan Phu	7.6	3.4	9.0	0.182	6.25	0.120	0.01	0.38	0.0010	0.082	0.02	0.0003	0.00110	0.0004	0.007	0.0097	0.0072	0.48	13.58
Song Rong	Vo Nhai	7.3	2.6	9.4	0.168	6.19	0.084	0.02	0.32	0.0040	0.151	0.03	0.0007	0.00194	0.0003	0.009	0.0116	0.0068	1.80	12.60
S. Cho Chu	Cho Moi	7.5	2.8	9.8	0.105	19.2	0.060	0.01	0.53	0.0009	0.060	0.03	0.0006	0.00176	0.0005	0.006	0.0080	0.0068	0.92	12.51
Song Cau	Gia Bay	7.5	3.1	9.2	0.088	8.01	0.097	0.01	0.32	0.0010	0.052	0.03	0.0004	0.00170	0.0004	0.007	0.0190	0.0060	1.00	11.87
Song Du	Pho Du	7.4	1.2	8.6	0.165	7.05	0.060	0.01	0.41	0.0020	0.142	0.03	0.0005	0.00201	0.0002	0.008	0.0080	0.0065	1.08	12.71
Phu luu 13*	Yen Do	7.6	4.1	5.9	0.098	6.25	0.060	0	0.32	0.0010	0.055	0.02	0.0006	0.00226	0.0005	0.006	0.0078	0.0057	1.92	9.95

**Table 70 - Results of water samples from Thai Nguyen city in November 1995**

Type of water sampled	Sampling location	pH	BOD mg/l	DO mg/l	Mn mg/l	Zn mg/l	Cd mg/l	Pb mg/l	Hg mg/l	As mg/l	CN mg/l	Phenol mg/l	H2S mg/l	Tong Do c mg mg/l	Can Lo l mg mg/l
Eau domestique	The Duyen	7.5	19.2	0.71	0.06	0.012	0.0008	0.0009	0.00042	0.006	0.011	0.017	0.002	1.24	3.55
Eau mixte	Khu Gia sang	7.5	17.6	1.28	0.07	0.030	0.0008	0.0014	0.00022	0.009	0.022	0.022	0.00018	1.00	3.41
Eau industrielle	Kenh Gang thep	7.6	4.6	4	0.08	0.021	0.001	0.0013	0.00047	0.008	0.018	0.015	0.0021	1.08	2.55

## **Appendix VI : Principal causes of deforestation in Vietnam**

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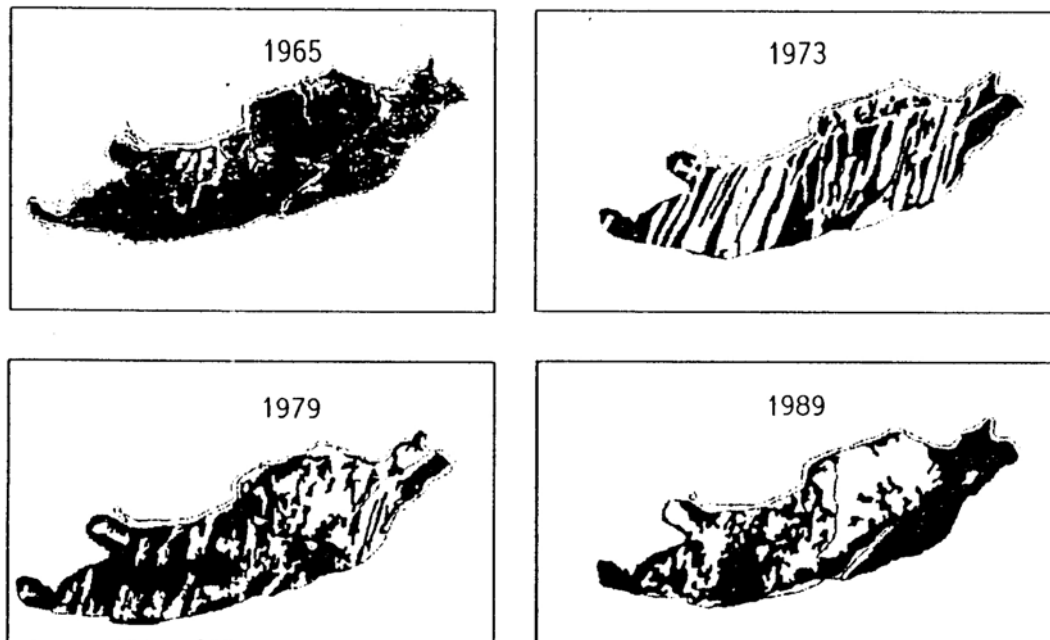
Vietnam's forest cover declined from 67 per cent of the national territory in 1943 to 29 per cent in 1992 (see Figure 27). The principal causes of degradation of natural forests in the Vietnamese uplands are: (i) agricultural clearings conducted by spontaneous or organised migrants; (ii) shifting cultivation; (iii) spontaneous forest fires; (iv) extractive logging; (v) fuelwood collection; (vi) insects, rodents and diseases; (vii) rural infrastructure development; (viii) mining; and (ix) degradation due to military conflicts.

1. *Agricultural clearing.* Organised or spontaneous migration of farmers of Kinh origin from the deltas to the uplands of Vietnam led to a significant decline in vegetation cover and forest quality in these new settlements (CERED, 1994). Regrettably, little information is available on the extent of the phenomenon.
2. *Shifting cultivation.* A number of Vietnam's ethnic minorities have practised a sustainable form of shifting cultivation for generations. Fields were cultivated for a few years and then left in fallow for long periods. This farming system would temporarily clear only very small forest areas (typically, less than two hectares) and actually promoted biodiversity by facilitating the introduction of new animal and opportunistic vegetation species. The sustainability of this farming system depends largely on population density. Shifting cultivation is regarded as sustainable as long as the population density does not exceed 50-70 people per square kilometre (World Bank, 1995). The exact threshold varies according to the land's vulnerability to degradation and depends also on the type of cultivation practised. The growth of ethnic minorities, combined with substantial organised and spontaneous migratory flows, broke the balance of the traditional farming system of Vietnam's uplands. Current fallow periods are not long enough to permit a complete regeneration of the cleared areas, and shifting cultivation has consequently become a major cause of forest degradation.
3. *Extractive logging.* Vietnamese legislation requires that forests be restored to their original state after logging. It also restricts logging of a number of species and export of tropical timber. Forest logging is also prohibited in watersheds that are critically important for soil and water conservation. But sadly, budgetary constraints and the substantial economic interests associated with logging mean that this legislation is rarely enforced. It is estimated that legal and illegal logging together degrade over 70,000 ha of forest per annum - this results in an annual loss of over 30,000 ha of forests (MOSTE/UNDP/GEF, 1994).
4. *Fuelwood collection.* The annual demand for fuelwood in Vietnam is estimated at 50 million m<sup>3</sup> (UNDP/FAO, 1996). Fuelwood collection takes place on a huge scale and is even more difficult to control than commercial logging. Many villagers collect wood to sell on the roadside. In some villages, wood is made into coal before sale to facilitate transport. Although very little information is available on this subject, it seems that fuelwood collection ranks as the main cause of forest degradation and loss of biodiversity in some locations of Vietnam (MOSTE/UNDP/GEF, 1994). The deltas of the Red River and Mekong, along with the hills of Northern Vietnam, already suffer from localised but important fuelwood shortages for domestic and industrial consumption. In high population density areas, people must sometimes travel over 20 to 30 km to find fuelwood (UNDP/FAO, 1996). In the absence of an economic alternative to fuelwood collection, all attempts to control this activity have so far failed.
5. *Forest fires.* About 56 per cent of Vietnam's 9 million hectares of forest are vulnerable to fire. Fires generally occur during the dry season when hot winds from the west are at their peak. They are usually caused by human activities such as agricultural clearing, hunting, mining, cooking, and wild honey collection by smoking out bees. It is estimated that between 20,000 and 30,000 hectares are burned annually in Vietnam in this way, and that over 100,000 ha can disappear in the worst years (MOSTE/UNDP/GEF, 1994). The rapid expansion of coniferous tree plantations dramatically increases the vulnerability of many areas to spontaneous fire.
6. *Development of the rural infrastructure.* In order to attract domestic and foreign investors, most Vietnamese provinces are carrying out ambitious road development programmes. The pilot province of Lam Dong recently built 1,7444 km of roads, including 317 km of national roads,

390 km of provincial roads, 119 km of municipal roads, 309 km of district roads, 494 km of communal roads and 117 km of “special use” roads to provide access to new economic development zones (Economic Atlas of Vietnam, 1997). These road development programmes also enable logging companies and landless farmers to access natural forests previously protected by their remoteness.

7. *Insects, rodents and diseases.* 13,000 ha of forests - mostly plantations - were lost because of insects, rodents and diseases in Vietnam in 1989. Despite substantial efforts, pests and diseases continue to degrade many thousands of hectares every year. Natural forests are, however, little affected and the impact on their biodiversity is believed to be negligible (MOSTE/UNDP/GEF, 1994). Most damage inflicted by pests and diseases affect recent plantations of eucalyptus that are not properly adapted to local conditions.
8. *Mining and quarries.* Soil is destroyed by excavation. To that must be added areas occupied by rubble. This form of forest degradation is particularly important in Vietnam’s Uplands because of the large number of unregulated small tin and gold mines.
9. *Degradations due to military conflicts.* More than 13 million tons of bombs and 72 million litres of defoliants were poured on Vietnam by the American military between 1964 and 1975. Part of the mangrove forests of the Mekong delta was destroyed, as well as large tracts of tropical forest containing great and valuable biodiversity in the central plateau. The total forest area destroyed during this conflict is estimated to have been 2 million hectares. Because of their persistence, defoliants, such as Agent Orange, continue to have an important impact on public health. However, these are no longer considered harmful to biodiversity and forest quality. The mangroves of Minh Hai, in the Mekong delta, provide one of the best possible illustrations of the respective roles played by the main mechanisms of forest degradation in Vietnam. These mangroves are among the richest in terms of biodiversity in the world. They were, in large part, destroyed by defoliants during the war, but were restored at the end of the 1970s by forest brigades and the army. They were again cleared for shrimp culture in the 1980s. Figure 28 shows the variations in area of these mangroves of 1965 to 1989.

**Figure 27 : Changes in Mangroves area in Vietnam, 1965 to 1989**



# APPENDIX VII : PRINCIPAL WATER EROSION PROCESSES

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## 1 VARIOUS PROCESSES OF SOIL EROSION

The processes of land degradation are numerous, their varied causes and the factors modifying their expression are multiple and sometimes contradictory. In his work *Land Husbandry - Components and Strategy* (1994), E. Roose identifies five main processes of soil erosion:

**Implement erosion.** This form of “tillage” is a process (removal + transport + deposition) that takes place without the action of water. Through gravity and the simple pressures of farm implements, the top horizons are stripped from the upper slopes and from areas where the slope surface is irregular. The mass of soil carried out by each tillage and each hoeing accumulates to the bottom of the toposequence. When all this is added up, one-metre banks can be built in just 4 to 5 years.

**Sheet erosion.** This is the first phase of water erosion. The force of raindrops impacting on bare soils and dislodging particles of earth causes it. Water run-off intervenes as soon as the intensity of the rains exceeds the soil’s infiltration capacity. Sheet runoff starts once puddles have formed and water that has not infiltrated overflows from one puddle to another. This run-off translates, in moderate climates and moderate land gradients, into sheet erosion that consists of a not very apparent but regular displacement of fine surface-level particles.

**Linear erosion.** Linear erosion appears when sheet runoff becomes heavier, digging deeper and deeper into the ground. When rainfall intensity exceeds the absorption capacity of the soil surface, puddles form and are then joined up by rivulets of water. Above a speed of about 25 cm per second, they acquire energy of their own. The energy that this erosion generates is confined to, and concentrated in, flow lines on the steepest slopes, and is no longer spread all over the whole surface. Linear erosion therefore indicates that runoff has become organised, picking up speed and acquiring a kinetic energy capable of cutting into the soil and carrying away ever larger particles - effectively opening up drainage lines. The results are described as grooves, rills and gullies depending on the size of these drainage lines.

**Mass movement.** This is the third and last mechanism of water erosion. While sheet erosion attacks the soil surface, and gullying affects drainage lines on a slope, mass movements involve massive erosion of a large volume of the soil cover. Mass movement is caused not by surface water, but by the wetting of the soil when it goes beyond the point of plasticity or liquidity. The factors that facilitate these movements of mass movement include earthquakes, cracking with the alternation of frost and thaw, wetting of the soil cover to the point of saturation, and the presence of rocks with preferential fracture planes (argillite, clay, marl, schist, micaceous rocks, gneiss).

**Wind erosion.** Although this can also take place in wet climates that have some particularly dry months, wind erosion is only important when the annual rains are less than 600 mm, when there are more than six dry months, where the potential *evapotranspiration* exceeds 2000 mm, where land is stripped and where the vegetation graduates from savannah to steppe to stripped beaches of soil. It is also necessary that the wind speed exceeds a threshold of about 20 km/h on dry lands. The phenomena of wind erosion are all the more important when there are strong and regular winds. When these conditions are met, wind erosion can be particularly dramatic. The massive wind erosion in the plains of the western United States in 1934 and 1935 (Dust-bowl) marked the beginning of a major effort to combat water and wind erosion.

## 2 PRINCIPAL FACTORS OF WATER EROSION

Sheet erosion, linear erosion and mass erosion are the three principal mechanisms of soil loss in the hilly and mountainous zones of Vietnam. As indicated in 3.2.1.1, the Universal Soil Loss Equation

(Wischmeier and Al, 1958; Wischmeier and Smith, 1978) is the most widely used model for estimating soil erosion on a cultivated field. In this model, erosion is seen as a function of rainfall erosivity, multiplied by soil erodibility, topography, plant cover and erosion control practices.

### 2.1 Rainfall erosivity index

The influence of rain on soil erosion will depend largely on two factors: the kinetic energy of rainfall and its duration. Table 71 classifies 183 erosive rains according to their intensity, and gives an erosion average for each class of rain intensity.

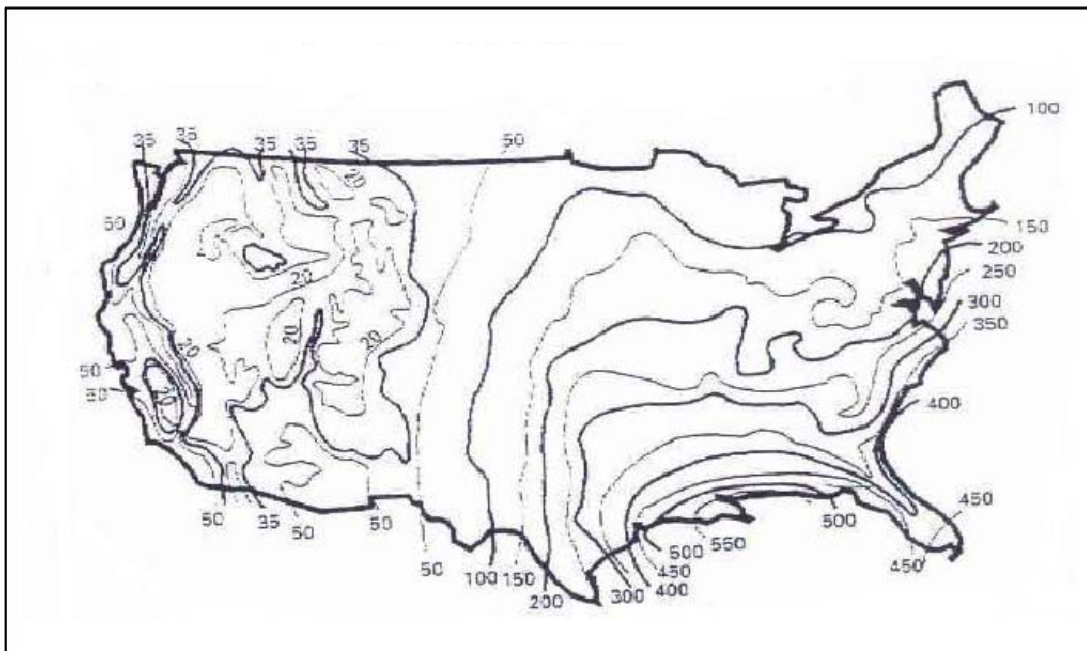
**Table 71 - The influence of rainfall intensity on soil erosion**

Intensity of rains in mm/h during les 5mn where maximum water is received	Number of rains	Average erosion (In t/ha)
0 - 25,4 mm	40	3,75
25,4 - 50,8	61	5,95
50,8 - 76,2	40	11,78
76,2 -101,0	19	11,44
101,6 -127,0	13	34,24
127,0 -152,4	4	36,32
152,4 -177,8	5	38,72
228,6 -254,0	1	47,93

(Zanesvilles, Ohio, 1934-1942, after F. Fournier, Soil Conservation, European Council).

Wischmeier (1978) combined the kinetic energy of each rainstorm multiplied by the maximum intensity of rain in 30 minutes (in mm/h) into a single erosivity index. Using a model similar to the isohyets, curves of iso-erosivity can be established.

**Figure 28 : Curves of Iso - Erosivity in the United States**



Given that these curves and that the required information on rainfall intensity are not available for all the areas of the world, and that the examination of the pluviograph of each storm is a tedious operation, a number of authors have tried to simplified the estimation methodology of the rainfall erosivity index.

By analysing 20 stations of West Africa, located between Séfa in Senegal and Deli in Chad, and between Abidjan into Low Ivory Coast and Allokoto in Niger, Roose (1977) showed that in Western Africa there is a simple relationship between the mean annual aggressiveness index and the mean annual rainfall over long enough periods (more than 10 years), as follows:

MAR = HAM x 0,5 + 0,05 in West Africa  
 0,6 on a coastal strip 40km wide  
 0,3 to 0,2 in mountains  
 0,1 in the Mediterranean area of Algeria  
 0,01 in the oceanic temperate zone

## 2.2 Soil Erodibility

In the United States, Wischmeier and Smith calculated multiple regressions between soil erodibility and 23 different soil parameters on reference plots under both natural and simulated rainfalls. The standard reference plot is defined as a plot having a 9 per cent slope, 22.2 metres length, cultivated in the direction of the slope and having received no organic matter for three years. After simplification, it was found that erodibility depended mainly on the amount of organic matter, the texture and the structure of the soil, and its permeability. On the basis of this work, various monographs allow a rapid evaluation of the factor “K” of the USLE – the soil erodibility (see Roose, 1994).

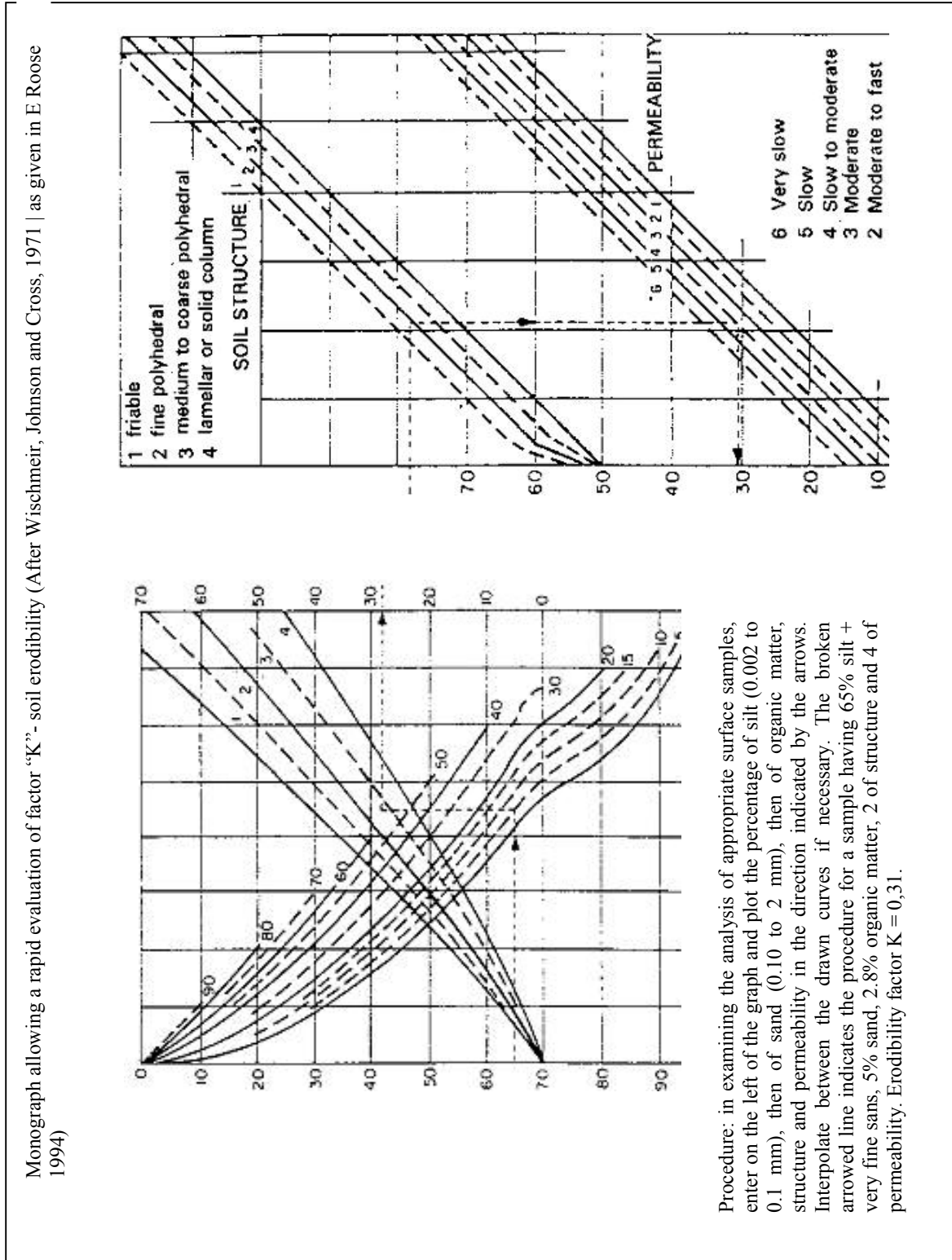
A short description of the importance of the soil texture and structure, and of the structural role played by the organic matter, substantiate the empirical results obtained from Wischmeier’s statistical analysis.

**Texture of the soil.** The texture of a soil is its proportion of coarse and fine sands, silts, clay, *humus* and limestone (D. Soltner, 1987). The Atterberg international scale, shown in Table 72, classes these elements according to their size.

**Table 72 - The Atterberg International classification**

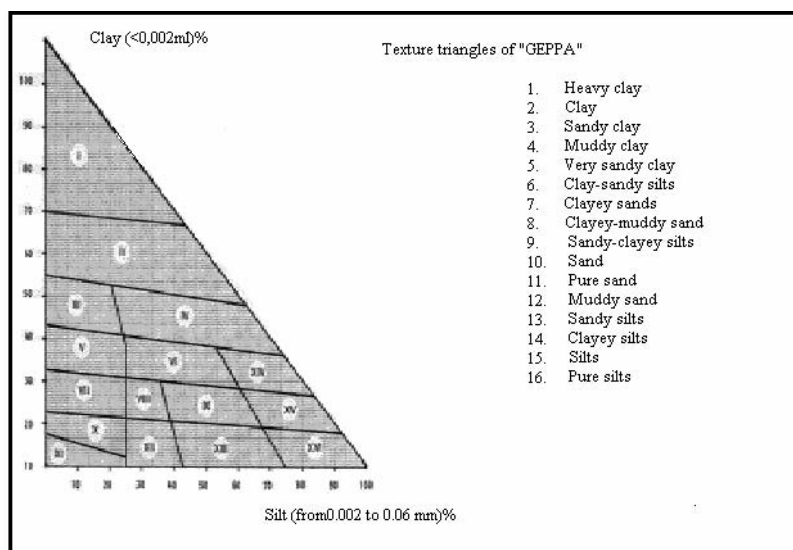
Diameter of particles	Millimeters	Micrometers
Coarse sand	2 - 0,2	2 000 to 200
Fine sands	0,2 - 0,02	200 to 20
Silt	0,02 - 0,002	20 to 2
Clay	- From 0,002	- From 2

Figure 29 : Soil Erodibility



The “triangle of textures” represented in figure 31 enables to classify soils in function of their texture.

**Figure 30 : Triangle of textures**



**Soil Structure.** The structure of a soil is the mode of assembly, at a given moment, of its solid components (D. Soltner, 1987). The form and the solidity of the structure of a soil also depend on the proportions of its various components, and on the nature of the structuring elements of this soil – the “*colloids*”. The colloids develop either from the deterioration of the bedrock, such as clay, or from the decomposition of organic matter such as humus. These colloids are either in a dispersed state, or flocculated. When flocculated, they give rise to an argilo-humic

complex, which welds the various components of the soil between them.

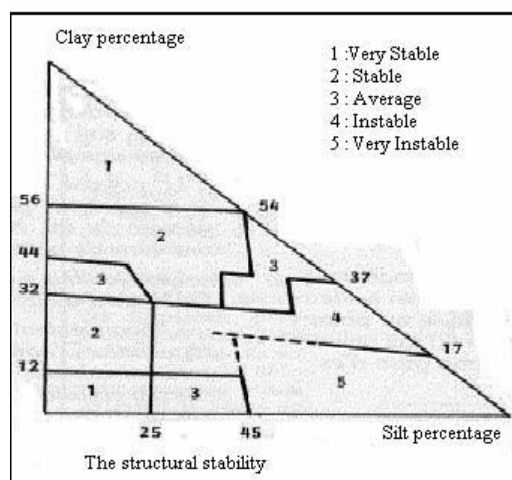
There are three major types of structure: (i) particulate or elementary structures, in which the solid components are piled up without any liaison, due to the absence of colloids; (ii) compact or continuous structures, whose elements, buried in a mass of dispersed clay, constitute a single block; (iii) fragmentary structures, in which the components, assembled in aggregates, are usually grouped in large structural elements, effectively allowing air and water to penetrate, and so having a significant degree of permeability.

The inherent susceptibility of a soil to erosion will depend on its texture, but more still on its structure. In coarse sand soils, for example, vacuums exist between particles and readily allow air and water to circulate. They offer little resistance to the dispersing capacity of water and wind, and are sensitive to erosion. In the absence of humus, this land will have a particulate structure.

Where fine sands and silts accompany coarse sands, the vacuums are clogged. The soil is easily packed down by rain and becomes impermeable to water and air. This facilitates water run-off and soil erosion. Like sandy soils, these packed down soils will display a particulate structure, especially in absence of humus.

If enough clay and humus accompany sands, they will form aggregates enabling a good water and air circulation but welding firmly the different soil elements together. The colloids make for a fragmented soil structure and provide strong resistance to erosion. Figure 32 illustrates the structural stability of a soil according to its texture.

**Figure 31 : Structural stability of a soil according to its texture**



Following in Wischmeier's steps, Singer (1978, after Roose, 1994) showed that in order to fully understand the soil's resistance to erosion, it is necessary to incorporate also some additional factors - such as iron and aluminium content, the type of clay and the salinity. With knowledge of the texture and structure of the surface horizons, their level of organic matter, the content of iron-free aluminium and the type of clay, plus some observations on the profile, an initial estimate can be made of the resistance of the soil to sheet and rill erosion. Since these parameters are not taken into account in high-level soil science classifications, Roose (1994) stresses that a strict relationship between soil erodibility and currently recognized soil type is not found.

### 2.3 The topographic factor ( factor SL)

The slope intervenes in erosion by its form, its gradient and its length.

**The form of slopes.** According to Wischmeier (1974), with a smooth average slope, sediment transport is reduced on a warped or concave slope (due to localised sedimentation), while a convex slope increases it according to the gradient of its steepest portion. However, Roose also underlines the difficulty of estimating the influence of the concavity, convexity, regularity or warp of a slope, which leads authors to divergent results.

**Slope Gradient.** The greater the gradient of a slope, the greater is its vulnerability to erosion. As the gradient increases, the kinetic energy of rainfall remains constant, but it accelerates towards the bottom as the kinetic energy of the runoff increases and exceeds the kinetic energy of the rainfall - when the slopes are greater than 15 per cent (Roose, 1994). Additionally, Zing (1940; in Roose, 1994) showed that soil losses grow exponentially with the slope gradient. In the United States, the exponent is close to 1,4 ( $A = K.S^{1.4}$ ) whereas Hudson (1973; in Roose, 1994) found it to be about 2 under African conditions. Table 73 shows that even minor slopes (less than 10 per cent) can produce strong erosion.

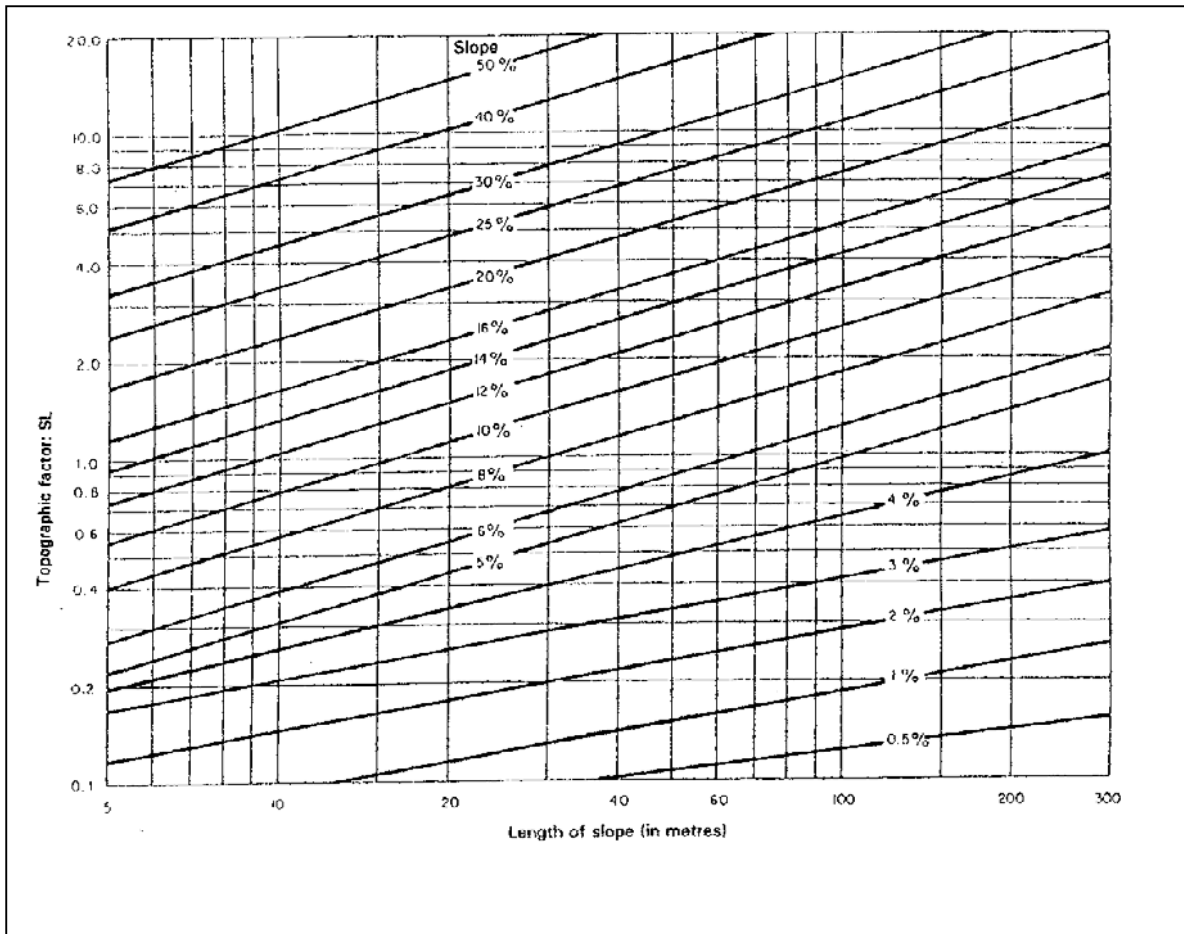
**Slope length.** In theory, the steeper the slope, the more runoff will accumulate, gathering speed and acquiring its own energy, causing rill erosion and then deeper gullies. Zing (1940) found that erosion increases by an exponent of 0.6 with the length of slope, while Hudson estimates that a higher exponent value is more appropriate in tropical areas. Having examined 532 annual results on erosion plots, Wischmeier concludes that the relationship between erosion and the length of slope vary more from year to than from one site to another. It is estimated that the value of the exponent (from 0.1 to 0.9) is strongly affected by a number of factors, including changes in soil, the plant cover, and use of crop residues.

**Table 73 - Influence of slope on runoff and erosion (experiments in 5 soil conservation stations in the United States, cited by F. Fournier)**

Soil Type	Average rainfall (mm)	Slope Length (m)	Slope gradient (%)	Crop	Average Erosion T/ha	Average runoff (% of rain)
1. Clayey silt from Miles (Texas)	526	30	0	Cotton	5,43	6,4
1			12,84		15,1	
2			17,29		15,5	
2. Fine Silt from Muskingum (Ohio)	926	22	8	Maize	148,25	30,4
12			180,87		42	
3. Clay from Houston (Texas)	889	22	2	Maize	26,18	13,4
4			75,11		16,6	
4. Fine Sandy silt from Kirvin (Texas)	1041	22	8,75	Cotton	68,94	20,9
16,5			177,90		14,6	
5. Silt from Shelby (Missouri)	940	27,5	3,7	Maize	48,67	29,4
8			170,00		28,3	

As with the “K” factor, various monographs allow a rapid consideration of the topographic factor according to the length and the shape.

**Figure 32 : Topographic factor (After Wischmeier and Smith, 1978; in E. Roose,1994)**



## 2.4 The Influence of Plant Cover and Farming Practices ( factor C)

Plant cover is effective in preventing erosion, because it absorbs the kinetic energy of raindrops, covers a large proportion of the soil during periods of the year when rainfall is most aggressive, slows runoff and keeps the soil surface porous. Roose (1994) stresses that among the conditional factors of erosion, plant cover is certainly the most important, as erosion increases from 1 to 1,000 tons when, all else being equal, plant cover on a plot decreases from 100 % to 0 %.

While a land cover that respects soil properties can compensate for an inherent susceptibility to erosion, deforestation and inappropriate practices will heighten that susceptibility.

**Deforestation.** Trees play a number of important roles, including production of firewood and of construction materials, regulation of the hydrological cycle and of the climate, soil and biodiversity conservation, and provision of recreational amenities. The steeper the slope, the more critical is their soil conservation role.

With its excellent land coverage, forest protects the soil against the kinetic energy of raindrops and slows down water run-off, giving it time to infiltrate. Research conducted on Vietnamese soil, on slopes from 10 to 15 per cent, estimated the following variations of runoff and erosion according to the extent of forest cover.

**Table 74 - Influence of forest cover on soil erosion in Vietnam**

Forest cover (%)	Runoff (m <sup>3</sup> /ha)	Erosion (T/ha)
100	44	1
30-40	62	-
0	2 000	100

(SVR Tropical Forestry Action Plan, Protection Forest, Towards 2000 - Ministry of Forestry- Hanoi, 1988).

These Vietnamese experiments found that the complete destruction of a dense forest cover led to a 5,000 per cent increase in water run-off, and a rise of 10,000 per cent in soil erosion (Ministry of Forestry, 1988).

The forest also facilitates the maintenance of a good soil structure by its action on the bases cycle (their dense and penetrating root systems bring nutrients from lower horizons back to the surface, acting as geo-chemical pumps), and by their continuous recycling of litter. In tropical conditions, the biogeochemical cycle functions perfectly under dense forest. Even on ferralsols, which are among the least naturally fertile soils, forest can thrive thank to this continuous recycling. On ferralsols, deforestation results in an extremely important soil erosion given its low content in humus and its rapid acidification due to an insufficient supply of cations. This acidification contributes to dissolving iron oxides, which can move up and create ferrallitic crusts.

**Inappropriate farming practices.** Some cultivation methods are particularly harmful to soil conservation.

*The absence of plant cover during rainstorms:* the more the soil is covered, the more it resists erosion. Not all crops have the same anti-erosive capacity. Crops including broad bare intervals, such as corn or cotton, provide only a partial cover to the soil and are particularly erosive. In Texas and Missouri, on slopes from 8 to 9 per cent, it was calculated that the time needed to remove 20 cm soil was 46 and 50 years under cotton and corn, compared to 27,000 years under forest, and 170,000 years under meadow (in Soltner, 1987).

*Simplification of crop rotation:* monoculture or disassociation of livestock and crops deprive the soil from the humus essential to its conservation. It also limits the positive influence of various root systems on the soil structure. Table 75 illustrates the influence of crops and rotation on the soil resistance to erosion.

*Cultivating marginal land:* cultivating land that would have, because of its slope or very weak natural fertility, otherwise been under meadow or forest, is a major cause of erosion. This situation is often found in areas where there is a strong population pressure on natural resources.

*Overgrazing:* A given environment is able to nourish only a given number of herbivores. This carrying capacity depends on the soil, climate and vegetation. If that number is exceeded, the excess load destroys vegetation and the soil's surface structure. The stripped and unstructured soil is then exposed to water and wind erosion. So the more an environment weakens, the more sensitive it is to overgrazing.

**Table 75 - Influence of crop and crop rotation on the soil's resistance of erosion**

Crop system	Annual average runoff (%)	Annual average soil loss in T/ha	No of years necessary to erode 17.5 cm of soil
Tilled fallow	30,3	41,1	24
Continuous Maize crop	29,4	19,7	50
Continuous wheat crop	23,3	10,1	100
Maize, wheat, clover rotated crops	13,8	2,8	368
Continuous Blue gras crop	12,0	0,3	3 043

(Miller cited by D. Soltner)

Table 76 shows the results obtained for plant cover factor "C" in Tunisia. These results, which vary from 1 (bare soil) to 0.01 (improved pastures) - account for the key influence of plant cover in erosion mechanisms.

**Table 76 - Influence plant cover factor (C) in Tunisia**

Plant cover	Annual average C
-Bare soil, bare fallows	1
-Fruit trees	0,9
-Winter wheat	0,7
-Cereal in rotation	0,4
-Forage crops	0,2
-Cereal in rotation and forage crops	0,1 to 0,01
-Improved pastures	0,01

(Cormary, Masson, 1964, cited by Roose, 1994)

## 2.5 The influence of erosion control practices (factor P)

Erosion control practices aim to reduce water runoff and erosion damage. They include cropping techniques used exclusively with a view to control soil erosion, and erosion control structures.

*Anti-erosive cropping techniques.* The most widespread techniques are: (i) contouring; (ii) contour ridging; (iii) buffer strip cropping; (iv) natural or artificial mulching; (v) artificial mulching with products such as polyvinyl acetate; and (vi) plant providing a good cover (leguminous).

*Erosion control structures and water management.* The four main methods are: (i) runoff farming (e.g. small dams permitting cultivation after water infiltration); (ii) total infiltration (e.g. steppes or Mediterranean terraces); (iii) diversion of surplus waters (e.g. drainage ditches); and (iv) dissipation of runoff energy to keep the speed of water lower than 25 cm/s.

Table 77 compares results respectively achieved by anti-erosive cropping techniques and erosion control structures. It clearly shows that biological techniques are far more effective than mechanical techniques, which are more expensive to establish and more difficult to maintain.

**Table 77 - Erosion control practices (factor P)**

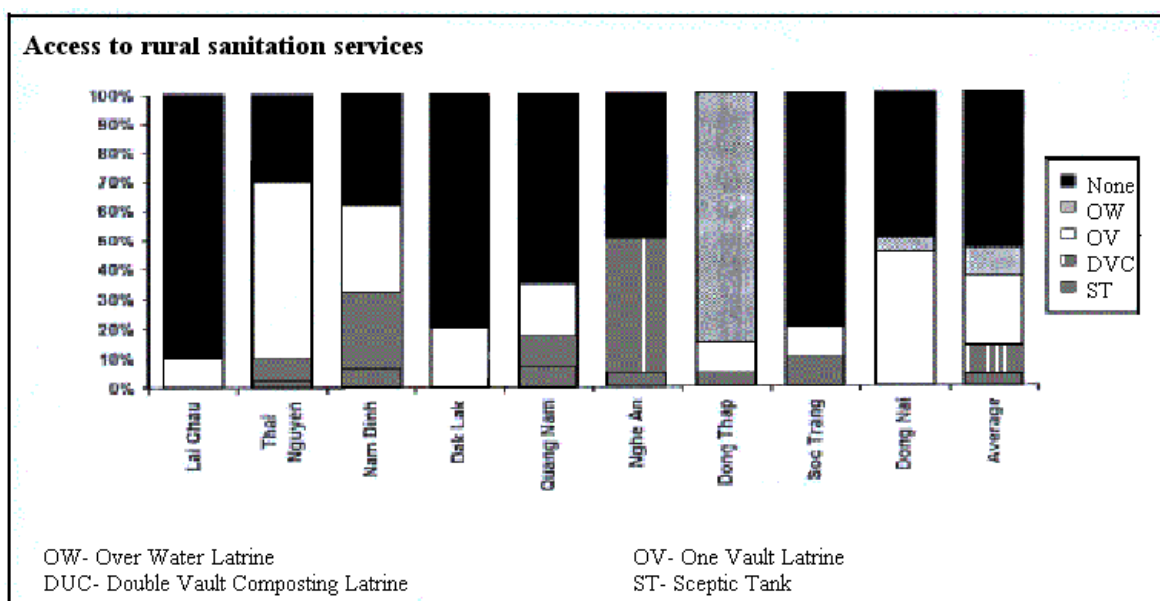
West Africa (Roose, 1977)	Erosion control practices factor P
<ul style="list-style-type: none"> <li>- Tied contour ridging</li> <li>- Erosion control strips 2 o 4 m wide</li> <li>- Straw mulch, over 6 t/ha</li> <li>- Artificial mulch</li> <li>-Temporary pasture or cover plant (depending on cover)</li> <li>-Low earth bunds protected by stones or rows of perennial grass or low dry stone walls every 80 cm + contour tillage + hoeing + fertilisation</li> </ul>	<ul style="list-style-type: none"> <li>0,2 to 0,1</li> <li>0,3 to 0,1</li> <li>0,01</li> <li>0,5 to 0,2</li> <li>0,5 to 0,01</li> <li>0,1 to 0,05</li> </ul>

## APPENDIX VIII: MAIN SOURCES OF WATER POLLUTION IN VIETNAM'S UPLANDS

Publicly available information on water pollution in Vietnam is scarce. But recent reports by the Vietnamese Government and a number of international organisations do identify the following sources of pollution: (i) faecal contamination; (ii) domestic and industrial pollution; (iii) manure and insecticides; (iv) sedimentation; and (v) mining industries.

**Faecal contamination.** Open air defecation is the dominant sanitation practice in the Vietnamese Uplands. Figure 31 shows that over 90 per cent of the population of Lay Chau province in North Vietnam practice open air defecation. In Thai Nguyen province, this figure is nearly 30 per cent. Other common sanitation practices in the Uplands also contribute to water pollution. Without the minimum composting time, the agricultural use of human excreta from double vault composting latrines (DVC) presents a strong faecal contamination hazard. Leakages from septic tanks located over shallow aquifers also pose major public health risks (DANIDA/CERPAD, 1997). The very high incidence of diarrhoea and intestinal parasites suggests that the northern Uplands experience significant faecal contamination of water.

Figure 33 - Access to Rural Sanitation Services In 10 Vietnamese Provinces



In the plains, UNDP sampled faecal coliforms in 31 sections of the Mekong and Bassac rivers in the late 1980s (UNDP, 1989). The results varied from 1,500 to 3,000/100 ml on the banks of the two rivers, and from 3,800 to 12,500/100 ml in the main irrigation and drainage canals. These figures also indicate significant faecal contamination.

**Domestic and industrial waste-water effluents.** Although data on these are sparse, it appears that organic pollution of water (oxygen demand) is relatively limited. This could be due to the fact that most large urban and industrial centres discharge their waste water into major rivers that have a strong water pollutant purification capacity. A UNDP project (1996) to control industrial pollution showed that the

combined effluents of the industrial complex of Viet Tri north of Hanoi were naturally purified by the Red River within a few kilometres. According to the Vietnam Water Sector Review (World Bank, ADB, FAO, UNDP, 1996), the combined potential organic pollution of all industrial investments approved from 1989 to 1993 in Vietnam would be equivalent to the annual domestic pollution of a small town of 18,000 inhabitants. Although industrial pollution is expected to increase considerably in the years to come, these figures clearly show the prevalence of domestic effluents over industrial ones for organic pollution.

**Sedimentation.** Sedimentation of river water is closely connected to land and forest degradation. Soil erosion and deforestation accelerates the siltation of dams and reservoirs, increases water run-off and, in certain cases, causes floods. A direct consequence of sedimentation is the shortening of the economic life of reservoirs and dams. To understand the importance of siltation, it should be remembered that the erosion of one millimetre of surface soil per hectare corresponds to the loss of 10 m<sup>3</sup> - or about 13 tons - of soil. Sedimentation raises riverbeds - Vietnam therefore has to periodically raise the height of its 5,000 kilometres of flood protection dykes. Because of the accumulation of sediments over centuries, the level of riverbeds can be up to 5 or 6 metres higher than that of surrounding land in some lowland areas (T. Lustig, M. Silver, Y. Glemarec, T. Aadmot, 1994).

Furthermore, sedimentation increases the costs of treating drinking water. Suspended particles and artificial fertilisers transported by surface water will affect water quality. Turbid water is also difficult and expensive to filter and its disinfection requires larger quantities of disinfecting chemicals (Jain, 1993).

Nearly 80 per cent of the sediments are flushed out during the rain season. Water turbidity varies much from one area to another. The highest concentrations are recorded in the upstream sections of the Red and Black Rivers in the northern Uplands (over 1,000 mg/l/year). These provinces are subject to heavy storms, have undulating relief and suffer from significant deforestation.

**Mining industries.** Vietnam is rich in basic and rare minerals, and also has important coal reserves. Coal mining is primarily concentrated in the coastal province of Quanh Ninh on the Chinese border and, to a lesser extent, in Thai Nguyen province. The coal industry produces 1.5 million tons of extraction materials annually, in addition to tons of dust released in the air. The main sources of water pollution from coal mining are the disposal of extraction materials and coal washing. A number of open zinc, lead and gold mines are exploited without proper supervision, and result in high concentrations of arsenic, cyanide and other metals in the water system. Arsenic has been recorded in concentrations of up to 2 mg/l in several provinces. The WHO recommended limit is 0.01 mg/l. There is also a strong correlation between arsenic concentrations and various forms of cancer.

**Fertilisers and pesticides.** Water pollution by fertilisers and pesticides seems to be limited because of the relatively low use of these chemical compounds in agriculture. Although cases of nitrate pollution are reported, they still remain very localised (World Bank, 1995). Studies undertaken by the Ministry for Health on the impact of pesticides in Vietnam proved inconclusive. A preliminary study carried out in 1990 on crop residues only found concentrations that were well within permitted levels. But a second study conducted in the Mekong delta found concentrations above permitted WHO levels. The World Bank's Environment Sector Review concluded, with some reservations, that pesticides do not yet pose a major water pollution problem in Vietnam.

# APPENDIX IX : CALCULATION OF WATER REQUIREMENTS FOR IRRIGATED RICE CULTIVATION IN THAI NGUYEN

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The calculation of water requirements for immersed rice is different from that of rainfed crops. Irrigation is necessary not only to cover evaporation losses, but also to compensate for losses by percolation in fields that are almost continuously flooded. Before replanting, moreover, substantial irrigation is necessary for nurseries and tillage. The following empirical equation is used to estimate water requirements for irrigated rice systems in Thai Nguyen province (Miloradov and Marjanovic, 1998):

$$Q = Q_{ir} \frac{S}{K_s + K_a}$$

Where:

- S = Total irrigated area (ha)
- K<sub>s</sub> = Coefficient of effectiveness of the irrigation system
- K<sub>a</sub> = Coefficient of water loss in the irrigation network
- Q<sub>ir</sub> = Specific water demand Besoin expressed in m<sup>3</sup>/year/ha

The specific water demand for irrigated rice in Thai Nguyen was calculated using the CROPWAT software for irrigation planning and management developed by the FAO (version 7.0, November 1995). This software is based on the Penman-Monteith equation for estimating evapotranspiration (ET<sub>0</sub>), and the USDA-SCS method for estimating effective rains. The Penman-Monteith equation is expressed as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34u_2)}$$

Where:

- ET<sub>0</sub> = reference evapotranspiration [mm day<sup>-1</sup>].
- R<sub>n</sub> = net radiation at the crop surface [ MJ m<sup>-2</sup> day<sup>-1</sup>].
- G = soil heat flux density [ MJ m<sup>-2</sup> jour<sup>-1</sup>].
- T = mean daily air temperature at 2 m height [°C].
- u<sub>2</sub> = wind speed at 2 m height [m s<sup>-1</sup>].
- e<sub>s</sub> = saturation vapour pressure [kPa].
- e<sub>a</sub> = actual vapour pressure [kPa].
- e<sub>s</sub>-e<sub>a</sub> = saturation vapour pressure deficit [kPa].
- Δ = slope vapour pressure curve [kPa °C<sup>-1</sup>].
- γ = psychrometric constant [kPa °C<sup>-1</sup>].

Based of studies undertaken by UNDP in the Red River Delta and by GRET in the district of Tam Dao (on the side of Tam Dao located in Phu Tho province), the following assumptions to estimate water requirements at the plot level were made:

- Two rice crops per annum on each plot (a spring rice from January to May, and a monsoon rice from June to September). These two rice crops can sometimes be followed by corn or winter sweet potato crop, which have less water requirements than rice;
- Nurseries cover 10 per cent of the replanted area;
- The nursery period lasts for 40 days and the total growing cycle is 150 days;
- A maximum of 150mm of water is necessary for tillage of spring rice, and 50 mm water for monsoon rice;
- Tillage lasts 30 days;
- The maximum rate of percolation is of 2.5 mm/day.

Only the weather station of Thai Nguyen has the data necessary to estimate the Penman-Monteith equation's evapotranspiration. The values provided by that weather station were extrapolated to the entire province of Thai Nguyen. Based on these data, the average water requirements for the spring rice are estimated at 480.3 mm, and 258,5 mm for monsoon rice in Thai Nguyen province. By assuming negligible irrigation requirements for the non-rice autumn crop, these results give a total water demand of 738.8 mm per hectare per annum. Tables 78 and 79 show the details of these calculations.

It is difficult to estimate the effectiveness of irrigation in Vietnam. It can vary from one to three for a same site according to the price of water and to the management practices of irrigated areas. Thus, Luong Xuan Chinh (1999) showed that water consumption for spring crops could vary from 3,175 m<sup>3</sup>/ha to 9,774m<sup>3</sup>/ha for similar areas in Nam Thanh district in the Red River delta. The most water-efficient irrigation areas were directly managed by the villagers, whereas the largest consumption of water was in areas supplied by the National Hydraulic Company.

Assuming that most lateral losses from upstream plots contribute to the water supply of downstream plots, the average irrigation efficiency was estimated at 70 per cent in Thai Nguyen. This gives an overall consumption of 10,550 m<sup>3</sup>/ha/year in the province. Considering that 2/3 of water losses in irrigation canals immediately return to the hydrological system, the figure of 8,440 m<sup>3</sup>/an/ha was used in calculating the pressure on water resources from agricultural abstraction.

**Table 78 - Evapotranspiration and irrigation requirements for winter and spring rice**

<b>RICE EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENTS</b>											
<b>Rain climate station: Thai Nguyen</b>						<b>Crop: Rice</b>					
<b>ETO climate station: Thai Nguyen</b>						<b>Transplanting date: 1 February</b>					
Month	Dec	Stage	Area %	Coef Kc	Etcrop mm/day	Perc	Lprep mm/day	RiceRq mm/day	EffR mm/dec	IrReq mm/day	IrReq mm/dec
Dec	3	Nurs	10	1.20	0.22	0.3	1.4	1.8	0.4	1.77	15.9
Jan	1	Nu/La	23	1.17	0.49	0.;	4.2	5.3	1.7	5.10	51.0
Jan	2	Land	52	1.11	1.01	1.3	4.5	.8	4.4	.37	3.7
Jan	3	Land	84	1.04	1.59	2.1	4.5	8.2	9.5	7.40	81.4
Feb	1	Init	100	1.00	1.91	2.5	-	4.4	12.2	3.19	31.9
Feb	2	Init	100	1.00	1.99	2.5	-	4.5	14.0	3.09	30.9
Feb	3	In/De	100	1.01	2.07	2.5	-	4.;	12.5	2.2	21.0
Mar	1	Deve	100	1.02	2.18	2.5	-	4.7	1.7	3.00	30.0
Mar	2	Deve	100	1.04	2.28	2.5	-	4.8	18.1	2.97	29.7
Mar	3	De/Mi	100	1.05	2.0	2.5	-	5.1	24.2	3.10	34.1
Apr	1	Mid	100	1.05	2.89	2.5	-	5.4	25.1	2.88	28.8
Apr	2	Mid	100	1.05	3.18	2.5	-	5.7	28.2	2.86	28.6
Apr	3	Mid	100	1.05	3.51	2.5	-	.0	3.1	2.40	24.0
May	1	Mi/Lt	100	0.99	3.3	1.9	-	5.;	4.4	0.92	9.2
May	2	Late	100	0.87	3.4;	1.0	-	4.5	54.7	0.00	0.0
<b>Total</b>					<b>330</b>	<b>29</b>	<b>149</b>	<b>775</b>	<b>304</b>	<b>480.3</b>	

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**Table 79 - Evapotranspiration and irrigation requirements for moonson rice**

<b>RICE EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENTS</b>											
<b>Rain climate station: Thai Nguyen</b>						<b>Crop: Rice</b>					
<b>ETO climate station: Thai Nguyen</b>						<b>Transplanting date: 1 July</b>					
Month	Dec	Stage	Area %	Coef Kc	Etcrop mm/day	Perc	Lprep mm/day	RiceRq mm/day	EffR mm/dec	IrReq mm/day	IrReq mm/dec
Dec	3	Nu/La	10	1.20	0.49	0.3	0.5	1.2	6.0	0.75	8.2
Jan	1	Land	25	1.17	1.23	0.6	1.5	3.4	13.2	2.04	20.4
Jan	2	Land	55	1.10	2.64	1.4	1.5	5.5	29.4	2.58	25.8
Jan	3	La/In	85	1.03	3.91	2.1	1.5	7.5	46.1	2.92	29.2
Feb	1	Init	100	1.00	4.52	2.5	-	7.0	55.6	1.46	14.6
Feb	2	In/De	100	1.00	4.60	2.5	-	7.1	56.7	1.43	14.3
Feb	3	Deve	100	1.01	4.48	2.5	-	7.0	60.1	2.01	22.1
Mar	1	Deve	100	1.03	4.39	2.5	-	6.9	52.0	1.70	17.0
Mar	2	De/Mi	100	1.04	4.30	2.5	-	6.8	50.1	1.78	17.8
Mar	3	Mid	100	1.05	4.33	2.5	-	6.8	54.9	2.29	25.2
Apr	1	Mid	100	1.05	4.40	2.5	-	6.9	51.1	1.79	17.9
Apr	2	Mid	100	1.05	4.44	2.5	-	6.9	51.4	1.80	18.0
Apr	3	Mi/Lt	100	1.04	3.96	2.4	-	6.3	45.7	1.77	17.7
May	1	Late	100	0.96	3.25	1.7	-	4.9	39.2	1.02	10.2
May	2	Late	100	0.84	2.51	0.7	-	3.2	27.2	0.00	0.0
<b>Total</b>					<b>539</b>	<b>295</b>	<b>50</b>	<b>885</b>	<b>639</b>	<b>258.5</b>	

CROPWAT 7.0

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## **ABSTRACT**

### **INDICATEURS D'ENVIRONNEMENT EN ZONE TROPICALE**

#### **Application à la dégradation des forêts, des eaux et des sols dans la province de Thai Nguyen au Viet Nam**

Dans le cadre d'une action de recherche coordonnée par l'Institut de Recherche pour le Développement (IRD, anciennement ORSTOM), la réalisation d'une base de données géographique (SIG) a été entreprise pour aider au développement durable de trois provinces pilotes situées dans les zones de collines et de montagnes du Vietnam. La présente recherche a pour objet de définir des indicateurs d'environnement afin de faciliter l'analyse et la communication aux décideurs locaux des informations disponibles au sein du SIG. Cette étude décrit les méthodologies mises en œuvre pour élaborer des indicateurs : (i) de dégradation des forêts et de perte de biodiversité ; (ii) d'érosion des sols ; (iii) de pénurie en eau ; et (iv) de pollution de l'eau. En accord avec le cadre conceptuel STRESS, des indicateurs de pression, d'état et de réponse ont été développés pour chacune de ces quatre composantes fondamentales de l'environnement des hautes terres tropicales.

L'étude de cas de la province pilote de Thai Nguyen confirme l'intérêt des indicateurs d'environnement comme instruments de traitement de l'information pour sensibiliser des décideurs à la fragilité et aux contraintes de développement d'un écosystème trop souvent perçu comme riche et sous-exploité. Ils permettent d'analyser, de hiérarchiser et de synthétiser de larges quantités de données biologiques, physiques et socio-économiques en quelques cartes et chiffres directement pertinents pour la prise de décision. Cette étude de cas met aussi en évidence l'importance d'une banque de données fiable pour le développement durable des hautes terres tropicales. De nombreux pays en voie de développement souffrent de l'absence de mesures de terrain de qualité, et des restrictions diverses limitent communément l'accès à ces données. Prenant avantage des nombreuses fonctions d'analyse et de communication des SIG, cette étude propose une approche pour développer des indicateurs d'environnement pour les hautes terres tropicales à partir de données officielles et accessibles au public.

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## **ABSTRACT OF THE FRENCH VERSION**

### **ENVIRONMENTAL INDICATORS FOR TROPICAL AREAS**

#### **A methodology applied to forest, water and soil degradation in Thai Nguyen Province in Viet Nam**

Within the framework of research on sustainable management of tropical uplands coordinated by the French Institute for Development Research (IRD, formerly ORSTOM), the establishment of a Geographical Information System (GIS) has been undertaken for three pilot provinces situated in tropical upland hills and mountains areas of Vietnam. The objective of the present research is to define environment indicators to facilitate the analysis and communication to local decision-makers of the information generated by this GIS information. The document describes the methodologies developed to define environmental indicators of : (i) forest degradation ; (ii) soil erosion ; (iii) water shortage ; and (iv) water pollution. Using the STRESS model, environmental indicators of pressure, state and response have been developed for each of these fundamental conditions of tropical uplands.

The case study of Thai Nguyen province confirms the usefulness of environmental indicators as information instruments to raise the awareness of decision-makers about the fragility of an eco-system too often wrongly perceived as rich and under-exploited. Environmental indicators facilitate the analysis and conversion of large amounts of biological, physical and socio-economic data into only a few maps and figures directly relevant for decision-making. The case study of Thai Nguyen Province also highlights the importance of data quality and data availability for sustainable tropical uplands management. In developing countries, complete and reliable field measurements are often lacking, and various restrictions commonly exist preventing full access to even this limited information. Taking advantage of the analysis and communication functions of a GIS, the present document gives an example of how to develop environmental indicators sufficiently strong to support decision-making in a developing country using commonly available published information and data.