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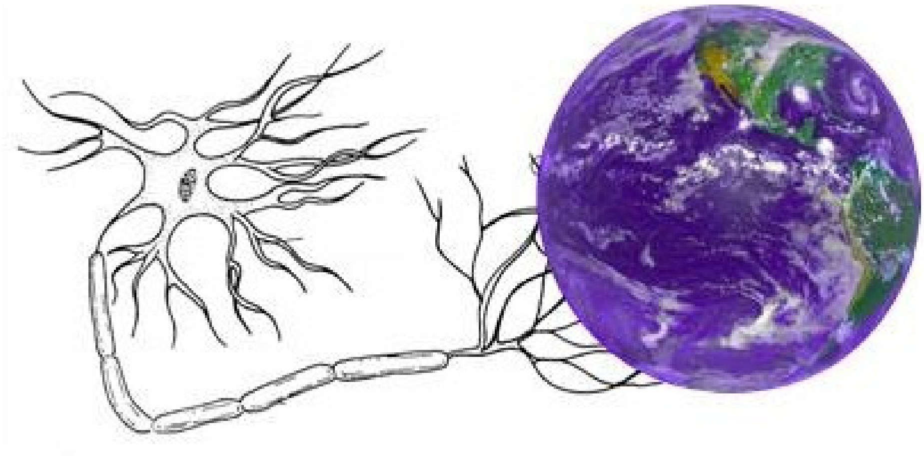

Environmental Conflict:
Feasibility study on the use of neural networks

Magisterarbeit

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Abstract

Environmental conflict will probably become more likely in the future because of the growing pressure on environment and society due to climate change and population growth. Whether this is really true has to be examined with suitable data and well performing analytical tools. If it is possible to actually predict the likelihood of environmental conflict, an early warning system for violent environmental conflicts could be developed. Unfortunately, any attempts to create such a system, usually with the help of a statistical regression analysis, have failed to produce usable and scientifically proven results. Therefore, this feasibility study intends to assess if neural networks are a suitable analytical tool to predict the probability of environmental conflict. As input data for the analysis the 40 ENCOP case studies from Bächler (Bächler and Spillmann (1996a) Bächler and Spillmann (1996b), and Bächler et al. (1996)) were used. These case studies were re-examined to reduce the number of input variables to 39. Even with the limitations of only using 40 case studies and 39 simple input variables from the ecosphere, the economy, the social and the political system, and a very simple design of the neural network, a recognition rate for environmental conflict in the case studies of as much as 82 % was achieved. Compared with results from statistical methods which yield probabilities for other similar questions within a range from 55 to 88 % with both quantitatively and qualitatively better data, using neural networks for the prediction of the likelihood of environmental conflict looks promising. Several options exist to optimize the performance of an analysis with neural networks. The quantity of the input data can be increased by using an increased number of suitable case studies. The quality of the input data can be improved by using an increased number of variables and by using quantitative indicators instead of simple statements of importance as in this study. In addition, the design of the neural network can be improved in comparison with the simple design that was used in this study. Thus, a prediction of the likelihood of environmental conflict in the future, in particular considering climate change and population growth, with the help of a neural network seems possible.

Abstract (German)

Es ist anzunehmen, dass Umweltkonflikte in Zukunft wegen des zunehmenden Druckes auf Umwelt und Gesellschaft durch den Klimawandel und das Bevölkerungswachstum wahrscheinlicher werden. Ob dies tatsächlich der Fall ist, Bedarf der Untersuchung mittels geeigneter Analysemethoden und Ausgangsdaten. Die Fähigkeit, die Wahrscheinlichkeit von Umweltkonflikten tatsächlich anzugeben, würde auch den Aufbau eines Frühwarnsystems für Umweltkonflikte ermöglichen. Allerdings sind alle Versuche brauchbare und wissenschaftlich nachprüfbare Ergebnisse, in der Regel unter Verwendung statistischer Untersuchungsmethoden, zu gewinnen, gescheitert. Daher wurde in dieser Machbarkeitsstudie der Versuch unternommen festzustellen, ob neuronale Netze als Untersuchungsmethode für die Vorhersage der Wahrscheinlichkeit von Umweltkonflikten tauglich sind. Als Eingangsdaten für die Analyse wurden die 40 ENCOP Fallstudien von Bächler (Bächler und Spillmann (1996a), Bächler und Spillmann (1996b) und Bächler et al. (1996)) verwendet. Diese Fallstudien wurden so ausgewertet, dass sich die Zahl der Eingangsvariablen auf letztlich 39 reduzierte. Trotz der Begrenzungen durch lediglich 40 Fallstudien, der Verwendung von nur 39 einfachen Eingangsvariablen aus den Bereichen Ökosphäre, Wirtschaft, Gesellschaft und Poltisches System und einem sehr einfachen Design des neuronalen Netzes, konnte eine Erkennungsrate für Umweltkonflikte in den Fallstudien von 82 % erreicht werden. Verglichen mit den Ergebnissen von statistischen Methoden, die in ähnlichen Fragen zutreffende Vorhersagen mit einer Wahrscheinlichkeit von 55 bis 88 % erlauben, und dabei sowohl mehr als auch qualitativ bessere Daten verwenden, erscheinen neuronale Netze damit als brauchbares Instrument für die Vorhersage der Wahrscheinlichkeit von Umweltkonflikten. Verschiedene Optionen existieren, um die Leistung eines neuronalen Netzes für diese Anwendung noch weiter zu verbessern. So können weitere zusätzliche Fallstudien verwendet werden. Die Zahl der Eingangsvariablen kann erhöht und Ihre Qualität durch die Verwendung quantitativer Indikatoren an Stelle von einfachen Relevanzfaktoren verbessert werden. Außerdem kann das Design des neuronalen Netzes verfeinert werden. Die Vorhersage der zukünftigen Wahrscheinlichkeit von Umweltkonflikten unter den Bedingungen eines Klimawandels und einer wachsenden Weltbevölkerung mit Hilfe von neuronalen Netzen erscheint daher möglich.

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Acronym Glossary

AIC	Akaikes information criterion
AKUF	Arbeitsgemeinschaft Kriegsursachenforschung (Working group causes of war)
ARW	Advanced Research Workshop
BAR	Basins at risk
BCP	Basin-country-polygon
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany)
DETR	Department of the Environment, Transport and the Regions (United Kingdom)
DOD	U.S. Department of Defense
ENSO	El Niño Southern Oscillation
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GLASOD	Global assessment of human induced soil degradation
GMES	Global Monitoring for Environment and Security
KOSIMO	Konflikt-Simulations-Modell (Conflict simulation model)
NATO	North Atlantic Treaty Organization
NIC	National Intelligence Council
NN	Neural Networks
OCR	Optical character recognition
OECD	Organisation for Economic Co-operation and Development
ROC	Receiver Operator Characteristic
RSQ	Pearson's R^2
SBC	Schwarz's Bayesian criterion
SHIBATA	Shibata's criterion
SRES	Special Report on Emission Scenarios
SSE	Sum of squared errors
TSS	Total sum of squares
UNEP	United Nations Environment Programme

VDEW	Verband der Elektrizitätswirtschaft (German Electricity Association)
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (Scientific advisory committee of the German Government on global change)
WEKA	Waikato Environment for Knowledge Analysis

Abbreviations

app.	approximately
e.g.	*exemplum gratum*
i.e.	*id est*
p.a.	*per annum*
pers. comm.	personal communication
vs.	*versus*

Glossary/ Definitions

Armed conflicts:	“Armed conflicts are violent conflicts of a lesser intensity. They are often the first step in an escalation process.” (Nicholson 1992: 14)
Climate Change:	Sub type of Environmental Change
Conflict:	“An acute national or international conflict is a conflict which involves a substantial probability of violence.” (Homer-Dixon 1991: 77)
Environmental change:	“Decline in the quantity or quality of a renewable resource that occurs faster than it is renewed by natural processes.” (Homer-Dixon 1994: 4)[1]

[1] Note that the definition from Homer-Dixon is a negative one. Environmental change could also be positive.

Environmental conflict:	“Environmental Conflict manifest themselves as political, social, economic, ethnic, religious or territorial conflicts, or conflicts over resources or national interests or any other type of conflict.” (Libiszewski 1992: 13)
Environmental degradation:	“The term environmental degradation understood as a human-made environmental change having a negative impact on human society expresses rather precisely what we mean by an environmental cause of a conflict.” (Libiszewski 1992: 4)
Environmental refugee:	“People who have been forced to leave their traditional habitat, temporarily or permanently, because of marked environmental disruptions that jeopardized their existence and / or seriously affected the quality of their life.” (el-Hinnawi, 1985: 4, cited from Lonergan 1998a: 7)
Environmental stress:	“The intensity of an environmental change that involves an undesirable departure from long-term or “normal” conditions.” (Alcamo and Endejan 1999: 2)
State susceptibility:	“The ability of a state to resist and recover from […] environmental stress.” (Alcamo and Endejan 1999: 2)
War:	“War is continuous, armed, and violent conflict, where more than one armed forces are participating. One of these armed forces has to be a regular armed force of a government and both must have a minimal degree of central organization.” (Gantzel 1987: 33).

Symbols

a_i	neuron value
f(.)	activation function
$_i$	external threshold
u(.)	basis function
u_i	net value
W	matrix of the weights w_{ij}
w_{ij}	synaptic weight
x	input of the neural network
y	output of the neural network

A	Consumption behaviour
I	Environmental Degradation
P	Population
T	Technology

1 Introduction

1.1 Objectives of work

Environmental conflicts, i.e. conflicts in which environmental degradation is one factor and not necessarily the only factor that leads to the development of a conflict, have been explained and described by a number of authors. Homer-Dixon (1991 and 1994) and Bächler *et al.* (1996) are probably the most important among them. They have both described a variety of case studies about environmental conflict and built theories on the causes and the development of environmental conflicts.

Environmental conflicts have already occurred in the past and they are still ongoing today. In the future the probability of environmental conflict may further rise due to population growth, climate change, and the associated ecologic stress. “Climate changes could both increase and decrease the likelihood of international frictions… Our challenge is to identify those cases in which conflicts are likely to be exacerbated and to work to reduce the probability and consequences of those conflicts.” (Gleick 1996b: 15). The Head of UNEP, Klaus Töpfer, even demanded that an early warning system for violent environmental conflicts be developed (Thüringische Landeszeitung, 1998-09-29). An early warning system for environmental conflict would allow for the effective use of measures to work against the onset of violent conflicts. Thus, methods that are able to identify the likelihood of environmental conflict shall be the focus of this paper.

Unfortunately, the human-environmental system is very complex (see also Gimblett 2002 on complexity) and it is particularly difficult to identify possible future environmental conflicts. The possible effects of climate change on our environment, the socio-economic and the political system are diverse, and theories that sufficiently and in detail cover all possible connections and causal relationships between environmental degradation and violent conflict are not yet developed (see also chapter 2). The difficulty in the prediction of these security problems is that it is not known which factors are actually decisive. Possible factors that may influence the likelihood of conflict could be patterns of land distribution, family and community structures, the system of property rights and markets, perceptions of long term political and economic stability, historically rooted patterns of trade and interaction with other societies, religious or social beliefs, the form and effectiveness of institutions of governance, precipitation, level of ground water, adaptability of farmers, productivity of the soil, land use, population density, level of democratization and many more. The causal links between these factors are not tight or deterministic and the human-environmental system shows great adaptability.

The effect of future population growth and climate change on security (human physical, social, and economic wellbeing) or the likelihood of conflict is perhaps the hardest to predict. The reason for this is the non-linearity of many relationships. The beginning of a violent conflict may show such a non-linear behaviour, which is reflected in the German saying “Der Tropfen, der das Fass zum Überlaufen bringt” (The drop that causes the barrel to overflow). The climate system also shows such non-linear behaviour. As an example water temperatures in the tropics can grow warmer without generating any hurricanes, but once the water passes 26° C it begins to promote them (McNeill 2000: 4). A very drastic projection of the expected effects of climate change on security is given in an internal paper of the U.S. Department of Defense by Schwartz and Randall (2003). They dramatized the impact climate change could have on society if society was unprepared for it. The projected collapse of the global thermohaline circulation in 2010 disrupts the temperate climate of Europe which is made possible by the warm flows of the Gulf Stream (the North Atlantic arm of the global thermohaline circulation). With fewer dramatizations it can be said that the environmental degradation induced by population growth or climate change will possibly raise the level of stress within national and international society, thus increasing the likelihood of many different kinds of conflict and impeding the development of solutions based on co-operation.

At the side event "Climate Change and Conflict Prevention" which was held during the 16th meeting of the Subsidiaries Bodies to the United Nations Framework Convention on Climate Change (UNFCCC) in Bonn on June 10, 2002 (see BMU 2002) it was stressed that there is a need to go beyond the assessment of hot spots for potential conflict. The aim of this study is therefore, to evaluate the use of neural networks as an analytical tool for predicting the likelihood of environmental conflict.

1.2 On forecasting

It is clear that we will never be able to know enough to precisely predict climate change let alone environmental conflict. Therefore, some thoughts from Burroughs (1997: 134-136) on the nature of forecasting are outlined here. In order to calculate the "simple" mechanical problem to predict the course of ten billiard balls in a row under ideal conditions (perfect elastic balls and cushions, and no resistance to motion) it would be necessary to include the gravitational effects of an electron on the far side of the universe. For practical reasons even this simple mechanical problem cannot be solved exactly. The decision for a conflict cannot be forecasted, either. The decision to escalate a conflict into a violent conflict is always a decision taken by single or collective actors and cannot be predicted. We can, however, predict a statistical likelihood. If we throw a perfectly balanced die 600 times, we can predict that each number from one to six will come up about 100 times, but we can never predict the precise sequence of numbers.

1.3 Outline of this paper

At the beginning of this paper some aspects are first explained how print media sees the problem of environmental conflict and how governments responded. Then the basic theory on environmental conflict from Homer-Dixon (1991 and 1994) and Bächler et al. (1996) will be briefly summarized (see chapter 2). This review leads to the description of the relevant spheres which have to be considered and the factors that might contribute to the development of environmental conflict.

The analytical framework that was chosen for this paper is a case study analysis with neural networks. Neural networks are a powerful tool for modelling problems for which the explicit form of the relationship among the variables is not known, which is indeed true for environmental conflict. The mathematics behind artificial neural networks is described in chapter 3 to allow a better understanding of the analytical approach, which is described in detail in chapter 4.

It is then shown in chapter 5 how an effectively trained neural network could be used to assess the likelihood of environmental conflict.

Finally, the results of the analysis will be discussed and compared with other analytical approaches in chapter 6, before an outlook is given on a possible avenue for method improvements and further research on the identification of the likelihood of environmental conflicts.

Chapter 7 gives a summary which answers the question of this feasibility study whether the prediction of the likelihood of violent environmental conflict induced by climate change and population growth with neural networks as an analytical tool might be possible.

2 Political theory of environmental conflicts

2.1 Climate change and environmental conflict in the print media

In the past 15 years the discussion on the effects of climate change including its impact on security has taken place mainly in academic circles. In recent years, however, several articles about the topic and the connection between climate change and environmental conflict appeared in the general print media or in specialized magazines read by industry. Table 1 gives a short, non-statistical and naturally incomplete overview. It shows that the problem is discussed in wider circles and obviously gains more importance.

Table 1 Articles about environmental conflict or the impact of climate change on national security in the press

Publication	**Date**	**Topic**
Erneuerbare Energien	08/2002	According to a UNEP study in parts of southern Africa crop growth will decrease by up to 20 % because of climate change.
Frankfurter Allgemeine Zeitung	2000-01-08	The UNEP World Water Commission estimates that the global water consumption will rise from 2000 km^3 to 2250 km^3 in 2025. The annual costs to meet this demand are estimated to be 125 billion $.
Frankfurter Allgemeine Zeitung	2000-03-22	Disputes about the value of water and water distribution on the second World Water Forum in The Hague. Access to water might be a reason for future wars.
Frankfurter Allgemeine Zeitung	2000-05-30	Food crisis may lead to war.
Frankfurter Allgemeine Zeitung	2000-07-05	Extreme drought affects the Iran-Afghanistan border region.
Frankfurter	2000-07-19	Israel wants to buy water in Turkey because of

Allgemeine Zeitung		acute shortages.
Frankfurter Allgemeine Zeitung	2000-10-17	Covering natural disaster becomes more expensive by insurance companies. Climate Change might accelerate this trend.
Frankfurter Allgemeine Zeitung	2000-11-03	Climate Change is accelerating – drastic changes for Europe cannot be averted.
Frankfurter Allgemeine Zeitung	2000-11-18	Differences in the ecological interests and the willingness to pay for climate programmes endanger an effective climate policy.
Frankfurter Allgemeine Zeitung	2001-07-11	Water crisis in Israel
Frankfurter Allgemeine Zeitung	2001-08-04	Poland has to expect more floods if climate change continues.
Frankfurter Allgemeine Zeitung	2003-10-11	Debated oil pipeline between Chad and Cameron begins operation.
Frankfurter Allgemeine Zeitung	2003-10-24	Peace talks in Sudan focus on oil, water and Islamic law.
Global Emissions	2002-09-05	The environmentalist group World Wildlife Fund (WWF) reports that climate change will have significant impacts on biodiversity and food security in Africa.
Global Emissions	2002-09-05	Melting glaciers could lower summer river flows reducing the electricity generation potential in Canada.
Handelsblatt	2000-08-08	Northern China hit by the worst drought in decades.
National Geographic	09/2002	The Earth’s six Billion people already overtax its supply of accessible fresh water. National Geographic asks what happens when the planet gets a few billion more hands.
Die Tageszeitung	2004-02-23	The Pentagon detects climate protection US climate protection activists surprisingly

		gained support from the armed forces. Climate change is danger for national security.
Spiegel Online (www.spiegel.de)	2003-11-05	The Gaza strip runs out of water.

2.2 Government responses

Governments throughout the world have reacted to the growing discussion. "The war over water" (Cooley 1984) in the Near East has been on the political agenda since the 1950s. Dwight D. Eisenhower sent Eric Johnston to negotiate regional water-sharing arrangements. The topic got a greater importance in the early 90ies. The US government has started to think about a policy on the nexus between environment and security from 1991 on without, however, agreeing on a cohesive, overarching policy or plan (Dabelko and Simmons 1997). In 1995 the U.S. Department of Defense (DOD) started a joined project with the North Atlantic Treaty Organization (NATO) to "assess security risks posed by environmental problems, prioritize those risks for action, and devise an action plan to address them" (Dabelko and Simmons 1997). As early as in 1989, the Norwegian Defence Minister Johan Jørgen Holst argued that environmental stress seems likely to become an increasingly potent contributing factor to major conflicts between nations (Holst, 1989: 123 cited from Gleditsch 1999a). Finnish and Danish positions have also included the environment as a major security issue (Vandeveer and Dabelko 1999). 1989 was also the year in which the Soviet Union suggested the establishment of an UN environmental security council. France and the UK followed with statements from president Chirac and Foreign Minister Rifkind in 1997. (Carius and Imbusch 1998). The European Commission responded with a special seminar on the topic (European Commission 1999).

2.3 Short overview on the theory of environmental conflicts

2.3.1 Environmental conflict as resource conflict

As a first assumption an environmental conflict may be reduced to a resource conflict, e.g. a conflict over the resource water. Westing (1986) initially followed this approach and grouped resource conflicts about land, fresh water, non-fuel minerals, fuels, food, and ocean fisheries into the same category. Resource constraints have frequently led to war. The most important resource in respect to inter state war in the past 350 years was territory. The second most important reason that led to interstate war were governmental questions (Gleditsch 1999a). The access to strategic raw materials or sources of energy did become another resource besides territory over which wars were fought. A prime example would be the conflicts around the Persian Gulf. There are some experts who think that the scarcity of water may replace oil as a flashpoint for future conflict. 214 major river systems are shared by two or more countries, and many of them are subject of unresolved disputes (see Gleditsch 1999a). Food is another resource that may become the focal point of conflict. Even in the North Atlantic confrontations between fishing ships and armed coastal guard ships did in fact take place (Gleditsch 1999a).

The link between environmental degradation and violent conflict was described in depth by Homer-Dixon (1991 and 1994) and Bächler et al. (1996) who started an intensive academic discussion about environmental conflicts with their works. Both works have the probably greatest influence on theory building centring on environmental conflict. They are, therefore, briefly presented here.

2.3.2 Theories of Homer-Dixon

Homer-Dixon has gone beyond the first assumption in the theory of environmental conflicts that environmental conflicts might be just another form of resource conflicts (Homer-Dixon 1991). Homer Dixon (1991) has first and foremost established causal links between environmental change and conflicts or environmental conflicts. Environmental change can have an effect on security (human physical, social, and economic wellbeing) and in consequence a conflict may arise (war, terrorism, or diplomatic and trade disputes). Environmental change can have different causal roles. It can be proximate and powerful or minor and distant in its role. Many political, economic, and physical factors can influence the role environmental change can play. Environmental change may lead to acute conflict in the following ways:

- Environmental Change shifts the balance of power between states either regionally or globally producing instabilities that could lead to war.
- As global environmental damage increases the disparity between North and South, poor nations may militarily confront the rich for a greater share of the world's wealth.
- Warmer temperatures could lead to contention over new ice-free sea-lanes in the Arctic or more accessible resources in the Antarctic.
- Bulging populations and land stress may produce waves of environmental refugees that spill across borders with destabilizing effects on the recipient's domestic order and on international stability.
- Countries may fight over dwindling supplies of water and the effects of upstream pollution.
- In developing countries, a sharp drop in food crop production could lead to internal strife across urban-rural and nomadic-sedentary cleavages.
- If environmental degradation makes food supplies increasingly tight, exporting countries may be tempted to use food as a weapon.
- Gradual impoverishment of societies in both the North and South, which could aggravate class and ethnic cleavages, undermine liberal regimes, and spawn insurgencies.
- Environmental degradation will “ratchet-up” the level of stress within national and international society, thus increasing the likelihood of many different kinds of conflict and impeding the development of cooperative solutions.

Poor countries are generally more vulnerable to environmental change because they lack the financial, material or intellectual resources of developed countries. Their social and political institutions are in many cases less stable. Furthermore, developing countries depend on agriculture which makes them more vulnerable to environmental change. A range of atmospheric, terrestrial and aquatic environmental pressures will produce reduced agricultural production, economic decline, population displacement and finally the disruption of regular and legitimized social relations.

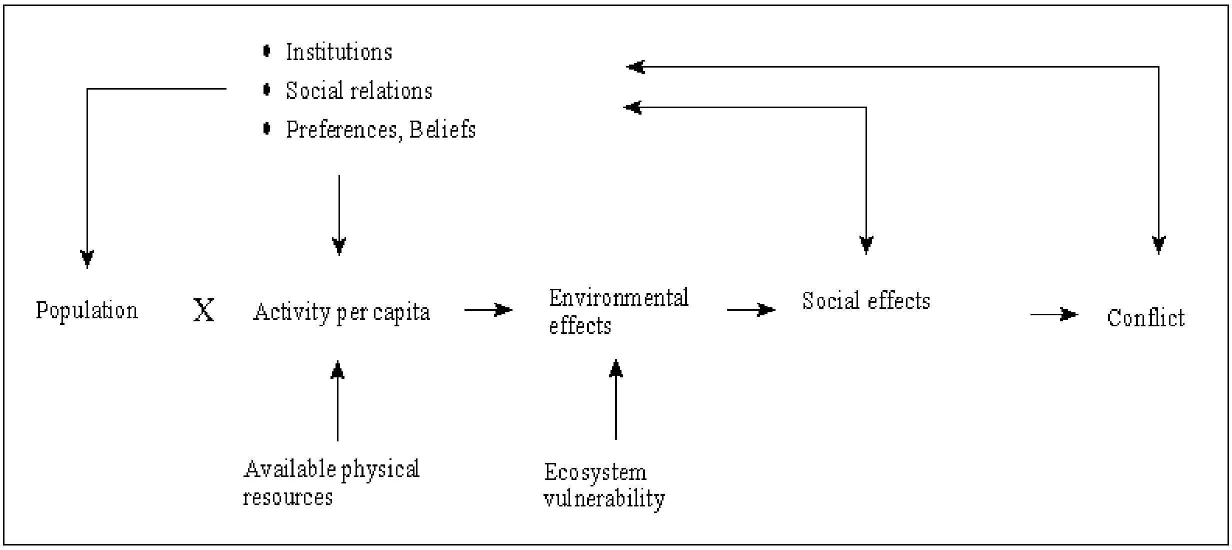

Figure 1 Causal links between environmental change and acute conflict according to Homer-Dixon (1991: 86)

The causal links outlined by Homer-Dixon (1991) are shown in Figure 1. In summary human activity leads to environmental change which in turn leads to social disruptions and as a last consequence to conflict. Acute conflicts may have the form of scarcity disputes between countries, clashes between ethnic groups or civil strife and insurgency.

Each of these conflicts has potentially serious repercussions for the security interests of the developed world. Homer-Dixon (1991) does not see conflict as a consequence which cannot be averted. It is possible to reduce the effects of human activity on the environment, of environmental change on the social system, etc. The causal links between the variables are not tight or deterministic. The great resilience, variability, and adaptability in the human-environmental system cannot be determined easily. Interactive, synergistic and nonlinear causal relations are at the heart of the problem. Some factors which might influence the way the human-environmental system behaves according to Homer-Dixon (1991) are:

- Population growth
- Population distribution
- Demographic structure

- Patterns of land distribution
- Family and community structures
- Economic and legal incentives to consume and produce goods
- The system of property rights and markets
- Perceptions of long run political and economic stability
- Historically rooted patterns of trade and interaction with other societies
- Debt and export relations
- The distribution of coercive power within and among nations
- The form and effectiveness of institutions of governance
- Metaphysical beliefs about the relationship between humans and nature
- Social relations and institutions,
- Class, ethnic and linguistic structure
- Culture of leadership
- Beliefs about the social good that motivate challengers and elite groups
- Repressiveness of a regime

Classical cleavages may also overlap with these factors. Different religious or social beliefs can be decisive. And not only population growth puts the pressure on the environment. Changes in agricultural practice and land distribution (land owners contra small farmers) are also important. However the simple density-dependant models of resource competition cannot model the problem adequately, either. Resource competition is powerfully constrained by social and political structures.

The major environmental problems which are listed by Homer-Dixon (1991) all affect agriculture most.

- Greenhouse warming
- Stratospheric ozone depletion (global)
- Acid deposition
- Deforestation
- Degradation of agricultural land
- Overuse and pollution of water supplies

- Depletion of fish stocks
- Reduced biodiversity
- Dumping of toxic waste

Then the following principal social effects are results of environmental change:

- Decreased agricultural production
- Economic decline
- Population displacement
- Disruption of legitimized and authoritative institutions and social relations
- Lost trust in institutions
- Lower tax income for the nation states
- Disruption of labour markets
- Changes in class structures
- Changes in the balance of the economical and political power of ethnic groups

In order to explain the next step to conflict, Homer-Dixon (1991) had to go back to general conflict theories. Environmental change does not necessarily have a direct effect on the economic, military or ideological power of a nation state. Homer-Dixon (1991) gives three theoretical perspectives on conflict.

- <u>Individual</u> (derived from frustration-aggression theories): civil strife, strikes, riots, coups, revolutions, guerrilla wars
- <u>Group</u> (derived from group identity theories): nationalism, ethnicity, religion
- <u>System</u> (derived from structural theories, economics and game theory): rational calculation of actors, power relations

Thus environmental change might lead to three principal types of conflict:

- <u>Relative deprivation conflicts</u> where less wealth makes people frustrated and the rate of change is the key (Individual)

- Group identity conflicts with large-scale movements of populations, where different groups are propelled together under stress which leads to inter-group hostilities (Group)
- Simple scarcity conflicts over river water, fish and agriculturally productive land (System)

Homer-Dixon revised and extended his theory in 1994 (Homer-Dixon 1994). Within the next 50 years the planet's human population will probably pass nine billion and global economic output may quintuple. As a result scarcities of renewable resources will increase sharply. The total area of high quality agricultural land will drop, as will the extent of forests and the number of species they sustain. Widespread depletion of aquifers, rivers and other fresh water resources, the decline of many fisheries, and perhaps significant climate change will increase the pressure through environmental change.

According to Homer-Dixon's (1994) view violence will usually be sub-national, persistent and diffuse. Poor societies will be particularly affected since they are less able to compensate environmental scarcities and the social crisis they cause. These societies are in fact already suffering acute hardship from shortages of water, forests and, in particular, fertile land.

However, social conflicts are not always negative. Mass mobilization and civil strife can produce opportunities for beneficial change in the distribution of land and wealth. But fast-moving problems can overwhelm efforts at constructive social reform. Scarcities can increase demands on key institutions, such as the state, while it simultaneously reduces their capacity to meet those demands. These pressures increase the chance that the state will either fragment or become more authoritarian. The negative effects of severe environment scarcity are therefore likely to outweigh the positive ones.

2.3.3 Theories of Bächler

Bächler *et al.* 1996 points out that environmental degradation might be a necessary factor for the development of a conflict but not the all decisive one. Doomsday scenarios of global environmental conflicts are fiction. Environmental conflicts only become violent under certain socio-economic conditions (Bächler 1998). Environmental degradation might act as trigger, target, channel or catalyst of violent conflict (Libiszewski 1996a: 442). The important contribution of Bächler *et al.* 1996 is the design of a typology for environmental conflicts. The point of departure is outlined in Table 2.

Table 2 Types of environmental conflict according to Spillmann and Bächler (1995: 6)

	Type 1	**Type 2**	**Type 3**
Cause	Non-anthropogenic environmental transformation by known, non-societal source	Anthropogenic planned / desired / accepted environmental transformation by known, societal source	Anthropogenic unplanned / undesired environmental transformation by diffuse / unrecognized human source
Examples	Natural disasters: • Floods • Droughts • Earthquakes • Storms • Volcanic eruptions	Large Engineering Works: • Dam Building • Mining • Diversion of water courses • Logging	Cumulative effects of large numbers of small actions, that individually are useful and appropriate: • Overgrazing • Clearing of land • Dumping of waste
Conflict	Between affected groups who are struggling for damage	Between those who cause the damage and the groups	Between groups that struggle for damage control and survival

	control and survival	suffering from deprivation by it	

Stemming from these initial types of conflict, Bächler *et al.* 1996 differentiates between the following different subtypes of environmental conflict.

- Centre-periphery conflicts (national and international)
- Ethno political conflicts
- Migration conflicts (within state boundaries and transboundary)
- Migration conflicts with a demographic component (population growth)
- International water conflicts

The relationship between environmental degradation and the contributing factors shown in Equation 1 that is given by Bächler *et al.* (1996) is simpler than that used by Homer-Dixon (1991) which is described in Figure 1.

$$I = P \times A \times T$$

Equation 1 Relationship between Environmental Degradation (I), Population (P), Consumption behaviour (A) and Technology (T) according to Bächler *et al.* (1996)

The reasons that lead to conflict according to Bächler *et al.* 1996 are listed below:

- Trapped development
- Lack of social regulatory mechanisms
- Environmental instrumentalization
- Organizational ability and opportunity to become armed
- Historical conflict patterns

2.3.4 Other theories

Schultink (1999) extends the theory of Homer-Dixon to other areas. According to him the imbalance between resource demand and resource production capacity does not only result in resource scarcity but promotes unsustainable production practices. In turn, these practices further undermine the long-term productive capacity of the natural resource base, resulting in environmental stress exemplified by various indicators of land degradation and ecosystem productivity loss.

Access to natural resources (territorial claims to water, energy, minerals, fishing rights) and trade restrictions (tariffs, import quotas, price controls and other forms of market restrictions) will increasingly become significant factors for international conflict resolution and foreign policy formulation. Trade wars as a type of potential conflict may be induced by environmental change.

2.3.5. Some open discussions

In academic circles the works of Homer-Dixon (1991 and 1994) and Bächler *et al.* (1996) have sparked an intensive debate. These debates are continuing and shall only be referenced here without delving into every aspect of the current academic discussion. The discussion on the linkage between environmental problems and security concerns is particularly controversial (e.g. Dabelko and Simmons 1997, Carius and Imbusch 1998, Dyer 1999 or Trombetta 1999). A multitude of arguments is used in favour and against this linkage and the possible intentions of the different actors to be in favour or against it.

A second topic under hot debate is the definition of environmental conflict (see e.g. Carius and Imbusch 1998). This paper uses the definition of environmental conflict from Libiszewski (1992: 13), simply because it is also the basis for the case studies that are used in this study: “Environmental conflicts manifest themselves as political, social, economic, ethnic, religious or territorial conflicts, or conflicts over resources or national interests or any other type of conflict.”

General overviews on the political theory around environmental conflict can be found in Carius and Lietzmann (1998), Diehl and Gleditsch (2001), Gleditsch *et al.* (1997), Lonergan (1999) or Piotrowski (1997).

2.4 A systematic approach

The difficulty in the prediction of environmental conflict lies in the "distance" between the environmental degradation and the outbreak of violent conflict. Several intervening spheres of influence or variables exist. In the following chapter an attempt is made to classify the types of effects and repercussions according to their principal sphere of influence. Figure 2 shows one possible, sensible classification of the variables that would have to be considered. Obviously, the initial effects on the ecosystem have to be considered. Possible subgroups include the lithosphere (or pedosphere), the atmosphere, the hydrosphere or the biosphere. In a next step environmental degradation leads to economic effects in the agricultural sector, in fisheries and also in the industrial sector. Economic effects are then mediated through the social system. The first direct effect is on the income and the wellbeing of the population. But of course the make up of the population, behaviour and beliefs or historic experience influence the likelihood of environmental conflict. Finally, the political system with its structures and institutions, its problem solving capacity or the balance of power in the external relations of a state are important. Potential effects of environmental change might cascade up and down from the ecosphere, the economy, the social system to the political system.

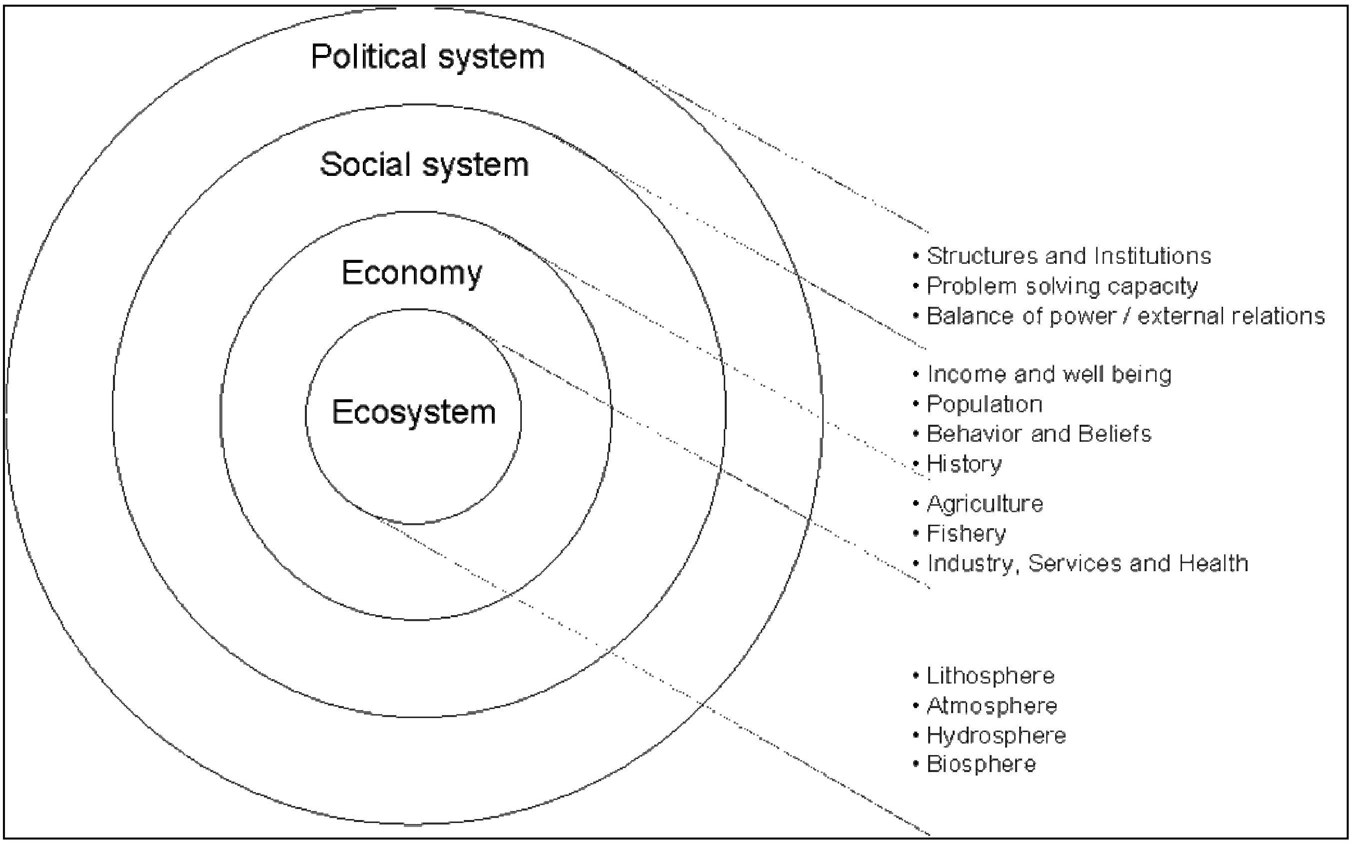

Figure 2 Systematic presentation of the factors that influence the likelihood of environmental conflict

2.4.1 Effects on the Ecosphere

The principal effects Homer-Dixon (1991) sees as most important are all affecting the ecosphere first.

- Climate change
- Stratospheric ozone depletion (global)
- Acid deposition
- Deforestation
- Degradation of agricultural land
- Overuse and pollution of water supplies
- Depletion of fish stocks

Thus, the principal effect of environmental degradation is ecosystem damage. Besides these primary ecological effects, environmental degradation then in turn affects the economic, social and eventually the political system. It can even transform the social system and, thus, environmental degradation can change these systems itself. The effects can be direct or indirect, weak or strong. None of the relations between the different factors are irreversible, nor is the carrying capacity of every affected region identical (Bächler 1998).

2.4.1.1 Lithosphere (Soil)

Degradation of agricultural land is caused by human impact, e.g. no regeneration periods, over-cultivation, too much livestock, deforestation or the mismanagement of water resources. The negative effects can be listed shortly:

- Salinization (because of overuse of water)
- Compaction of the soil
- Erosion because of wind, water and overuse

Drought is often a catalyser which emphasises the problems. The magnitude of the problems is not identical in all cases. Erosion problems are usually less severe in lowlands than in highlands with strong slope.

2.4.1.2 Atmosphere

The most important effects on the atmosphere are extreme weather events like storms whose frequency and intensity is expected to rise due to climate change. For today studies from the world's largest reinsurance company Munich Re (2003) show only a slight increase in storm activity over the North Atlantic and the Northwest Pacific Ocean from 1950-2003. It is noteworthy that only the number of smaller scale storms has increased. The number of severe hurricanes and typhoons has not increased. The annual average of six major hurricanes and 20 major typhoons remains unchanged (see Figure 3).

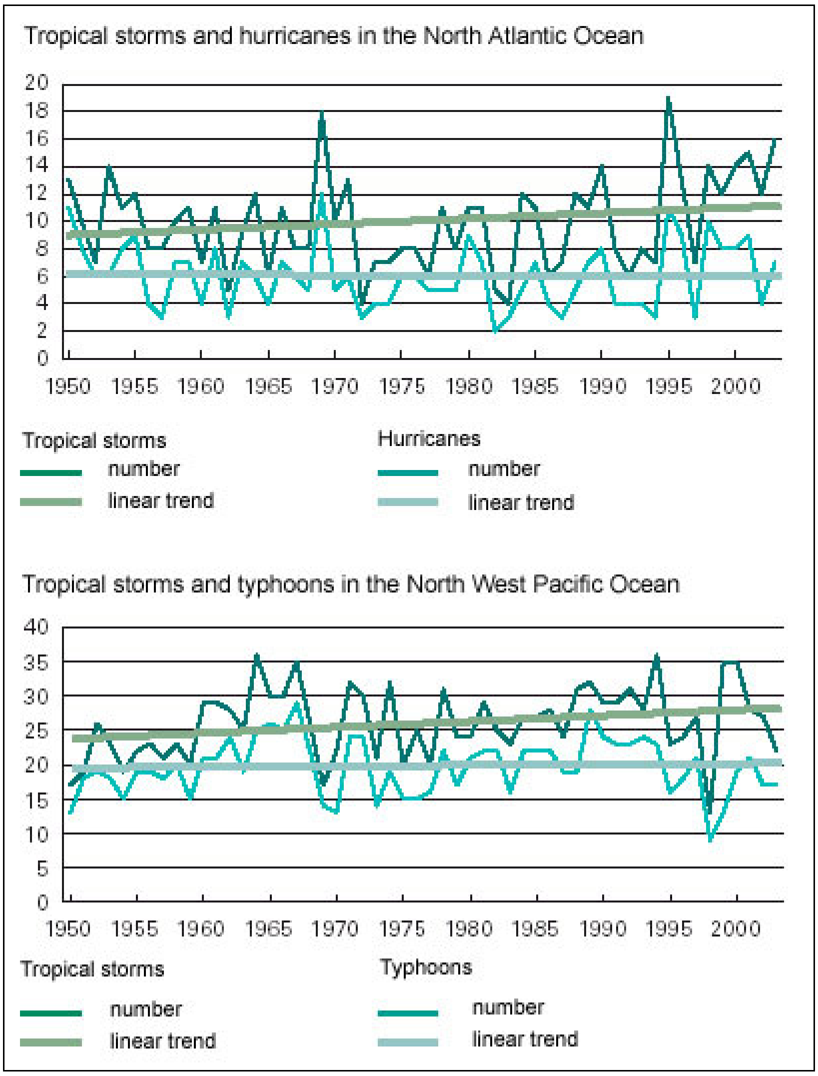

Figure 3 Development in the number of tropical storms from 1950-2003 (adapted from Munich Re 2003: 43)

2.4.1.3 Hydrosphere

Water is probably the most important renewable resource. It is needed for agriculture and industry, water transportation, hydroelectric power, fishing, drinking and, in general, for the general quality of life. The use of water resources may be a transboundary problem. There exist more than 210 international river systems. Popular examples include some of the largest river system on Earth: Rhine, Danube, Nile, Mekong, Ganges, Amazon, Ganges, Niger, Congo, Zambezi, Volta and La Plata. Furthermore, 47 % of all land territories are located in international river basins (Gleick 1989). This makes international cooperation a necessity because it is possible to externalize all costs to the downstream country. The control of river sources may result in war for territory, in particular if downstream countries depend on the imported water (Wöhlcke 1998).

Negative effects on the hydrosphere from environmental degradation include:

- Floods
- Droughts
- Overuse and pollution of water supplies

The use of fossil water resources (ground water) may alleviate the dependence on external water sources but it is not sustainable in the long term. The lowering ground water levels in the Near East or in the Great Planes of the USA illustrate the problems associated with the consumption of these non renewable resources. Effective irrigation measures, e.g. like they are used in Israel, may reduce some of the stress on water resources.

There are differences between the pollution of water resources by non-state actors, and e.g. a state program like the building of a dam. The latter is more direct, the former more indirect and will probably not lead to escalation so fast. Even polluted water may be used for certain industrial needs, polluted water can be cleaned by technical methods or water can be used more effectively. Thus, the conflict over water is not over the physical access but also over the distribution of water treatment costs. Lots of possibilities of cooperation exist.

According to Acreman (1998) a per capita water consumption below 1700 m^3 p.a. can be considered as water stress and a level below 1000 m^3 p.a. would mean acute water scarcity. It is expected that 22 African states will suffer from water stress by the year 2025 and 4 will face water scarcity (Kenya, Rwanda, Burundi and Malawi). This projection is based on only the population growth as a key assumption. It does not take climate change into account.

2.4.1.4 Biosphere

The most important effects on the biosphere are reductions of habitat and a reduction in biodiversity. Special problems exist in mountainous regions with a rich variety of microclimates and different ecosystems. Mountainous regions are particularly vulnerable. Damage in highlands can cause effects in far away lowlands (flooding due to deforestation).

2.4.2 Effects on the economy

Damage on the ecosphere usually translates directly into economic damage. The least developed countries the usually affected the hardest. A highly developed economy has the option to invest in new and cleaner technologies which may solve problems of environmental degradation (Gleditsch 1999a). Developing countries often lack this possibility. Clearly, many forms of environmental degradation such as deforestation, soil erosion and lack of freshwater are problems of poverty as well.

2.4.2.1 Agriculture

The most direct and important effect of environmental degradation is felt in agriculture. Direct and strong effects of environmental degradation are changes in the productivity of farmland which can lead to price increases or to famine. Two principal factors for the productivity of agriculture are the quality of the soil and the availability of water. Access or non-access to suitable land for agriculture may be cause for conflict. Conflicts because of differences in the intensity of agricultural use (farmer vs. nomads) or because of different forms of ownerships (subsistence farmers vs. large land owners) are also possible. Secondly, the access to water can be critical. According to Sherbinin and Dompka (1998) as much as 40 % of the world's food supply is grown under irrigation. Humans use more than half of all accessible surface water runoff. This proportion is expected to increase to 70 % by 2025. (Postel *et al.* 1996 cited from Sherbinin and Dompka 1998). 69 % of the consumed freshwater goes into agriculture (Data from 1996-1997).

For the development of agricultural problems or even violent conflict, a whole range of intervening factors have to be considered: The size of livestock, subsequent investments in an affected region, planting patterns, international food prices, the character of trade agreements or even strategic dependencies, like the soviet dependence on U.S. grain during the cold war (Gleick 1989).

2.4.2.2 Fishery

In 1990 fish that stands for roughly 8 % of the net primary productivity of the oceans was caught. About one billion people rely on fish as their main source of animal protein. The negative effects of a reduced fish catch can be seen from the example of Peru. Between 1967 and 1971 the Peruvian fishery peaked at 10-12 million tons, 20 % of the world's total. In 1972 the catch fell to 4.7 million tons and later on between 2-4 million tons for the next 15 years. This disaster hamstrung Peru's economy, contributing to the turbulent politics of the 1970s and 1980s in Peru which featured relentless inflation, mass unemployment, and the emergence of violent revolutionary groups (McNeill 2000: 243-252).

Even Canada and Spain, allies who had never fought each other, found themselves in a diplomatic conflict in spring 1995 that ultimately resulted in the firing of shots. Nationals of both states were engaged in fishing at the Grand Banks, off Newfoundland, for Greenland halibut (Matthew *et al.* 2002: 330 and Soros 1997).

2.4.2.3 Industry, Services and Health

Effects on industry are not obvious at first glance. There is little direct impact on the industry because of soil damage effects but agricultural development is a basis for (re)industrialization.

It is easier to recognize the effects of droughts on hydropower generation. German Hydropower plants generated 14 to 24 % less electricity in the summer of 2003 because of the unusually dry summer (VDEW-email-News-Service from 2004-01-19). A similar decline in electricity production in a region which is more dependent on hydropower could be devastating. Some countries of Central Asia (Tajikistan, Kyrgyzstan, and Uzbekistan) where hydro energy constitutes 25 % of the regional electricity production are a potential example (Sherfedinov 1999).

The building of dams for the generation of hydropower or irrigation is often in itself an important source of conflict, mainly because people need to be relocated for the construction of the dam and the flooding of reservoirs. A total of 40,000 large dams (higher than 15 m) have been built all over the world (McCully 1996 cited from Sherbinin and Dompka 1998).

Mining projects with their potentially harmful effects on the environment are another source of conflict. In particular, mining projects which have no connection to the economy and society of an area are significant since they are in fact an attack on the traditional economy (better paid jobs, etc.).

A last effect can be seen in the health sector. In a warmer climate some diseases, e.g. malaria, are about to spread. Infectious diseases are likely to slow socio-economic development in the hardest-hit regions.

2.4.2.4 General effects

The effects of environmental degradation on agriculture and industry differ in their magnitude. In most cases, the industrial sector is less affected than the agricultural sector (Bächler *et al.* 1996). Productivity in agriculture and industry in specific regions varies which results in a heterogeneous economy of a state or region. According to Bächler *et al.* (1996) the principal effect of environmental degradation is the growing scarcity of goods. The general economic stability of a country or region may then be decisive for the likelihood of environmental conflict. A high dependence on the agricultural sector (relative share of GDP) is therefore a vulnerability factor.

2.4.2.5 Cost estimates

The costs of environmental damage can be huge. They may even amount to tens of billions of $. Table 3 shows some calculations for the damages from droughts, floods and the restoration of the Aral lake region.

Table 3 Cost of environmental damages

Year	Country	Event	Cost	References
1992-1995	Spain	Drought	Several billion €	Demuth and Stahl 2002
1988-1989	USA	Drought	39-40 billion $	Demuth and Stahl 2002
1993	USA	Flood (Mississippi River)	15-28 billion $	Demuth and Stahl 2002
1960-today	Aral lake region	Overuse and pollution of water supplies	30-50 billion $ (Restoration costs)	Müller *et al.* 1994: 188 ff. cited from Bächler *et al.* 1996: 280

A direct economic effect from extreme weather events has been calculated by Munich Re (2003). Figure 4 shows that the damages (in prices from 2003) from big natural catastrophes, including earthquakes, tornadoes, hurricanes, storms, droughts, heat waves and forest fires have risen from 1950 until today although the frequency of storms did not rise extraordinarily (see Figure 3). Higher economic development, more insurance coverage and a higher population in risk areas also contributed to the higher damages.

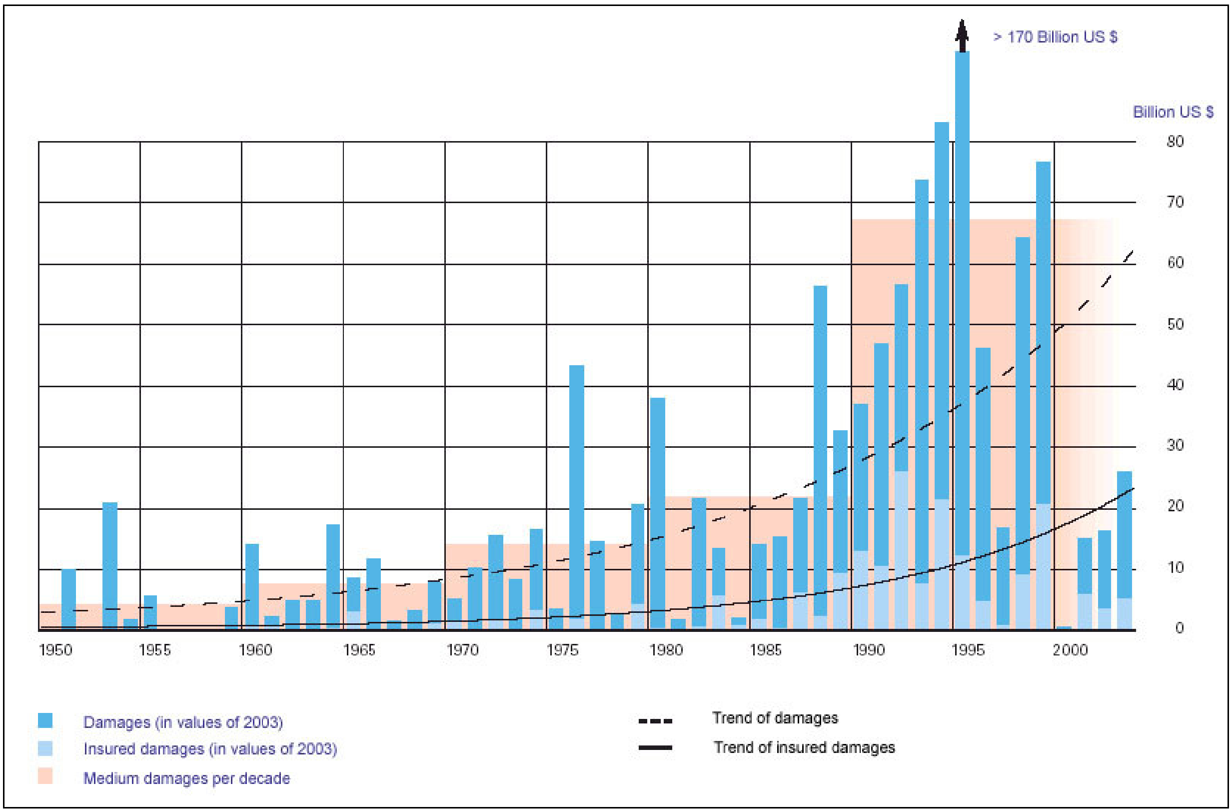

Figure 4 Damages from big natural catastrophes, including earthquakes, tornadoes, hurricanes, storms, droughts, heat waves and forest fires (adapted from Munich Re 2003: 15)

2.4.3 Effects on the social system

Bächler *et al.* (1996) conceived that social, economic and technological factors are decisive in the magnitude of the impact of a given population from environmental degradation. Economic heterogeneity can destroy a traditional economy. And often this also means that the traditional society is destroyed as well. Furthermore, many countries are seriously divided into ethnic and religious groups fighting for dominance or secession. Then environmental degradation might aggravate the situation but the importance of environmental degradation may also be seriously exaggerated in these cases (Gleditsch 1999a).

2.4.3.1 Income and wellbeing of the population

The income and the wellbeing of a society of course depends on its economic situation. Social structures influence the efficiency of the farming system, e.g. through the taxation system, distribution of work in caste societies (India), etc.

2.4.3.2 Population

Both Homer-Dixon (1991 and 1994) and Bächler *et al.* (1996) saw the absolute population or the population density as an important factor in the development of environmental conflict (see Figure 1 for Homer-Dixon and Equation 1 for Bächler). A growing population or a relative overpopulation may lead to the following problems:

- Urbanization
- Migration
- Impoverishment
- Landlessness
- Joblessness

Relative overpopulation always has to be seen in the context of the carrying capacity. A classical example for migration resulting from a relative overpopulation is Bangladesh (Suhrke 1997). The Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU 2002: 1) estimates the number of environmental refugees at 25 million per year. Lonergan (1998a and 1998b) estimates the number of environmental refugees at between 10-64 million in the 1980s, 15-25 million in the 1990s and he expects them to rise to 150 million people in 2050. Migration may be a trigger for violent conflict but migration may also act as a mechanism to redistribute population in greater conformity with water availability (Zaba and Madulu 1998). Furthermore, migration may occur due to water scarcity but not in all cases does water scarcity lead to migration (Sherbinin and Dompka 1998). Adaptation to new circumstances is always another option.

The importance of the population aspect was particularly highlighted by Wöhlcke (1998). The current trends in the global population development may seriously aggravate the possibilities of conflicts through the increasing demand for resources from the growing population base (see also chapter 2.5.2).

2.4.3.3 Behaviour and Beliefs

Behaviour and beliefs are especially important in traditional societies. Societies for whom soil, water or mountains have a special relevance because they are worshipped as deities may react very negatively if their deities are destructed.

2.4.3.4 History

“One of the strongest predictor to armed conflict, whether internal or external, is a history of armed conflict” (Gleditsch 1999a). Thus, the historical context cannot be neglected if the likelihood of conflicts is to be estimated. A vicious cycle of poverty, authoritarian rule, environmental degradation, violence and war which leads to more environmental destruction, and in turn with poor government, fuels new conflicts is also possible (Gleditsch 1999a).

2.4.4 Effects on the political system

According to Bächler *et al.* (1996) reasons for conflict are social, ecological or economic factors but the dynamics of a conflict are determined by the political system and the motivations of the different actors.

2.4.4.1 Structures and Institutions, negotiation of interests

The political systems of a country or supra national organisations may mediate between parties in conflict. The phenomenon known as the democratic peace is one obvious example. It is known that democracies rarely fight wars among themselves, and that they less frequently engage in lower-level armed conflicts. Furthermore, they are more responsive to victims of environmental degradation which may alleviate potential conflicts (Gleditsch 1999a).

International co-operations are an option to avoid violent conflicts. More than 2000 water related international treaties exist to govern the just distribution of this vital resource (McCaffrey 1993 cited in Carius and Imbusch 1998), and the importance of water commissions, etc. in building trust is also emphasised by Sherbinin and Dompka (1998).

2.4.4.2 Problem solving capacity

Conflicts between the modern sector (dam building, electricity) and the traditional sector of an economy are a possibility if state regulation or moderation is not available, i.e. no compensations are possible. Traditional structures compete with modern structures that may have a higher capacity for problem solving. Transition periods between traditional societies and modern ones are especially prone to conflicts because of structural heterogeneity.

2.4.4.3 Balance of power and external relations

Obviously, the military power of a state is also important in order to estimate the likelihood of conflict. The relative military power of Israel prevents Syria, Jordan and the Palestinians from actually getting the Jordan water (Bächler *et al.* 1996).

2.4.5 Environmental Conflict

Conflict is an inevitable part of social interaction. Conflict results from differences of opinion of two or more actors who are seen as incompatible with each other (Czempiel 1981: 199). But conflicts do not necessarily lead to war. There are several options to resolve a conflict: political pressure, evade a decision, negotiation, compromise, cooperation, back down. Most conflicts over resources and environmental issues do not lead to armed fights but are resolved peacefully. Indeed, a conflict of interests may stimulate increased collaboration and effectively lead to environmental co-operation (Gleditsch 1999a). The International Rhine Commission or the peace treaty between Jordan and Israel are examples of such co-operations.

Mechanisms of conflict resolution may also be improved by multilateral international co-operation. Prime examples for an international environmental policy are the 1994 Oslo Protocol on the reduction of sulphur emissions in Europe (targeting acid rain), the 1987 Montreal Protocol on substances that deplete the ozone layer (targeting ozone depletion) and the still not ratified 1997 Kyoto Protocol to the UN Framework Convention on Climate Change (targeting climate change). Over 100 international environmental agreements have been concluded to date (Oberthür 1999). A regime covering environmental security would theoretically be possible and can be explained by game theory (Trombetta 1999).

But sometimes environmental degradation leads to violent conflict. There is of course a difference between a punctual use of violence (road blocking etc.), wild-west style of violence and organised violence or war. Therefore, it is important to remember some of the fundamental definitions of war, armed conflict, and environmental conflict:

- “War is continuous, armed and violent conflict, where more than one armed forces are participating. One of these armed forces has to be a regular armed force of a government and both must have a minimal degree of central organization.” (Gantzel 1987: 33)
- “Armed conflicts are violent conflicts of a lesser intensity. They are often the first step in an escalation process.” (Nicholson 1992: 14)
- “Environmental conflicts manifest themselves as political, social, economic, ethnic, religious or territorial conflicts, or conflicts over resources or national interests or any other type of conflict.” (Libiszewski 1992: 13)

This paper will use the definition by Libiszewski (1992: 13). Actors in an environmental conflict can be ethno-political groups, regionally defined entities, religious minorities, social groups, opposition parties, states, etc.

2.4.6 Reverse effects

Environmental degradation does not work its way linearly through the effects on the ecosphere, followed by effects on the economy, the social and then the political system. There are reverse effects as well which work in the other direction and there are effects which alleviate environmental degradation. Environmental transformation depends from the economic, social and political structures of a country or region (Bächler *et al.* 1996). With correct policies or the necessary technical, scientific and economic capacity environmental degradation or its effect on the economic, social or political system can be alleviated or even stopped.

2.4.6.1 Reverse effects back to agriculture

A viable agricultural sector could well have the capacities to cope with the problems caused by environmental degradation or climate change if it has the capacity and resources to deal with the arising problems. Unfortunately, the agricultural sector in many developing countries is very inefficient. Inefficient farming is often a result of unsure or unjust property rights, incapable judicial systems, small and fragmented individual agricultural plots, high taxation, or the dependency on monopolies.

Another point is that war may also lead to deforestation. In Ethiopia the military deforested large areas because they wanted to eliminate the natural cover that was used by enemy forces. The U.S. forces in Vietnam used Agent Orange for similar purposes.

2.4.6.2 Reverse effects back to industry, services and health

Large projects like dam building, mining or oil exploitation have the problem that the positive economic effects often unfold themselves far away from the project area which has to bear the ecological costs of these projects. This is the origin of many problems. Mostly, transnational corporations or large international organizations with modern state-of-the-art operations are opposed to locals who are not integrated in the world market and rely on subsistence. The subsistence system is dramatically transformed, and in the view of the local people they are the victim of foreign powers. This can lead to a conflict between centre and periphery (Bächler *et al.* 1996). The material basis for their (mostly) subsistence lives as well as the cultural and religious basis is threatened. Environmental damage is always a part of the problem in addition to disappointment about unfulfilled development hopes. A conflict may become violent if the state is not honouring the law, or if the interests of minorities are not heard ("national sacrifice area"). In constitutional states like the USA, Canada or Australia these conflicts are solved mostly without violence on a political or judicial basis. If the conflict has escalated to a violent guerrilla war, the ecological origins become less important. Then the battle for existence of ethnic or religious groups, or nations becomes the identifying and unifying force in the conflict. Self determination, autonomy and secession or the avoidance of secession can then become the aim of the conflict.

2.5 Additional pressure from climate change and population growth

The previous chapters have only roughly sketched the complex web of relationships between environmental degradation and violent conflict. Lomborg 2001 has shown that many factors that are believed to contribute to environmental conflict, e.g. food supply, soil erosion, oil reserves, resources of basic metal (aluminium, iron, copper, and zinc), water, or unequal resource distribution are not worsening on a global level. Globally, the stress has lessened until the late 1990s. There are however, two important trends that potentially increase the pressure on the global human environmental system for the future, namely climate change and population growth (see Figure 5).

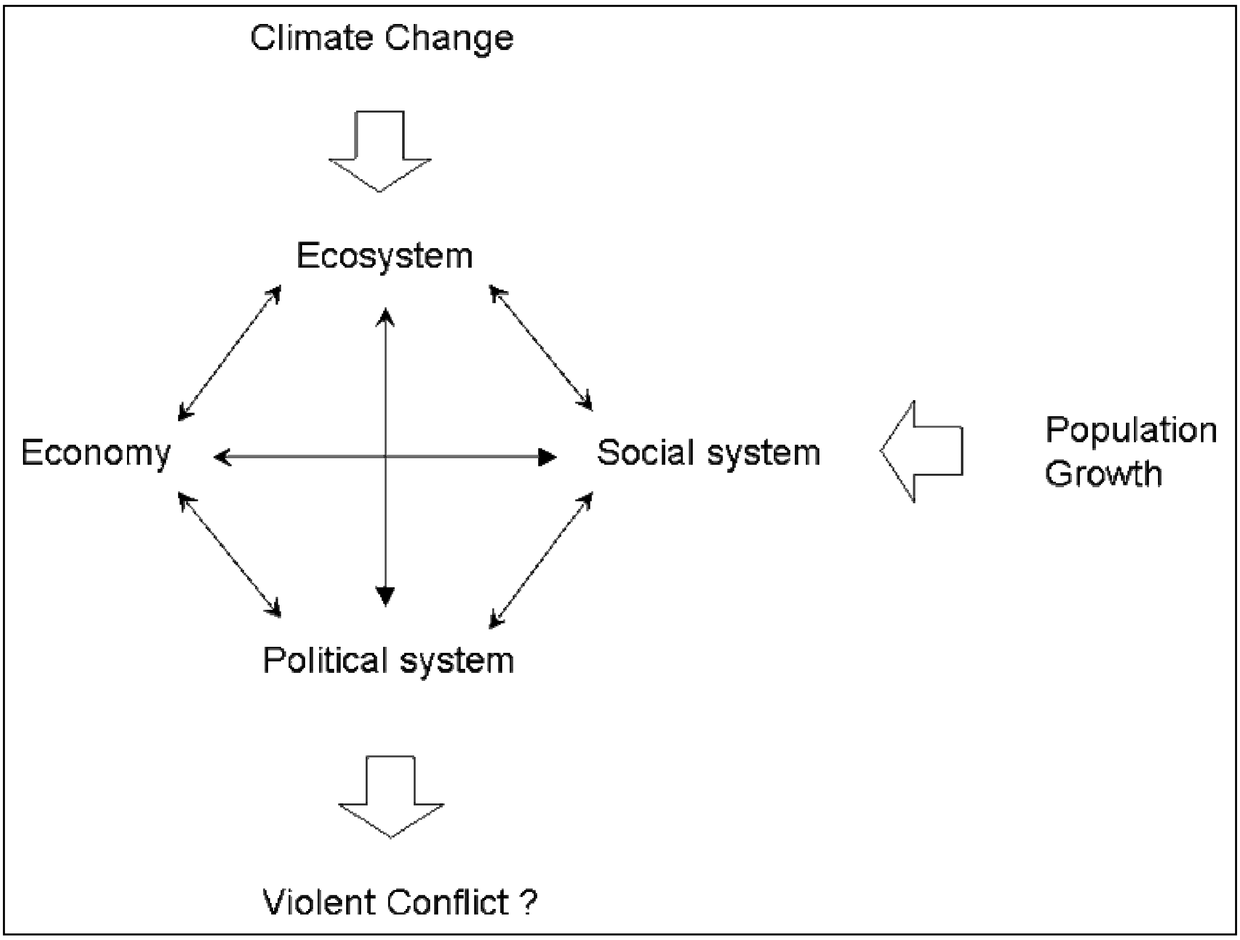

Figure 5 Additional pressure from climate change and population growth

2.5.1 Climate change

The IPCC concludes that the globally averaged surface temperatures have increased by 0.6 ± 0.2°C over the 20th century; and that, for the range of scenarios developed in the IPCC Special Report on Emission Scenarios (SRES), the globally averaged surface air temperature is projected by models to warm by 1.4 to 5.8°C by 2100 in comparison with 1990 (see Figure 6), and globally averaged sea level is projected by models to rise by 0.09 to 0.88 m by 2100 (IPCC 2001: 3).

The observed reduction of arctic sea ice by around 7.4 % in the last quarter of the century is perhaps the most obvious evidence that climate change is a reality (Johannessen *et al.* 2002). A second highly visible sign is the melting of many glaciers around the world (WWF 2003). Other effects were identified to take place in the biosphere. Changes in the growing season of plants, breeding times of birds, shifting ranges of organisms, community shifts, higher incidences of mass coral bleaching (thermal stress on tropical reefs) could already be detected (Walther *et al.* 2002). There is evidence for a warming trend of 4-5 °C in the mean annual air temperature in the Antarctic Peninsula over the past 50 years, and a reduced duration of fast-ice cover over a 90 year time-series in the South Orkney Islands. Key prey species such as the Antarctic krill (*Euphasia Superba*) are affected by the extent and duration of the ice cover. There have been overall reductions in krill biomass over the last decade. Krill predators are now regularly operating close to the limit of krill availability. The krill supply was estimated to be sufficient in the 1980s but not in the 1990s. Effects are felt all the way up the food chain to Antarctic fur seals, gentoo penguins, macaroni penguins and black-browed albatrosses. Thus, effects on the year strength of krill may affect the whole Antarctic eco system (Reid and Croxall 2001). Only 30-50 years of warming had these already measurable effects.

It is also likely that climate change cannot be avoided any more, in particular since some carbon dioxide sinks do not seem to work out in the long term. The estimates of increased carbon sequestration of forests, which is expected to partially compensate for increasing CO_2 in the atmosphere, are unduly optimistic. A CO_2-induced biomass carbon increment was undetectable at a nutritiously poor site, and it was transient stabilizing a marginal gain after three years at a nutritiously moderate site. A synergistic gain from higher CO_2 and nutrients was only detected when nutrients were added. Thus, fertility restrains the response of wood carbon sequestration to increased atmospheric CO_2 (Oren *et al.* 2001).

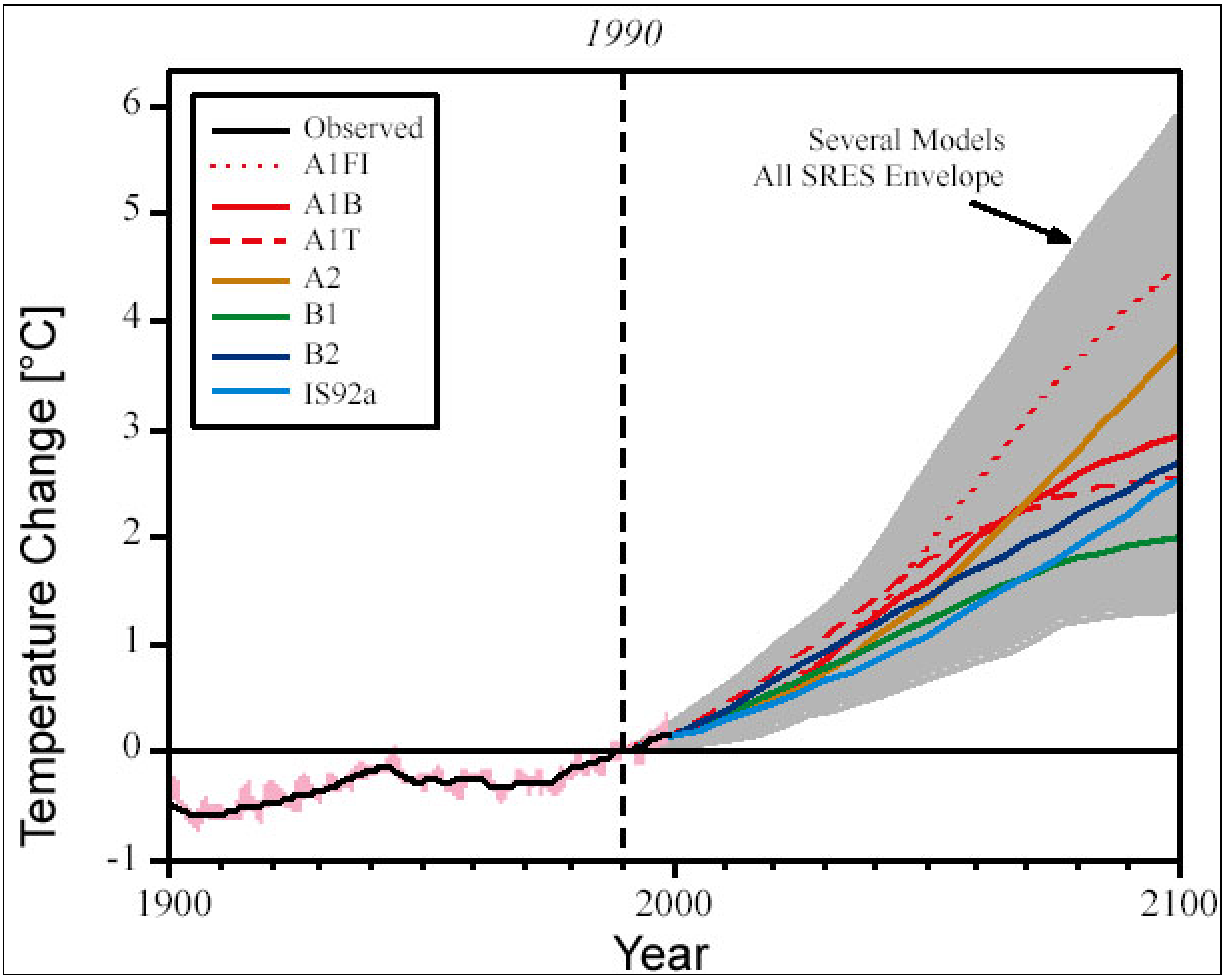

Figure 6 Projection of the global warming trend (adapted from IPCC 2001: 5)

Without taking the worst case scenarios of a significant slowing of the oceanic thermohaline circulation, the disintegration of the West Antarctic Ice Sheet or the melting of the Greenland Ice Sheet that was e.g. used by Schwartz and Randall (2003) into account the IPCC expects the following negative effects from climate change (IPCC 2001: 5):

- A general reduction, with some variation, in potential crop yields in most regions in mid-latitudes due to a rising annual average temperature of more than a few °C
- Decreased water availability for populations in many water-scarce regions, particularly in the sub-tropics

- An increase in the number of people exposed to vector borne (e.g. malaria) and water-borne diseases (e.g. cholera), and an increase in heat stress mortality
- A widespread increase in the risk of flooding for many human settlements (tens of millions of inhabitants in settlements studied) from both increased heavy precipitation events and sea-level rise
- Increased energy demand for space cooling (air condition) due to higher summer temperatures

The IPCC also expects positive effects (IPCC 2001: 6):

- Increased potential crop yields in some regions at mid-latitudes due to increases in temperature of less than a few °C
- A potential increase in global timber supply from appropriately managed forests
- Increased water availability for populations in some water-scarce regions, e.g. in parts of southeast Asia
- Reduced winter mortality in mid and high latitudes
- Reduced energy demand for space heating due to higher winter temperatures

Spillmann and Bächler (1995: 9) think that global climate change will contribute to conflict and war by exacerbating existing environmental stresses on the local and regional level. Storms, floods and droughts which would affect agriculture and infrastructure are named as the most important effects. The speed of the change may be important for the development of adaptation strategies but the highest risk is to be expected in vulnerable regions (coastal areas, marginally arable lands, forests near the height or temperature limit of forest growth) mainly of developing countries (WBGU 1999: 134-148). Today, as much as 46 million people are already affected by storm floods. This number might rise to 92 Mio. if the sea level rises by 50 cm.

The European Commission (1999: 24) sees climate change as a “massive multiplier for other risks to food security, the availability of land, and the productivity of the soil, the quantity and quality of the fresh water and the conservation of biological diversity.” Potential socioeconomic consequences of climate change including migration were already listed in the first report on the UN Framework Convention on Climate Change (BMU 1994). DETR (2000) and McKenzie *et al.* (2000) list a range of potential impacts from coastal and riverine flooding, effects on agriculture and the insurance sector and adaptation strategies for the UK.

It is also clear that there is an uneven distribution of contributors to climate change (developed world against developing world) and it becomes clear that there will be an uneven distribution of the consequences of climate change, too. Frictions between winners and losers of climate change include new possibilities of violent conflicts. Avoiding political polarization greatly depends on the perception of the participants whether they are winners or losers of climatic change (Gleick 1989).

Historic evidence for the relevance of climate change in socio-economic questions has been worked out by Burroughs (1997) and Wigley (1981) but both stop at the economic evaluation. They include effects on social or political system only sometimes. The problem is that although the reality of the climate impact on the biosphere cannot be disputed, higher order impacts on the economy, the social or political system are simply difficult to prove with rigorous statistical testing (Wigley 1981: 3). One of the obfuscating variables in determining impact is the adaptability of society to climatic stress (Wigley 1981: 4).

Estimations on the socio-economic effects from climate change that may lead to conflict exist (see e.g. Ierland *et al.* 1996 or Barnett 2001). For the hardest hit nations the effects can be very drastic. Coral bleaching will reduce future GDP by some 40-50% by 2020 in smaller Pacific islands. Furthermore, the World Bank estimates the losses due to climate change in Kiribati to amount to about 17-34% of current GDP by 2050 (Barnett 2001).

2.5.2 Population Growth

The second trend that potentially increases the likelihood of environmental conflict is the pressure on resources by a growing world population (see Figure 7). Despite lower projected fertility levels and an increased mortality risk to which some populations will be subject, the population of the world is expected to increase by 2.6 billion during the next 47 years, from 6.3 billion today to 8.9 billion in 2050 (UN 2002: 6). The higher resource pressure by a growing population is obvious for water consumption (Sherbinin and Dompka 1998) or food supply. The global grain production has exceeded global population growth by 15 % over the past decades. On a global level food scarcity is no problem, but the trend is weakening. Climate change in combination with population growth could lead to food shortages in only 20 years (WBGU 1999: 134-148).

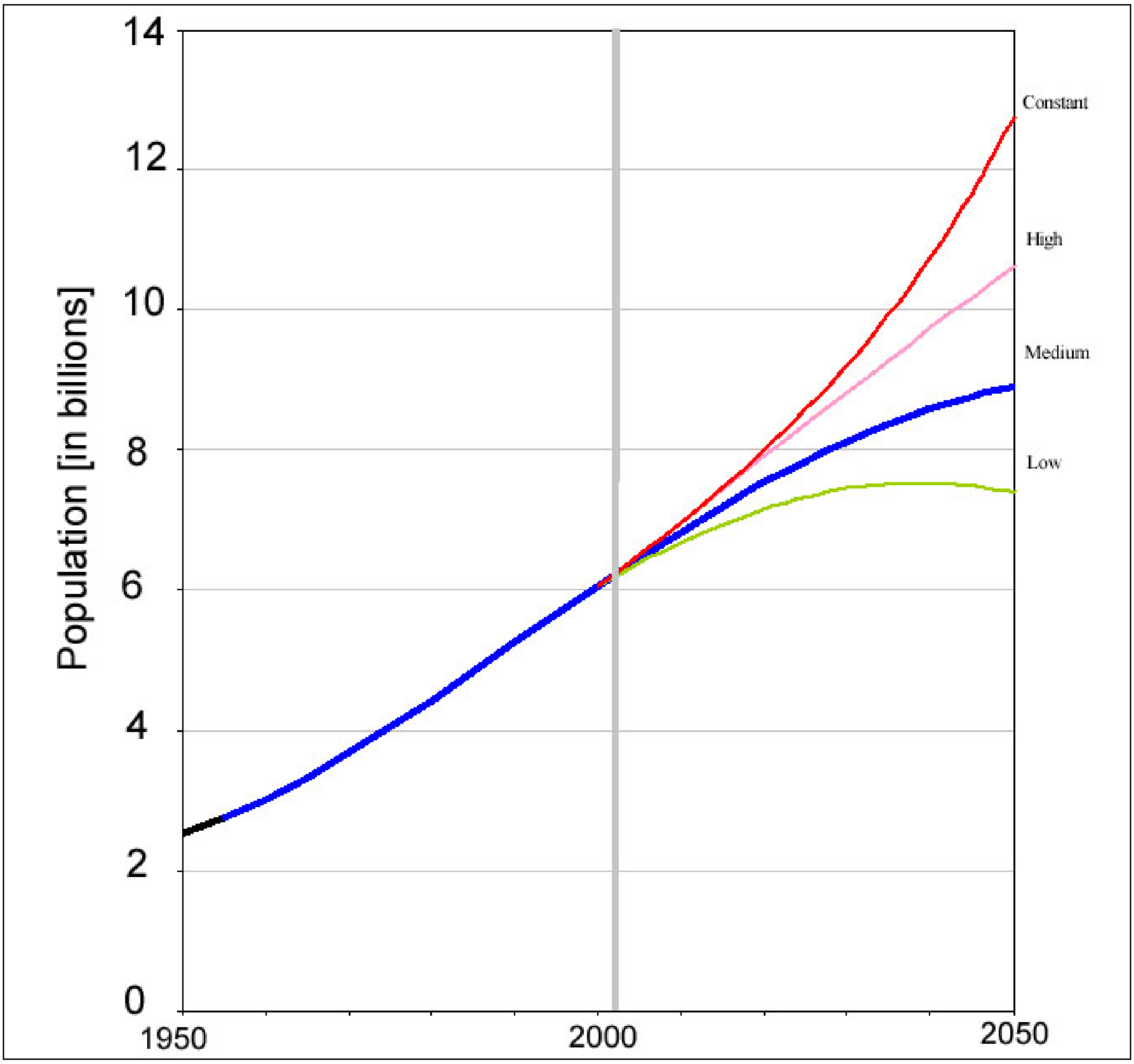

Figure 7 UN Population projection (adapted from UN 2002: 7)

The general effect of the population density on the likelihood of conflict has been evaluated by Tir and Diehl (1998). The likelihood of conflict increases by 7 % as one moves from very low to very high population density.

3 Neural networks

It should be clear by now that the number of possible variables for the analysis of environmental conflict is high. The causal relationship between these variables and possible explanations WHY environmental conflict happens have been studied by Homer-Dixon (1991 and 1994) and Bächler *et al.* (1996). However both have yet failed to produce a quantitative and proven prediction of the likelihood of environmental conflict. As described above, Homer-Dixon's (1991) and Bächler's *et al.* (1996) theories offer a good explanation HOW environmental change may lead to conflict. But they give limited clues about WHERE and WHEN conflicts may break out. Therefore, the use of neural networks in the prediction of the likelihood of environmental conflict shall be evaluated in this feasibility study. A neural network is used because several other methods to determine the likelihood of environmental conflict did not work out (see chapter 6.2) and because the causal relationships that actually lead to environmental conflict do not need to be known. Neural networks are a powerful tool for modelling problems for which the explicit form of the relationship among the variables is not known (Fausett 1994). Neural networks simply try to recognize a pattern based on a number of input variables.

3.1 Introduction to artificial neural networks

According to Kung (1993) an artificial neural network is an abstract simulation of a real nervous system that contains a number of neurons communicating with each other via axons (output) or dendrites (input). The connection between axon and dendrite is called a synapse. It is estimated that the human brain contains over 10^{11} neurons and 10^{14} synapses. Studies of brain neuroanatomy indicate that more than 1000 synapses are used for input and output of each neuron. Due to limited knowledge about the biological functions of a neural network only very coarse mathematical models are applied for artificial neural networks. But by embedding a vast number of simple neurons in an interactive neural network, very sophisticated information processing is possible, e.g. the architecture of the cerebral cortex can be reasonably modelled by 3 to 6 layers of artificial neurons (see Figure 8), where each neuron is connected to about 10 others.

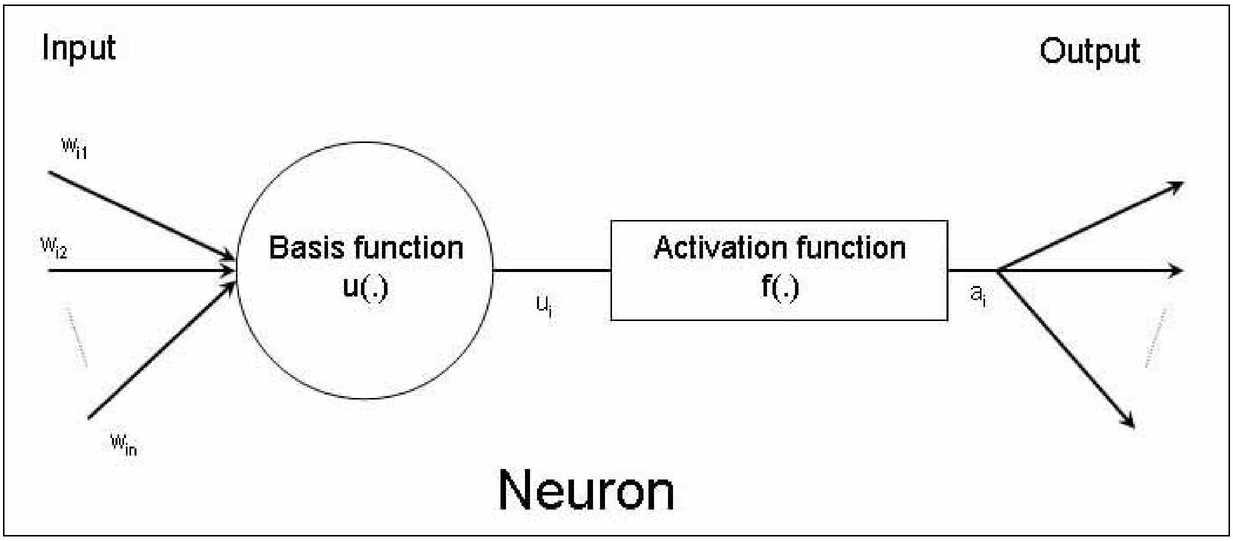

Figure 8 Artificial neuron

In general, neurons and axons are mathematically modelled by activation functions and basis functions. The selection of these functions often depends on the applications the neural networks are for, because it is impossible to specifically define the biological neuron functionalities. In other words, the application-driven neural models are only loosely tied to biological realities.

The most important applications for neural networks is pattern recognition. Prominent examples are optical character recognition (OCR), image classification, radar target identification, speech recognition, seismic processing, and others. Neural networks are trained with a training data set, and learn to recognize the appropriate patterns. The strength of neural networks is the ability to identify slightly distorted versions of the learning data set correctly. For the training of the neural network a training data set is used where the result of every pattern is known. E.g. for a neural network that shall distinguish between the images of cats and dogs, images of cats and dog would be used where cats and dogs have already been identified by other means. Thus, the neural network is fed with fully known pairs of input (images) and output (cat or dog?) patterns. This kind of learning rule is called supervised classification.

After the training the neural network is presented an also fully known test data set. It is then possible to gauge the accuracy of the neural networks for a classification of formerly unknown images of cats and dogs. A network is considered successfully trained if it can closely approximate the correct values of the test data set.

3.2 Mathematics of artificial neural networks

Each neuron has a neuron value a_i. This value is propagated through unidirectional connections to other neurons in the neural network. Associated with each connection is a synaptic weight w_{ij} that dictates the effect of the j-th neuron on the i-th neuron. All inputs to the i-th cell from other cells are accumulated together with the external threshold $_i$ to yield the net value u_i. This function is described by the basis function u(.). The net value u_i will then be further transformed by a nonlinear activation function f(.) to yield a new activation value a_i. The basis function and the activation function are usually predetermined. Thus, the neural network is able to learn by the adjustment of the weights w_{ij}, i.e. a matrix W. The final output of the neural network y can usually be expressed as a function of the input x and the weights W:

$$y = f(x, W)$$

Equation 2 Basic neural network equation

The size of neural networks varies. There are one or more layers of hidden neurons (neither input nor output). They are called hidden layers. The size of a neural network is also determined by the number of neurons. For a maximum performance, an optimal number of hidden layers or neurons has to be properly determined.

As an example a simple design for a neural network is given in Figure 9. It contains three neurons in the input layer, four neurons in the hidden layer and two neurons in the output layer. The neurons are connected with simple feed forward connections. The dashed lines also show other possible connections (feed backward and lateral).

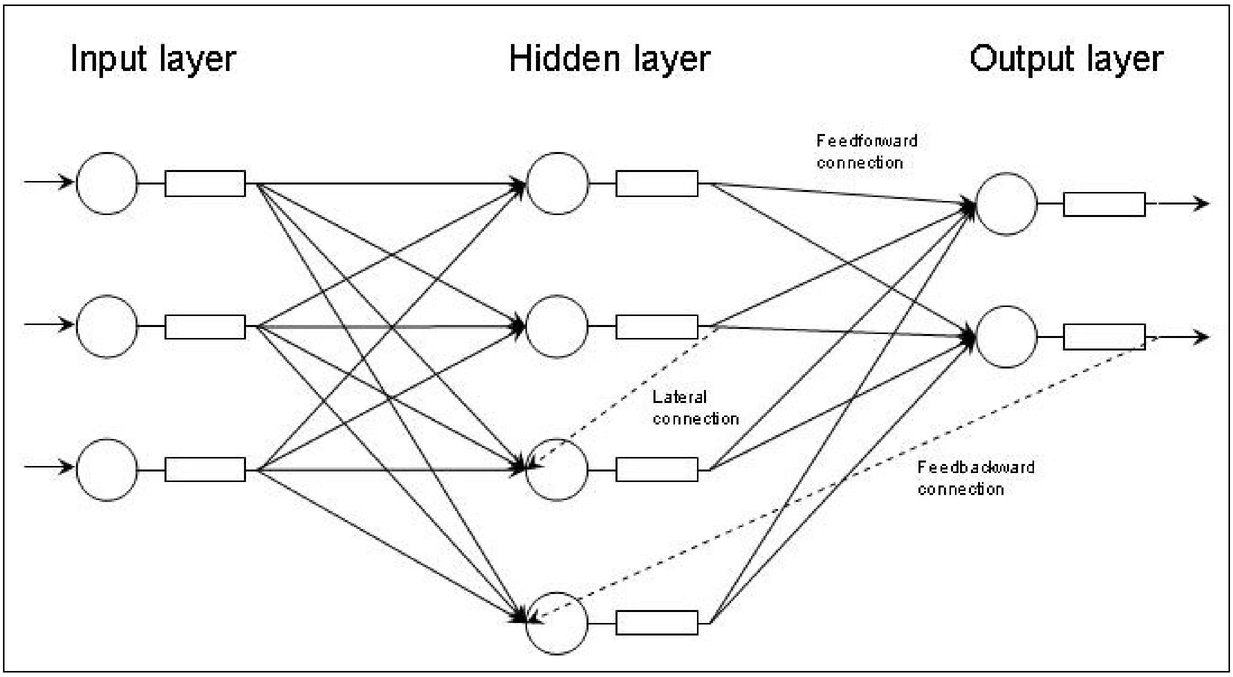

Figure 9 Artificial Neural Network

4 Material and Methods

The essence of the analytical approach with a neural network is its learning ability. A neural network is presented with a number of known cases, a training data set, from which it learns. Afterwards it is presented with other known cases, a test data set, which is used to assess the success of the learning process, and the ability of the neural network to correctly classify the test cases.

4.1 The selected case studies of environmental conflict

For the analysis the case studies described by Bächler and Spillmann (1996a), Bächler and Spillmann (1996b), and Bächler *et al.* (1996) were selected. The case studies used here are in a descriptive, narrative, and qualitative form as Alcamo and Endejan (1999) correctly comment. The case studies from Bächler and Spillmann (1996a), Bächler and Spillmann (1996b), and Bächler *et al.* (1996) were selected because they formed an available and coherent data set which was assembled with an identical definition of environmental conflict (see chapter 2.4.5). The case studies and their references are listed in Table 4. The case studies of Sherbinin and Dompka (1998) were not considered because they do not include the conflict category. Sherbinin and Dompka (1998) point out the problems associated with a shortage of resources (water) combined with population pressure but they stop in their argumentation with the social effects.

Table 4 Selected case studies for the neural network analysis

Case Study No.	**Location of Case Study**	**Reference**
1	Sudan (Southern Sudan)	Bächler *et al.* 1996: p.77, pp.90-93 Suliman 1996a
2	Ethiopia	Bächler *et al.* 1996: pp. 78-80
3	Niger	Bächler *et al.* 1996: pp.80-83

		Lume 1996b
4	Chad	Bächler *et al.* 1996: p.83
5	Brazil, Tapajos river	Schönenberg 1996b
6	Rwanda	Bächler *et al.* 1996: pp.93-107 Bächler 1996a
7	Near East (Palestine-Israel)	Bächler *et al.* 1996: pp.134-145 Libiszewski 1996a Cooley 1984 Kliot 1995 Isaac 1995
8	Near East (Syria-Israel)	Bächler *et al.* 1996: pp.134-145 Libiszewski 1996a Cooley 1984 Kliot 1995 Isaac 1995
9	Near East (Israel-Jordan)	Bächler *et al.* 1996: pp.134-145 Libiszewski 1996a Cooley 1984 Kliot 1995 Isaac 1995
10	USA / Mexico	Bächler *et al.* 1996: pp.145-147 Rogers 1996b
11	Hungary / Slovakia	Bächler *et al.* 1996: pp.147-149
12	India / Bangladesh	Bächler *et al.* 1996: pp.150-154 Hafiz and Islam 1996a
13	Bangladesh	Bächler *et al.* 1996: pp.150-154 Hafiz and Islam 1996a
14	Papua New Guinea Bougainville	Bächler *et al.* 1996: pp.175-186 Böge 1996a
15	Papua New Guinea Ok Tedi	Bächler *et al.* 1996: pp.187-189 Böge 1996a

16	Indonesia Freeport	Bächler *et al.* 1996: pp.191-194 Böge 1996a
17	Nigeria, Ogoniland	Bächler *et al.* 1996: pp.194-202 Okoh 1996a
18	India, Narmada	Bächler *et al.* 1996: pp.211-218
19	Chile Bio-Bio	Bächler *et al.* 1996: pp.218-221 Schwark 1996b
20	Brazil, Tucurui	Bächler *et al.* 1996: pp.221-223 Schönenberg 1996b
21	Nigeria, Bakolori	Bächler *et al.* 1996: pp.223-224 Okoh 1996a
22	Kenya	Bächler *et al.* 1996: pp.88-90
23	Philippines, Chico	Bächler *et al.* 1996: pp.226-228
24	Aral lake, Uzbekistan / Kyrgyzstan	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
25	Aral lake, Uzbekistan / Kazakhstan	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
26	Aral lake, Uzbekistan / Turkmenistan	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
27	Aral lake, Priaral region	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
28	Aral lake, Fergana Valley	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
29	Sudan, Darfur	Bächler *et al.* 1996: p.77, pp.90-93 Suliman 1996b
30	Nigeria, Urhobo Area	Okoh 1996a
31	Nigeria, Lake Chad region	Okoh 1996a
32	Aral lake, Tajikistan	Bächler *et al.* 1996: pp.239-289 Klötzli 1996a
33	Papua New Guinea, Porgera	Böge 1996a

34	Mekong Basin	Bächler *et al.* 1996: pp.154-158 Thomas 1996b
35	China, North-East Provinces	Smil 1996b Smil 1995
36	Thailand, Isan region	König 1996b
37	Algeria	Faath 1996b
38	Mauritania, Senegal	Bächler *et al.* 1996: pp.225-226 Wegemund 1996b
39	Brazil, Southern Para	Schönenberg 1996b
40	Brazil, Lower Amazon	Schönenberg 1996b

4.2 The input data for the neural network

The qualitative factors that have influenced the outcome (conflict: yes or no) in a case study have been used as input data for the neural network analysis. These factors have been determined by a re-examination of all case studies. Figure 10 and Figure 11 show an example of how the factors have been determined in detail. Based on the qualitative description these factors have been put into a causal relationship. The factors that have been determined as entry points (marked in red) have been chosen as relevant factors. Other important factors (marked in blue) that were only intermediaries were not chosen in order to reduce the amount of data needed. Thus, the causal relationship between the variables for each of the case studies has been determined based on the qualitative descriptions in order to reduce the number of relevant variables.

This procedure shall be explained with the case study of Bougainville in Papua New Guinea (see Figure 10 and Figure 11). The start of large copper surface mining operations forms the point of departure. These mining operations are the reason for environmental degradation, i.e. the pollution of water supplies or the loss of fertile land. The environmental degradation leads to a decreased per capita income from the traditional subsistence economy. The mining operation directly led to population displacement.

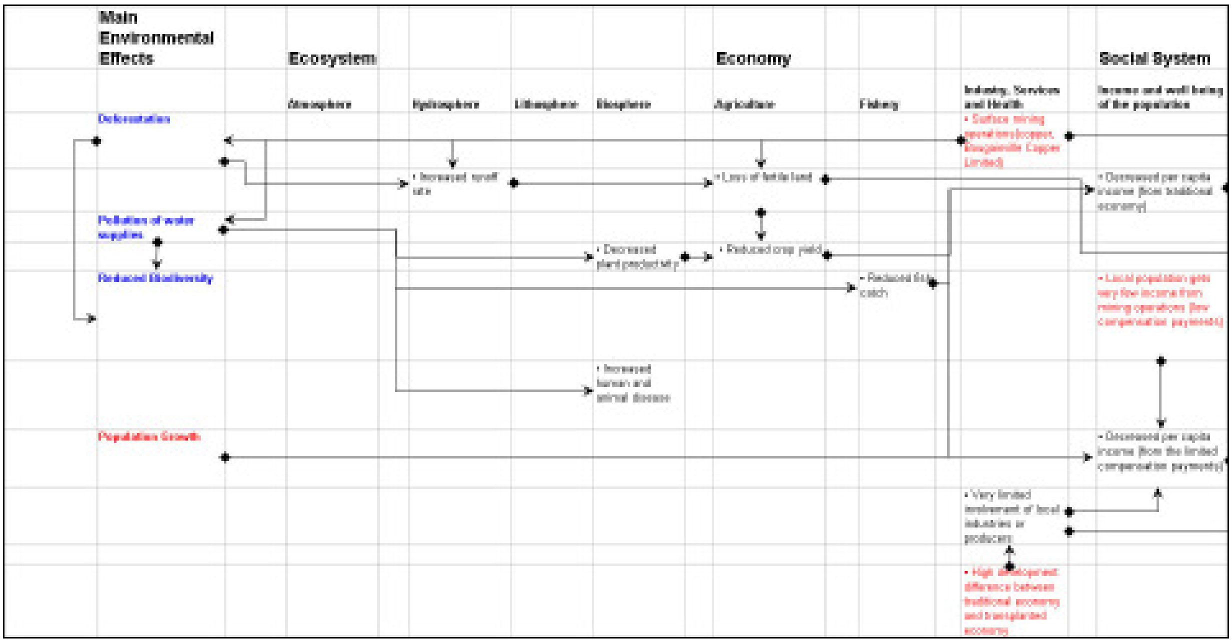

Figure 10 Relevant factors for case study 14: Papua New Guinea, Bougainville / 1st part (Original source: Bächler *et al.* 1996: 175-186, Böge 1996a)

Large differences in the development of the traditional economy and the transplanted economy led to the migration of foreign workers into the region. Thus, the local population got little income from mining operations and in addition they got only low compensation payments. The ethnic differences and the importance of land for the local population formed the next ingredients. Public unrest and strikes were the result. The central government reacted with a military intervention (with massive human rights violations) also because major state revenues depended on the mining operation which further fuelled the ensuing conflict.

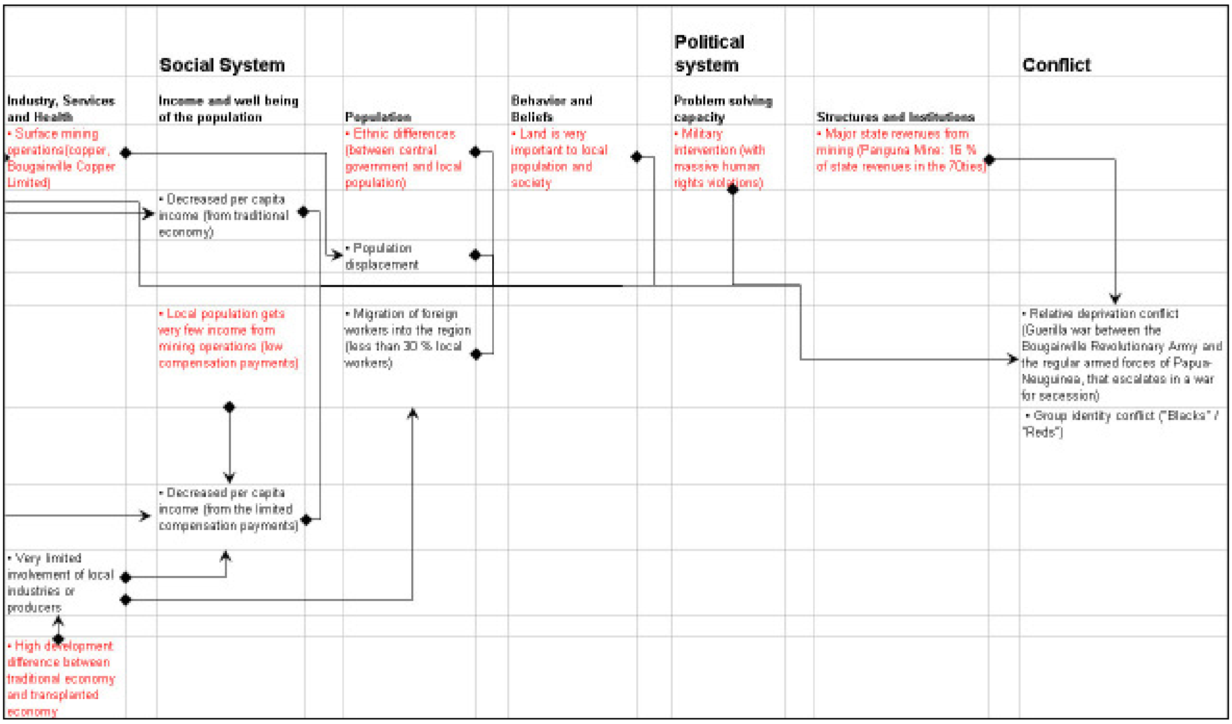

Figure 11 Relevant factors for case study 14: Papua New Guinea, Bougainville / 2nd part (Original source: Bächler *et al.* 1996: 175-186, Böge 1996a)

This kind of variable reduction has been made for each of the 40 case studies that are listed in Table 4. Overall, 39 factors have been identified as being of primary importance for the analysis. They are listed in Table 5.

Table 5 Selected relevant factors from the case studies for neural network analysis

Factor No.	Area of Effect	Factor
1	**Main Environmental Effects**	• Population growth
2		• Deforestation
3		• Degradation of agricultural land
4		• Overuse and pollution of water supplies
5		• Dumping of toxic waste

	Ecosystem	
6	Hydrosphere	• Change of precipitation patterns
	Economy	
7	Agriculture	• Irrigation projects
8		• Water as a common good
9		• Dam building
10		• High GDP share of agriculture
11		• Intensive cash crop agriculture
12	Fishery	• Introduction of industrial fishing
13	Industry, Services and Health	• Insensitive industrial activity (e.g. mining or oil exploration)
14		• Dependence on biomass as fuel
15		• Development difference between traditional economy and transplanted economy
	Social System	
16	Income and wellbeing of the population	• Income disparities or unequal access to resources
17		• No compensation payments for environmental damages
18		• Neglect of central government ("National sacrifice area")
19	Population	• Ethnic differences
20		• High population density
21		• Different method of production for different (ethnic) groups
22		• Policy of deportation
23	Behaviour and Beliefs	• Religious differences
24		• Special importance of land
25	History	• Negative historic experiences or conflicts in the past

26		• Beginning or incomplete nation building
27		• Existing territorial disputes or secession movements
	Political system	
28	Structures and institutions, negotiation of interests	• Water regime
29		• No or limited participation in decision making
30		• Inefficient and complicated property law
31		• Easy access to small arms
32	Balance of power and external relations	• Major state revenues from foreign investment (e.g. in mining or oil exploitation)
33		• Dependence on external water supplies
34		• Different states as major actors
35		• Huge differences in military power
36	Problem solving capacity	• International environmental assistance
37		• Military or paramilitary intervention
38		• Difference in problem solving capacity of central and provincial government
39		• Policy of divide and conquer between ethnic groups
	Conflict	
40		• Violent conflict

The factors that were determined by this method are not optimal. Several critical variables are missing or are only partly present. E.g. the degree of democratization is not mentioned explicitly. The reason for this is that the degree of democratization was not mentioned in the case studies which were used. Only a similar variable is given, i.e. no or limited participation in decision making. Another possibly important factor would be the youth bulge which is not mentioned explicitly in the case studies, either. It is however present in the factor population growth.

The data on the factors for the different case studies was aggregated in the form of a simple yes/no statement. Either there was conflict or there was not, either population growth was a relevant factor or not, etc. This was done because quantitative data on the variables (e.g. the degree on dependence from external water supplies) was usually missing in the qualitative descriptions of the cases studies.

Table 6, Table 7 and Table 8 show the entire list of all case studies and the associated relevant factors. It would make no difference in the analysis if the variables were grouped in a different way. The causal relationship between the variables as mentioned before is irrelevant, too. In the analysis, the neural network simply tries to recognize patterns or to classify the cases correctly into the classes “conflict” and “no conflict”. The causal relationship that was described for the case study of Bougainville in Papua New Guinea was only used to determine the relevant factors to reduce the number of variables. Each of the variables or factors initially has the same importance. There is no initial weighting of the factors. This only happens during the learning process of the neural network.

A careful examination of the entire data set (see Table 6, Table 7, and Table 8) would obviously reveal some clustering of case studies. This could not be prevented since some case studies e.g. in the Near East or the Aral Lake region are very similar in nature. It has not been possible to select either the most similar or the least similar cases for an analysis as it is usually done because the number of case studies was already so low. 19 case studies described an environmental conflict, 21 were without a conflict.

Note that the value “yes” was the decisive one. If there was no reference to a certain factor in the case studies, this factor was set to “no”.

Table 6 Entire dataset for the analysis (1st part)

	Main Environmental Effects					**Ecosystem**	**Economy**								
						Hydrosphere	Agriculture					Fishery	Industry, Services and Health		
Case Study No.	**Population Growth** 1	**Deforestation** 2	**Degradation of agricultural land** 3	**Overuse and pollution of water supplies** 4	**Dumping of toxic wastes** 5	**Change of precipitation patterns** 6	**Irrigation projects** 7	**Water as a common good** 8	**Dam building** 9	**High BDP share of agriculture** 10	**Intensive cash crop agriculture** 11	**Introduction of industrial fishing** 12	**Unsensitive industrial activity (e.g. mining or oil exploration)** 13	**Dependance on Biomas as fuel** 14	**Development difference between traditional economy and transplanted economy** 15
1	Yes	No	Yes	No	No	Yes	No	No	No	No	Yes	No	No	Yes	No
2	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
3	Yes	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No
4	No	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No
5	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
6	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No
7	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
8	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
9	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
10	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
11	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
12	Yes	No	No	No	No	No	Yes	No	No	Yes	No	No	Yes	Yes	No
13	Yes	No	No	No	No	No	Yes	No	No	Yes	No	No	Yes	Yes	No
14	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes
15	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes
16	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
17	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
18	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	No
19	No	No	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No
20	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No
21	No	No	No	No	No	Yes	No	No	Yes	No	No	No	No	No	No
22	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
23	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No
24	No	Yes	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No
25	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No
26	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No
27	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No
28	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No
29	Yes	No	No	No	No	Yes	No	No	No	No	Yes	No	No	Yes	No
30	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
31	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	No
32	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No
33	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes
34	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No
35	Yes	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No
36	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	No
37	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No
38	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No
39	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
40	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No

Table 7 Entire dataset for the analysis (2nd part)

	Social System												Political system			
	Income and well being of the population			Population				Behavior and Beliefs		History			Structures and Institutions, negotiation of interests			
	Income disparities or unequal access to resources	**No compensation payments for environmental damages**	**Neglect of central government ("National sacrifice ...**	**Ethnic differences**	**High population density**	**Different method of production for different (ethnic) groups**	**Policy of deportation**	**Religious differences**	**Special Importance of land**	**Negative historic experiences or conflicts in the past**	**Beginning or incomplete nation building**	**Existing territorial disputes or secession movements**	**Water regime**	**No or limited participation in decision making**	**Inefficient and complicated property law**	**Easy access to small arms**
Case Study No.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No
2	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No
3	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No
4	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
5	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
6	Yes	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	No
7	Yes	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No
8	No	No	No	Yes	No	No	No	Yes	No	Yes	No	Yes	No	No	No	No
9	No	No	No	Yes	No	No	No	Yes	No	Yes	No	Yes	Yes	No	No	No
10	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
11	Yes	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No
12	Yes	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	No	No	No
13	Yes	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No
14	No	Yes	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No
15	No	Yes	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No
16	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	No
17	No	No	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	No	Yes	No	No
18	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No
19	No	No	No	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No
20	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No
21	No	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
22	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Yes
23	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No
24	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	No	No	No
25	No	No	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No
26	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	No	No	No
27	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No
28	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	No	No	No
29	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	No	No
30	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
31	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No
32	No	No	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No
33	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
34	No	No	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	No	No	No
35	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
36	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
37	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
38	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No
39	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
40	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No

Table 8 Entire dataset for the analysis (3rd part)

	Political system								**Conflict**
	Balance of power and external relations				Problem solving capacity				
Case Study No.	**Major state revenues from foreign investment (e.g. in mining or oil expoilitation)** 32	**Dependence on external water supplies** 33	**Different States as major actors** 34	**Huge differences in military power** 35	**International Environmental Assistance** 36	**Military or paramilitary intervention** 37	**Difference in problem solving capacity of central and provincial governemnt** 38	**Policy of divide and conquer between ethnic groups** 39	**Violent conflict** 40
1	No	No	No	No	No	Yes	No	No	Yes
2	No	No	No	No	No	Yes	No	Yes	Yes
3	No	No	No	No	No	No	No	No	Yes
4	No	No	No	No	No	No	No	No	Yes
5	No	No	No	No	No	No	No	No	No
6	No	No	No	No	No	No	No	Yes	Yes
7	No	No	No	No	No	No	No	No	Yes
8	No	No	Yes	Yes	No	No	No	No	Yes
9	No	No	Yes	Yes	No	No	No	No	No
10	No	No	Yes	Yes	No	No	No	No	No
11	No	No	Yes	No	No	No	No	No	No
12	No	No	Yes	Yes	No	Yes	No	No	No
13	No	No	No	No	No	Yes	No	No	Yes
14	Yes	No	No	No	No	Yes	No	No	Yes
15	Yes	No	No	No	No	No	No	No	No
16	Yes	No	No	No	No	Yes	No	No	Yes
17	No	No	No	No	No	Yes	No	No	Yes
18	No	No	No	No	No	No	No	No	No
19	No	No	No	No	No	No	No	No	No
20	No	No	No	No	No	No	No	No	Yes
21	No	No	No	No	No	Yes	No	No	Yes
22	No	No	No	No	No	No	No	Yes	Yes
23	No	No	No	No	No	Yes	No	No	Yes
24	No	Yes	Yes	No	Yes	No	No	No	No
25	No	Yes	Yes	No	Yes	No	No	No	No
26	No	Yes	Yes	No	Yes	No	No	No	No
27	No	Yes	No	No	Yes	No	No	No	No
28	No	Yes	No	No	Yes	No	No	No	Yes
29	No	No	No	No	No	Yes	Yes	No	Yes
30	No	No	No	No	No	No	No	No	No
31	No	No	Yes	No	No	No	No	No	No
32	No	No	No	No	Yes	No	No	No	Yes
33	No	No	No	No	No	No	No	No	No
34	No	No	No	No	No	No	No	No	No
35	No	No	No	No	No	No	No	No	No
36	No	No	No	No	No	No	No	No	No
37	No	No	No	No	No	No	No	No	No
38	No	No	No	No	No	No	No	No	Yes
39	No	No	No	No	No	No	No	No	No
40	No	No	No	No	No	No	No	No	No

4.3 Architecture of the neural network

For the analysis of the case studies version 4.1 of the Stuttgart Neural Network Simulator (SNNS) was used. It was run on a standard PC with a Windows NT 4.0 (Service pack 6) operating system and an X-Windows emulator (X-WIN32 from Starnet Communications; Version: 5.0.1). The neural network used was designed for simplicity not for performance in order to evaluate the possibilities of an analysis with neural networks under the simplest conditions.

4.5.1 Topology of neural network

A very simple design for the neural network was chosen, a standard, fully connected, feed-forward neural network with 39 input units (the 39 relevant factors: yes/no), 9 hidden units, and 1 output unit (conflict: yes/no). A total of 360 connections or synaptic weights form the distributed memory of the trained neural network.

4.3.2 Basis and activation function

Two of the simplest basis and activation functions have been chosen. A first-order linear basis function (see Equation 3) and a sigmoid activation function (see Equation 4) were used (see also SNNS 1995 and Kung 1993).

$$u_i(w,x) = \sum_{n}^{j=1} w_{ij} \cdot x_i$$

Equation 3 First-order linear basis function

$$f(u_i) = \frac{1}{1+e^{-u_i}}$$

Equation 4 Sigmoid activation function

Time is not modelled explicitly. There is no propagation delay or explicit modelling of activation functions varying over time. Rather the neural network executes and learns in update cycles.

4.5.3 Training, Validation and Testing

An important focus of a neural network design is the question of how to adjust the synaptic weights to achieve the desired system behaviour. To this end the standard back propagation algorithm was used (SNNS 1995). The neural network is presented three different data sets for training, validation and testing.

- The training set is used to train the neural network.
- The validation data set is used to assess the performance of the neural network on patterns that are not trained during learning.
- The test data set finally checks the over all performance of the neural network.

Learning is done in cycles. The learning should be stopped in the minimum at the validation set error. At this point the net generalizes best. When learning is not stopped overtraining occurs and the performance of the net on the entire data decreases, despite the fact that the error on the training data still gets smaller (see also chapter 5.1).

For the purpose of training, validation and testing the entire data set was split up randomly into several different data sets, with each of them using 36 cases for training and 4 for validation or testing. The two possible classifications in the output were “conflict” or “no conflict”.

Table 9 Details on the neural network design

Topology of the neural network	1 input layer (39 neurons) 1 hidden layer (9 neurons) 1 output layer (1 neuron) simple feed forward connections
Activation function	sigmoid
Basis function	first-order linear
Number of input variables	39
Number of output classes	2 (conflict, no conflict)
Number of connections or synaptic weights	360
Number of training and test data sets	40
Learning algorithm	standard back propagation
Initialization	randomized weights
Update function	topological order

5 Results

The results of the analysis can be grouped into two parts. First the learning success of the neural network is evaluated on an abstract level. In a second step the performance of the network is tested with real case studies.

5.1 Training and validation

As has been pointed out in chapter 4.5.3, the neural network should not be over trained. If it is over trained the neural network does not generalize very well. One validation run is shown in Figure 12. It shows that the training data set reduces its error with each learning cycle (black curve). The weights of the neural network adapt to the case studies of the training data set. The figure also shows that the error of the validation data set reaches a minimum error after app. 40 learning cycles (red curve). This is the point of optimal training. Here the neural network's adaptation to case studies of the training data set is not too strong to impede generalization.

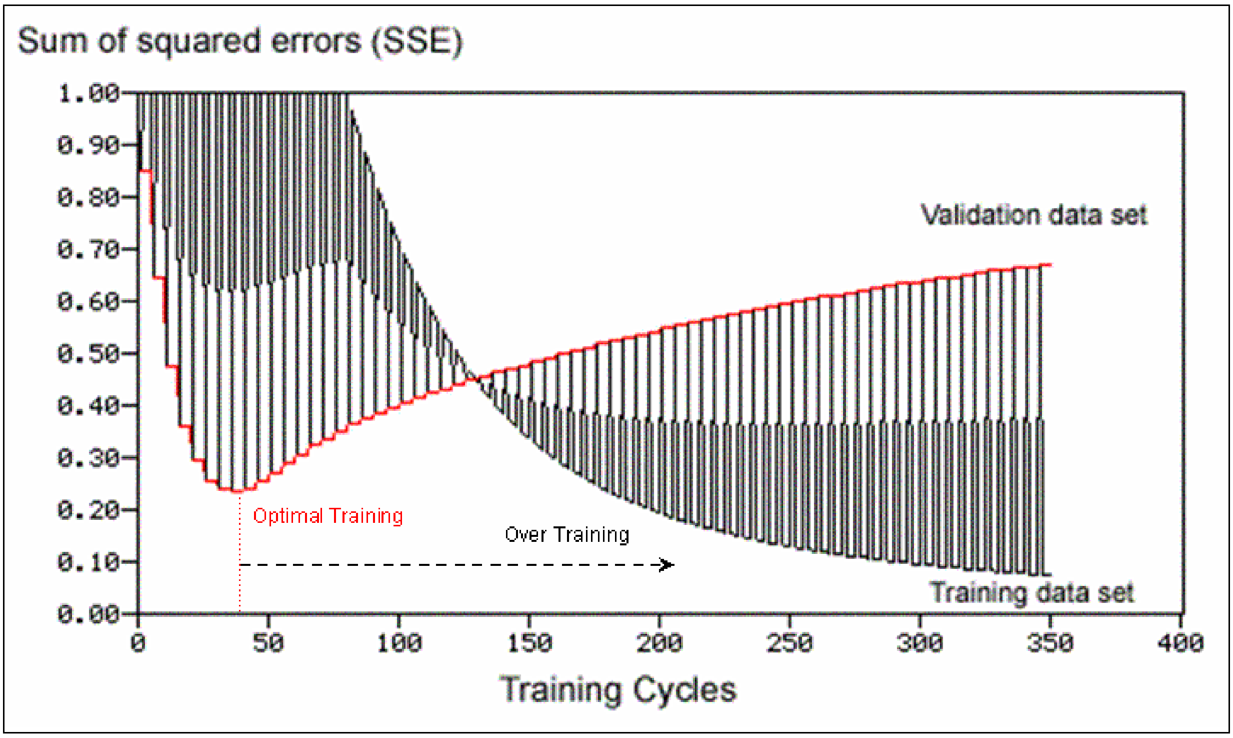

Figure 12 Development of the sum of squared errors (SSE) during a validation run

5.2 Characteristics of the trained network

The trained networks clearly showed balanced synaptic weights as well. They are visible in the network topology (see Figure 13) which, for technical reasons, is only partly visible in the figure and the overview on the synaptic weights (see Figure 14).

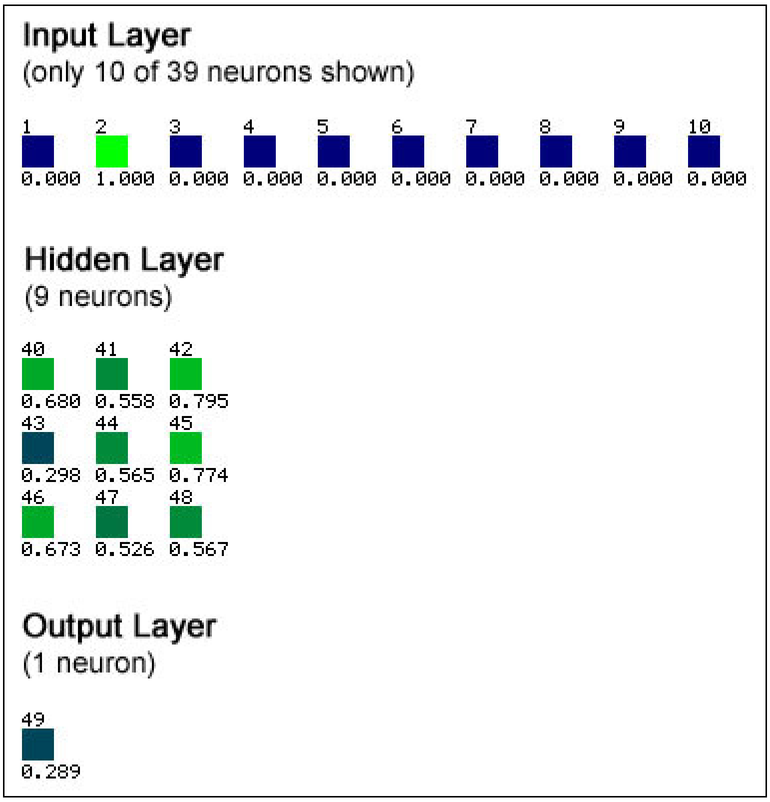

Figure 13 Trained neural network (Training Pattern 3)

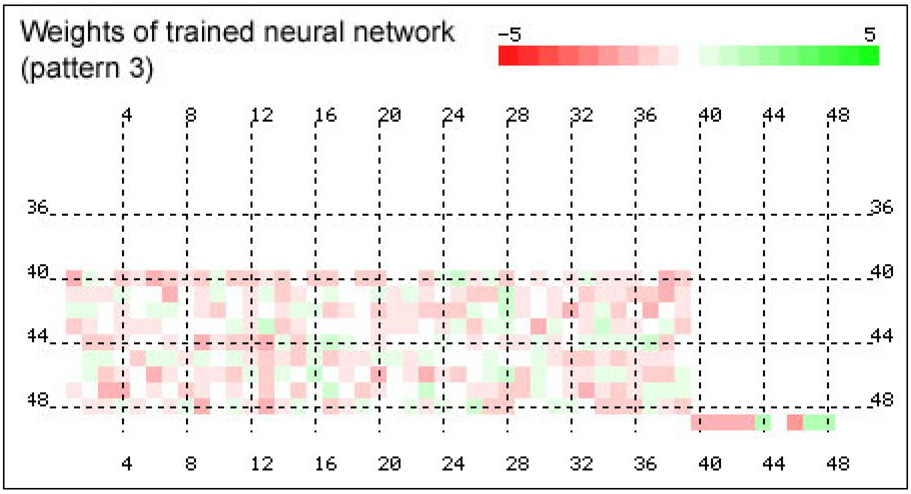

Figure 14 Weights for the trained neural network (Training pattern 3)

5.3 Test runs with the trained network

The overall performance of the neural network is determined by its ability to correctly classify case studies that were not used in training and are therefore unknown to the neural network. Seven test runs with always different data subsets have been conducted (see Table 10 and Table 11). Overall 82 % of the test cases were classified correctly, 18 % were classified incorrectly.

Table 10 Test results of the trained neural network (1st part)

		Test run 1	Test run 2	Test run 3	Test run 4
No. of training cycles		40	40	40	
Error statistics for training	SSE	0.1598	2.3348	2.3718	1.7238
	TSS	1,0000	8.9722	8.9722	8.9722
	RSQ	0.8402	0.7398	0.7355	0.8079
	SHIBATA	29.7187	50.3281	51.1473	37.1575
	AIC	727.1190	641.5188	642.1000	630.5964
	SBC	500.0479	1227.4208	1228.0021	1216.4984
Results of	**No. of correct**	4	3	4	2

testing	**classifications**				
	No. of incorrect classifications	0	1	0	2

Table 11 Test results of trained neural network (2nd part)

		Test run 5	**Test run 6**	**Test run 7**	**Total**
No. of training cycles		40	40	40	
Error statistics for training	SSE	0.6545	2.5170	1.7418	
	TSS	1.000	8.9722	8.9722	
	RSQ	0.3455	0.7195	0.8059	
	SHIBATA	121.7296	54.2553	37.5464	
	AIC	732.7590	644.2237	630.9713	
	SBC	505.6880	1230.1257	1216.8733	
Results of testing	**No. of correct classifications**	3	3	4	**82 %**
	No. of incorrect classifications	1	1	0	**18 %**

Detailed descriptions of computation of the errors can be found in SNNS 1995. They are indicated for completeness sake and were not compared to other studies because data on comparable errors in other studies could not be found.

6 Discussion

6.1 Validity of the results

6.1.1 Learning from past case studies

The approach to train a neural network with the help of historical case studies can of course be questioned because of the expected scale of environmental degradation in the next decades. ”[…] case studies of past events with tenuous environment-conflict connections are insufficient guides to future trends given the unprecedented rate and scale of environmental change” (Dabelko and Simmons 1997). However there is simply no other option than to learn from the past (case studies) if a neural network is used as analytical tool. Without suitable training data on past and present cases of environmental conflict a neural network is worthless. The introduction of newer case studies as time progresses could improve the capabilities of the neural network and keep it up to date.

6.1.2 Case selection bias

“Few, if any conflicts, justify single-issue labels like ‘environmental conflict’ or ‘ethnic conflict’” (Gleditsch 1999a). It has been criticized that the case studies used by Bächler and Spillmann (1996a), Bächler and Spillmann (1996b), and Bächler *et al.* (1996) were selected systematically on the dependent variable „conflict“ (Gleditsch 1999a). Case studies were chosen were conflict existed which leads to a negative bias towards a particularly conflict-rich selection. However, as Carius and Imbusch (1998) have also pointed out the named case studies also include cases where no violent conflict ensued.

In fact 47.5 % of the case studies used were conflict cases. In the real world it can be expected that the relationship between conflict and no-conflict cases is closer to the figures of Wolf *et al.* (2003a) who determined that only the conflictive events should make up 28 % of all cases and that actual conflict only develops in 2 % of all cases.

This has mathematical implications on the measurement of the performance of the analytical tool (the classification algorithm) which is described in chapter 6.3.13.

6.1.3 The weight of environmental degradation

Environmental degradation is sometimes portrayed as an independent cause of conflict. However, it may also be interpreted as a symptom of other societal failures which generate other forms of conflict as well. Other factors play a role, too, e.g. authoritarian rule, lack of international co-operation, poverty, excessive consumption in rich countries and others. Some studies point out that soil erosion, deforestation, desertification and the lack of clean freshwater may have lesser importance than political, economic and cultural factors, or a history of conflicts (Gleditsch 1999a). A detailed analysis with neural networks makes a principal component analysis (Kung 1993: 269ff) possible. Then it can be determined which factors actually influence conflict most. This has, however, not been done because of the limited number of case studies in this paper.

6.1.4 Missing concepts

Several important points are not reflected in the analysis yet. The sensitivity of eco systems, e.g. the fact that deforestation is usually much more critical in mountainous regions (highlands) than in lowlands, was not integrated. Another point to be mentioned are coping strategies, e.g. the forecast of El Niño events helped people in Brazil to cope with the situation and reduce their agricultural losses (Burroughs 1997:178). The precise forecast of the 1992 El Niño Southern Oscillation (ENSO) event allowed farmers in North Eastern Brazil to change their crops. For this reason, the harvest reached a level of 80 % of a normal harvest. In the earlier El Niño event of 1982 the drop was down to 20 % of a normal harvest. However, the reason for not including these factors is not the inability of an analytical approach with a neural network to integrate them. These factors had not been included in the case study descriptions.

6.1.5 Comparison with other classification results from Neural Networks

The performance of the neural network that was assessed here for the prediction of the likelihood of environmental change with 82 % correct classifications is relatively poor when compared with other applications of neural networks. The percentage of correct classifications is usually in the range of more than 90 %. Table 12 lists some applications. Abe (2001) also used a simple feed forward network with standard back propagation learning algorithm. Zhang and Poulton (2003) used the delta learning rule. However, these results have to be seen in the light of a significantly smaller training data set for this study.

Table 12 Comparison of the recognition rate of classifications with neural networks

Classification problem	**Number of Input variables**	**Number of Output classes**	**Number of training and test data sets**	**Recognition Rate**	**Reference**
Iris recognition	4	3	150	97,33 %	Abe 2001: 19-20, 41-46
Seismic first-break refraction picking	6	1	120	95-99 %	McCormack 2003
License plate identification	12	10	1630	99,43 %	Abe 2001: 19-20, 41-46
Blood cell classification	13	12	6197	97,53 %	Abe 2001: 19-20, 41-46
Environmental conflict	39	2	40	82 %	(this study)
Inversion of well-logging curves	41	5	400-900	89-95 %	Zhang and Poulton 2003

When compared to the statistical instruments which are widely used in political sciences the picture changes (see chapter 6.2.8).

6.2. Comparison with other analytical approaches

In addition to comparing the validity of the results with other applications of neural networks, the results of this work have to be evaluated against other analytical approaches to determine the likelihood of environmental conflict. These other analytical approaches are listed in an order which is trying to move from lower to higher complexity and from lower to higher usefulness to assess the likelihood of environmental conflict.

6.2.1 One-dimensional approaches

It was suggested that the susceptibility of nations to environmental conflicts may depend on the type of government. Democratic nations may be more competent in the mediation of environmental conflicts whereas authoritarian governments are better capable to remain in power and have the ability to cover up problems (pers. comm. Gleditsch / NATO ASW 1999). This leads to a u-shaped relationship between the susceptibility of nations towards environmental conflict and their level of democratization (see Figure 15). A similar u-shaped relationship is already confirmed for the susceptibility of nations for civil war (pers. comm. Gleditsch / NATO ASW 1999) and the relationship between the degree of democratization and state failure was confirmed by Esty *et al.* (1999).

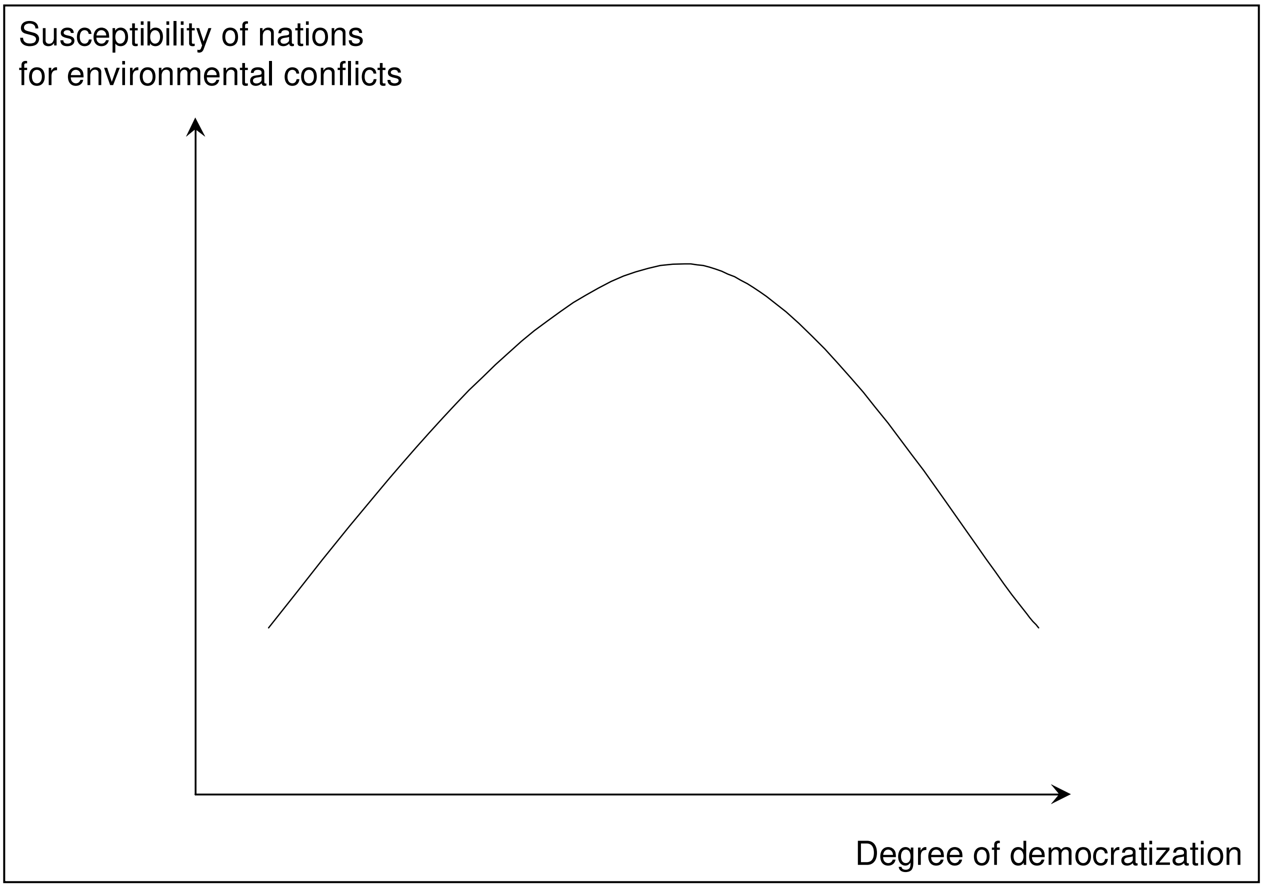

Figure 15 Qualitative function of the relationship between the degree of democratization and the susceptibility of nations for environmental conflicts (according to Gleditsch / pers. comm. NATO ASW 1999)

The precision of the prediction of the likelihood of environmental conflict based on this relationship is, however, relatively low because the relationship is significant but not all decisive (see also chapter 6.2.8).

Another simple one-dimensional approach may be to find areas where environmental change is likely to produce problems, simply because not enough renewable resources are available in a given area. One of these maps is shown in Figure 16 which is based on data from Gleick.

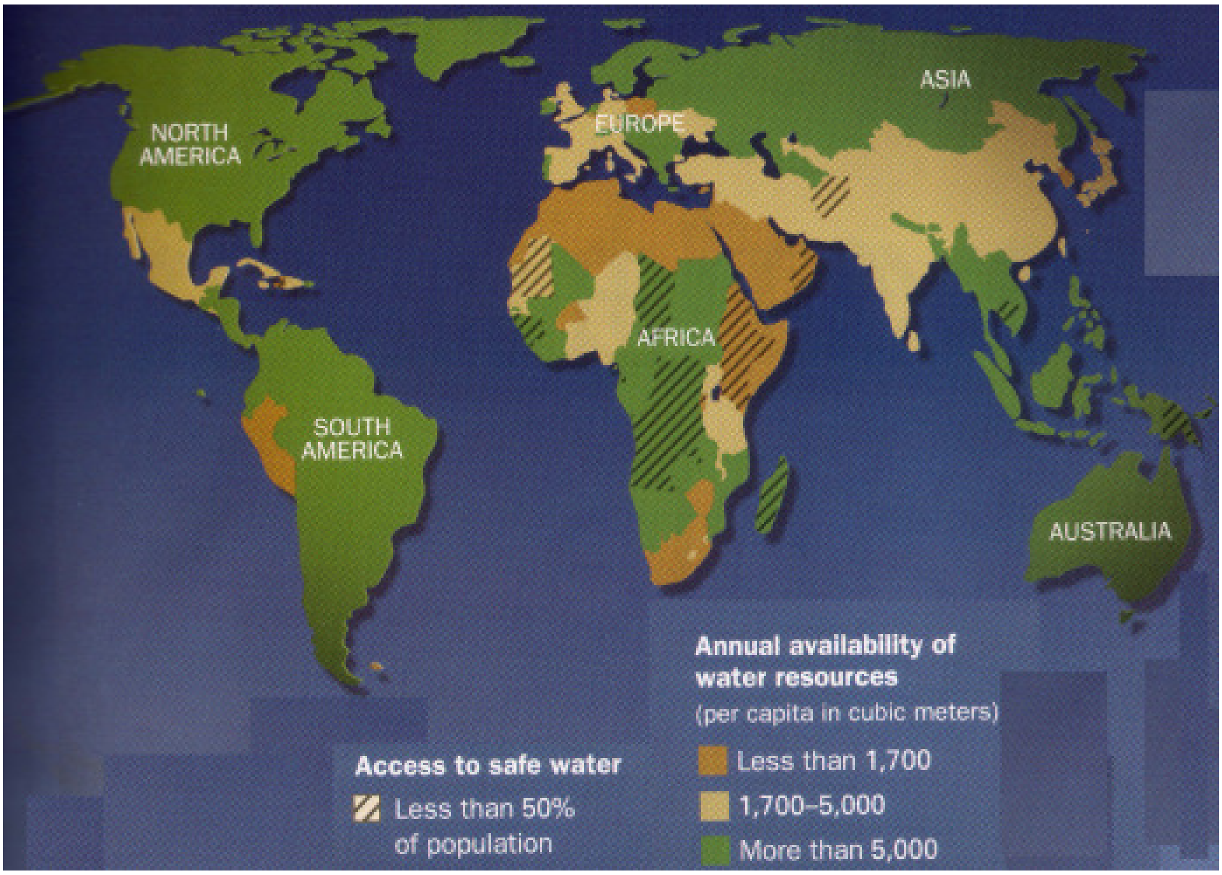

Figure 16 Annual availability of water resources (adapted from National Geographic 04/2001: VII)

However the works of Wolf *et al.* 2003a (see also chapter 6.2.9) tried to statistically link aridity with environmental conflict along international river basins. The relative frequency that was observed for a certain event on the basins at risk (BAR) scale level is expressed as an exceedance probability compared to random sample replications. Figure 17 shows e.g. that in arid and, even more pronounced, in semi-arid regions, the relative frequencies of the most conflictive events are significantly higher compared to what one can expect from random samples, while they are low for neutral to slightly cooperative events. In arid regions, however, there is also a high probability for the most cooperative events. Thus, the degree of aridity can in fact not be used as an indicator for conflict.

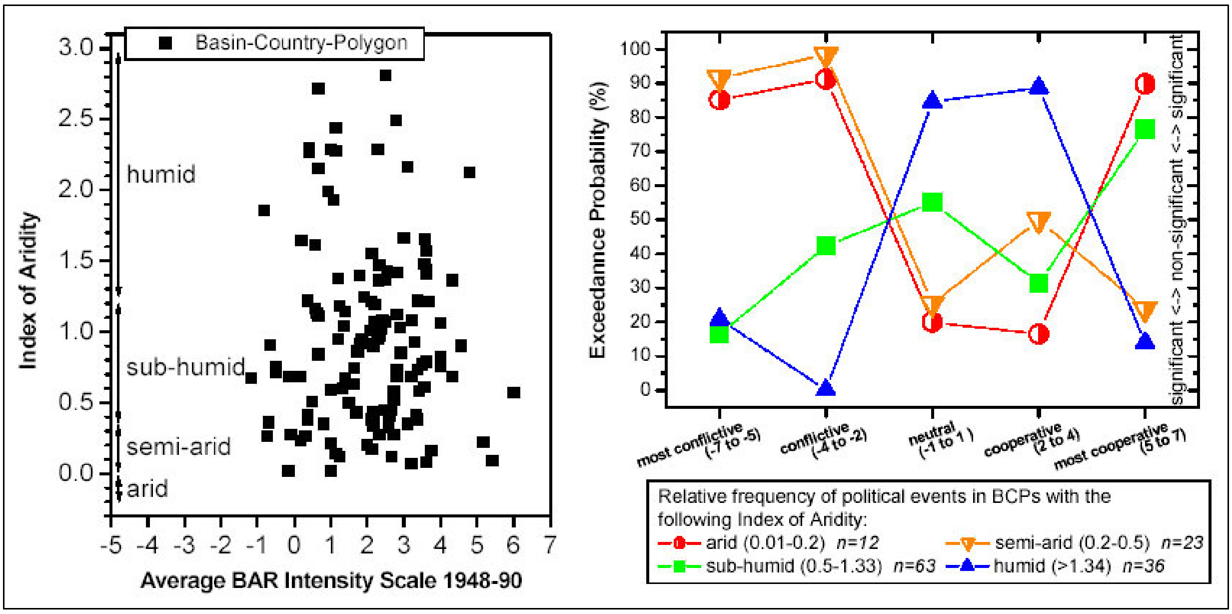

Figure 17 Relationship between hydro-climatic conditions and conflict-cooperation level of political events in the basin-country polygons; Right) Average BAR intensity versus index of aridity; Left) Exceedance probability of observed frequency for a certain conflict-cooperation level (adapted from Wolf *et al.* 2003a: 7)

6.2.2 Two-dimensional approaches

Alcamo and Endejan (1999) suggested an analytical approach combining “environmental stress”, “state susceptibility” and “crisis” (emergencies, famines and natural disasters). The combination of a sufficient level of environmental stress combined with a high state susceptibility would result in a crisis (see Figure 18). In a first analysis the per capita GDP was used as a first order approximation for state susceptibility. The FAO Crop suitability model was used to determine food stress as a possibility for environmental stress.

However, it is important to note that “crisis” is not equivalent to “conflict”. It is only an approximation. Secondly, the boundary zone between a low probability and a high probability of crisis is relatively large. A sharp differentiation is therefore unlikely.

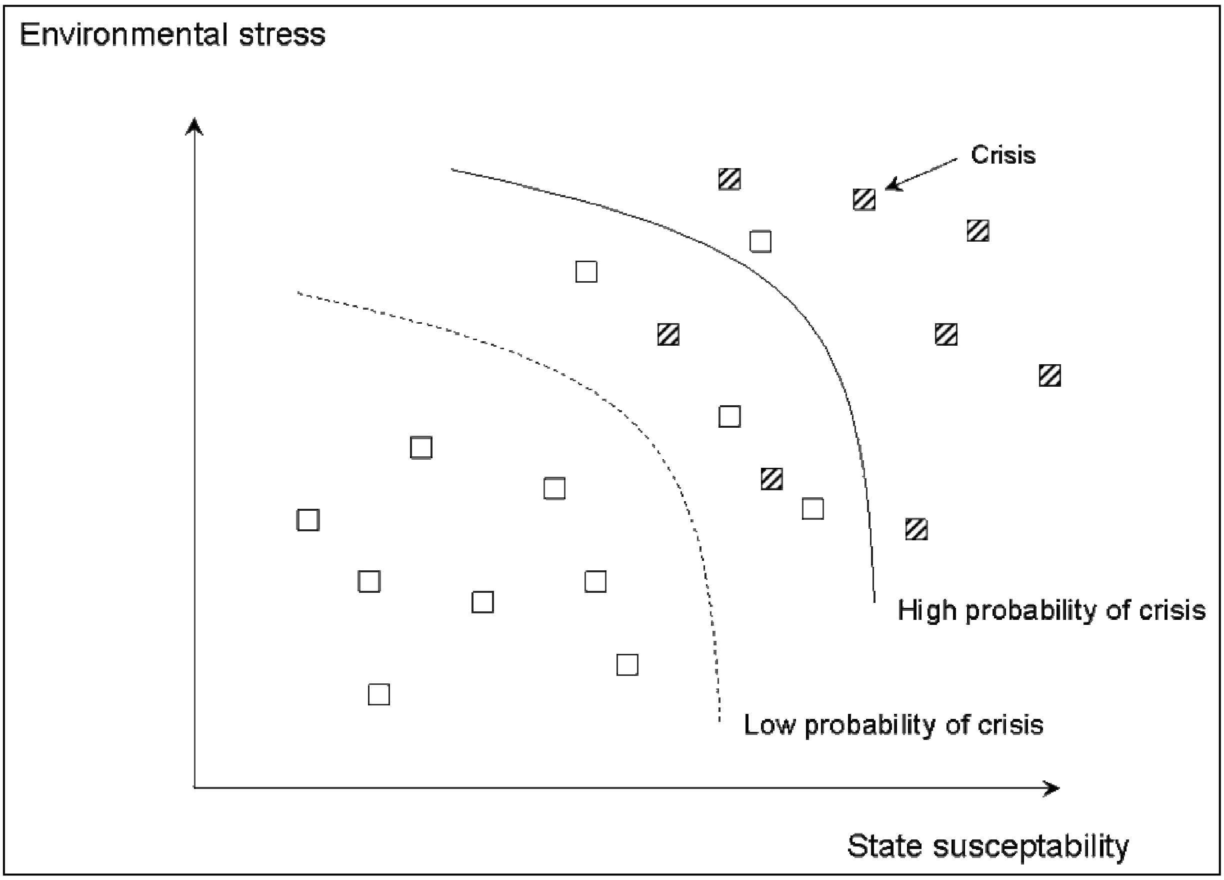

Figure 18 Relationship between environmental stress and state susceptibility (adapted from Alcamo and Endejan 1999)

Another interesting two dimensional approach was published in the popular magazine National Geographic (Issue: 09/2002) based on works of the University of New Hampshire. According to this approach, water stress defined as an area where people use more than 40% of available renewable water was coupled with the population density. Note that the definition of water stress here is different from definitions of water stress elsewhere (e.g. WBGU 1998). The produced map shows trouble spots where crisis or even conflict might be more likely. It is interesting to compare the statistical average of those countries which gives the impression that water stress is under control (see Figure 19, e.g. in China), with some of these country's regions in a detailed analysis which actually show problem areas within the countries (see Figure 20, e.g. in northern China).

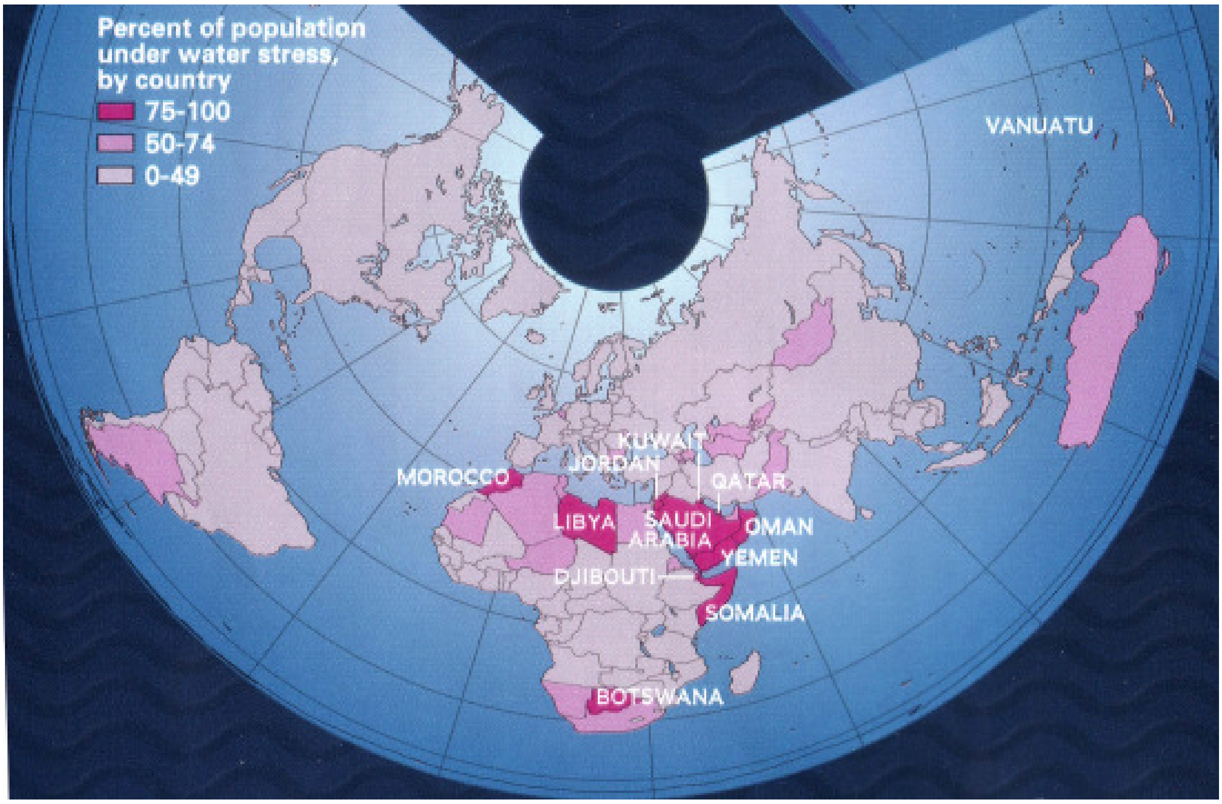

Figure 19 Map with the percentage of the population under water stress by country (adapted from National Geographic 09/2002: 16)

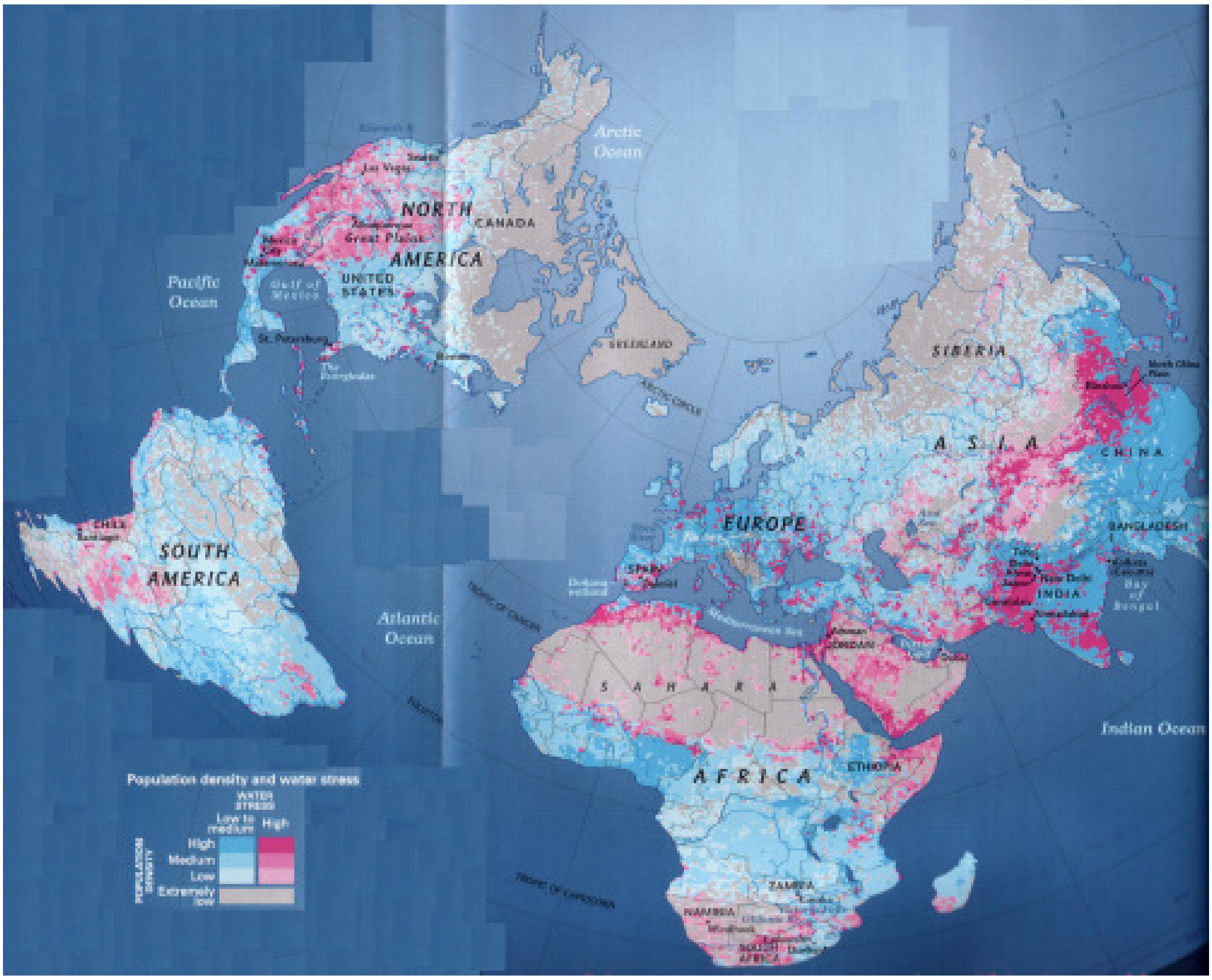

Figure 20 Map of a two-dimensional analysis covering water stress and population density in regional detail (adapted from National Geographic 09/2002: 16-17)

Similar maps on the potential criticality of water crisis have also been produced by WBGU (1998:133-140).

However, these approaches are just approximations for the likelihood of environmental conflict. They have not been statistically tested for conflict events.

6.2.3 Multi-dimensional approaches

6.2.3.1 Syndrome-analysis

One multi-dimensional approach discussed in greater depth, e.g. by Biermann (1998) and Windfuhr (1998), was the syndrome-analysis. WBGU developed the so called syndrome analysis (see also WBGU 1998:140-217). Some factors that are important in global change, like climate change, globalisation of markets, or degradation of soil, were grouped in areas like biosphere, hydrosphere, economy, etc. Then patterns were identified that could be associated with the same "symptoms". These were designated as syndromes. All in all 16 different syndromes were classified, e.g. the Sahel syndrome, the Aral Sea syndrome or the Dust-Bowl syndrome. In fact the syndrome concept bundles a range of hypothesises that are used to describe the connections between different factors. These connections or the intensity of certain factors or syndromes are partly described in a qualitative way and partly in a quantitative way. Thus, the syndrome approach is a multi-factor cluster analysis very similar to the analysis with a neural network. The difference between the patterns that are used in the syndrome concept and those that are identified in an analysis with neural networks is that the patterns for the syndrome analysis are qualitatively constructed patterns or classifications according to the presently available knowledge and expected causal relationships, whereas the patterns that are recognized by a neural network are an outcome of the learning process of the neural network from case studies.

Figure 21 shows the intensity of the Dust-Bowl-Syndrome which is named after the Dust Bowl in the 1930s in the USA and effectively is a combination of drought and overcultivation (and other factors). Syndrome intensity is measured based on certain indicators which come from the following areas: biosphere, atmosphere, pedosphere, economy, hydrosphere, population, psychosocial sphere, society, science and technology.

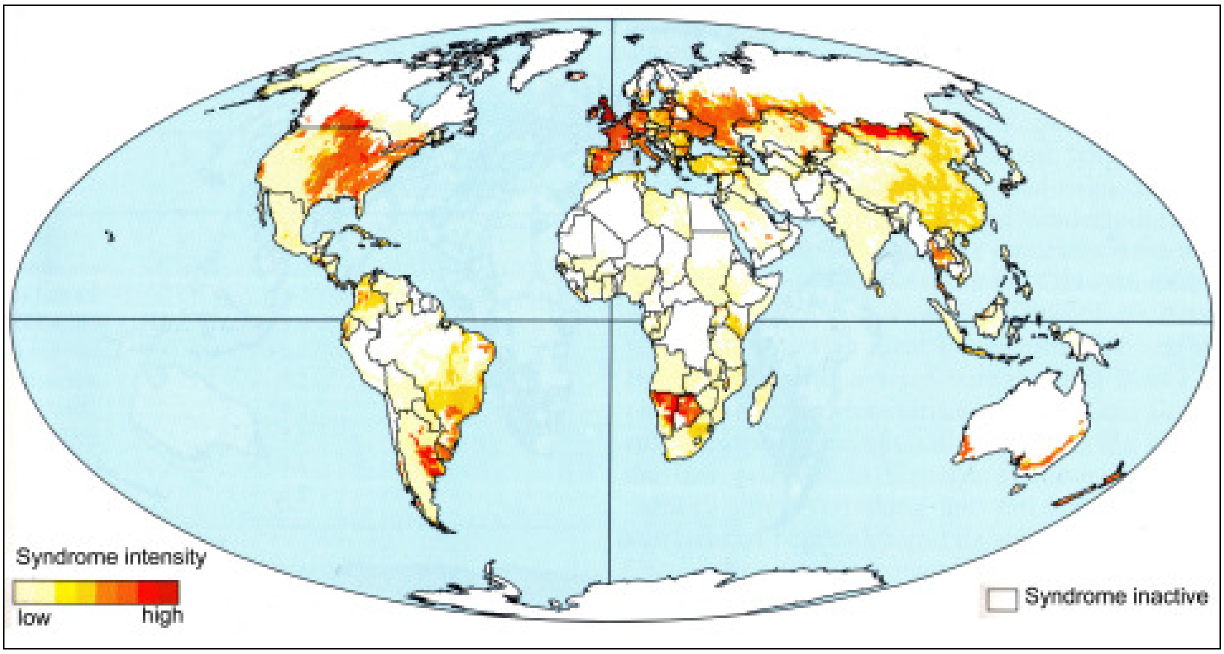

Figure 21 Intensity of the Dust-Bowl-Syndrome (adapted from WBGU 1999: 223)

Countries which are most at risk from the Dust-Bowl syndrome are listed in Table 13. However, except Thailand and Vietnam none of the countries are mentioned in literature as a case study for environmental conflict.

Table 13 Countries which are most at risk from the Dust-Bowl syndrome (WBGU 1999: 225)

Countries	**Dust-Bowl-Risk in relation to GDP [%]**
Georgia	28,5
Moldavia	11,3
Sri Lanka	11,3
Guatemala	9,9
Romania	9,0
Bulgaria	8,2
Thailand	8,0
Armenia	7,2
Vietnam	7,1
Ecuador	6,2

Bächler (1998) grouped together the ENCOP case studies (Bächler and Spillmann 1996a, Bächler and Spillmann 1996b, and Bächler *et al.* 1996) that were also used for the neural network analysis and associated them with the described syndromes. As a result it became clear that the existence of a specific syndrome did not automatically lead to environmental conflict. Biermann (1998) also notes that a correlation between a high intensity of a syndrome and migration or conflict does not determine a causal relationship. Syndromes are patterns that are global and can be recognized as a problematic human nature relationship (WBGU 1999: 214-228). They are useful to assess vulnerability but not environmental conflict. Sometimes the syndromes were probably a cause of a conflict (e.g. in Sudan), but sometimes also the result of a conflict (Angola). Thus, the syndrome concept has to be refined more before it can be used as an analytical tool for the prediction of the likelihood of environmental conflicts. However, the factors and indicators of the syndrome concept that have already been identified are a very good basis for further refinement of quality of the input data for future analysis.

6.2.3.2 Index of Human Insecurity

Lonergan (1998b) tried to construct an index of human insecurity. The purpose of this exercise was to determine whether migration flows, at least those affected by environmental degradation, could be projected based on an index of vulnerability. The indicators which comprise the "Index of Vulnerability" are listed below:

- Food Import Dependency Ratio
- Water Scarcity
- Energy Imports as a Percentage of Consumption
- Access to Safe Water
- Expenditures on Defence vs. Health and Education
- Indicator of Human Freedoms
- Urban Population Growth
- Child Mortality
- Maternal Mortality

- Income per capita
- Degree of Democratization
- Fertility Rates

Obviously, the index of Human Insecurity covers "wellbeing" to a great extend. It is strongly related to the Human development index (see UNDP 2002).

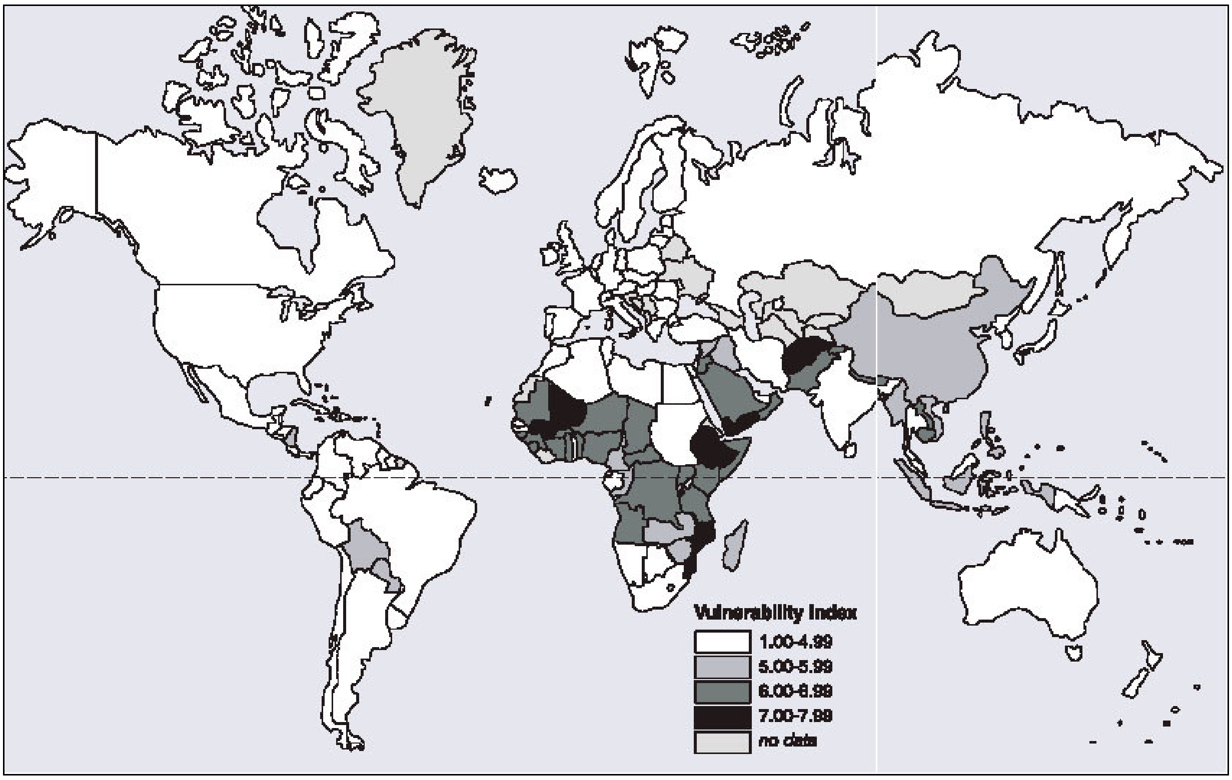

Figure 22 Vulnerability index (adapted from Lonergan 1998b: 28)

Ohlsson (1999) has built a similar index, the social resource water stress/scarcity index (SWSI), which effectively combines the stress level and the social adaptive capacity for which the UNDP human development index is used as a proxy.

However, both indexes have no proven relationship to environmental conflict.

6.2.4 Critical environmental values

Sprinz (1998) suggested to use certain critical values of an environmental factor that have to be exceeded before an environmental conflict will evolve. These critical values can combine with more than one indicator in a multidimensional critical environmental value. Windfuhr (1998) noted, however, that these values might be suitable to determine critical environmental problems but that they do not integrate intervening social factors.

6.2.5 Mathematical models of environmental conflict

In several cases mathematical equations have been developed to describe political developments or security issues. Scheffran (1998) mentions the Lanchester equation for the conduct of war, the Richardson equation for the dynamics of arms races, and the game theory. Scheffran (1998) has adapted the SCX-Model to simulate the effects of climate change on socioeconomic systems but he notes that the model description is still to rough and the model assumptions too simple for a profound analysis.

Bächler (1998) also designed a complex model of seven interconnected hypothesises as an analytical tool but this model was unsuitable for prediction because the relationship between the intervening factors was not precisely known.

The magnitude of work for building such a mathematical model can be estimated if we look at standard economic models. The UK treasury economic model covers 530 variables and 300 equations to describe the link between them (Burroughs 1997 (162). A mathematical model for the description of environmental conflict would have to include many more.

6.2.6 Other applications of neural network analysis: State failure

Esty *et al.* (1999) developed a model of the factors that contribute to state failures (revolutionary wars, ethnic wars, adverse or disruptive regime transitions, and genocides). They evaluated over 600 variables that might be relevant against 113 state failure cases and 339 randomly picked control cases in the period 1980-1990.

They selected 75 high priority variables from which 31 where deemed best at distinguishing state failures from non-failures. These variables were tested by statistical regression analysis, genetic algorithm modelling and neural network analysis. However, the results of the statistical analysis have been published only. According to Goldstone *et al.* (2000), the neural net was used to explore the possibility that the used logistic regression techniques overlook important variables or fail to specify the relationship between particular independent variables and the risk of state failure. Thus, the neural network was not used in the way it was in this study. The best model relied on three variables only: infant mortality as an indirect indicator for the quality of life, openness to trade measured as the value of imports and exports divided by GDP, and the level of democracy. Using these three variables it was discovered that partial democracies are much more vulnerable to state failure than full democracies or autocracies. They are three times more likely to fail. Trade openness is also defined as highly significant, the greater a country's trade openness the less likely is state failure. Countries that had experienced a negative annual change in their GDP per capita were on average twice as likely to experience state failure.

6.2.7 Fuzzy Logic

The use of fuzzy logic is another potential analytical approach as an alternative to neural networks. As Abe (2001: V-VI) explains, neural networks and fuzzy systems are often applied to pattern classification. The two approaches proved to be mathematically equivalent in that they are convertible. However, they show advantages and disadvantages.

Neural networks learn from data and train the network. If the trained network does not perform as expected, it needs to be retrained, redesigned, the number of layers or neurons has to be changed, etc. This is necessary because the algorithm for classification is acquired in the network weights that connect between layers of neurons and the meaning of each weight separately cannot be identified. On the other hand fuzzy rules need to be acquired. A complicated system is difficult to express in a fuzzy logic rule format. If the number of input variables increases, the number of rules to be defined increases exponentially. Thus, rule acquisition requires a lot of time. But once the fuzzy rules are obtained, analysis by the fuzzy system is relatively easy.

Possible fuzzy logic rules for the onset of environmental conflict were formulated by Bächler (cited from Windfuhr 1998) but a final rule set has not yet been developed.

According to Abe (2001: V-VI), the performance of a fuzzy system is usually inferior to that of a multilayer neural network for certain reasons. According to these reasons neural networks have been applied to the problems where domain knowledge is scarce but numerical data can be acquired easily, while fuzzy systems have been applied to problems where domain knowledge is abundant but numerical data are difficult to obtain (no training data sets are needed). One can now argue whether the knowledge of the causal relations for the generation of environmental conflict is sufficient to build a fuzzy system or whether there are enough potential case studies to thoroughly train a neural network.

6.2.8 Statistical approaches with more than two variables

Schrodt and Gerner (1996) tried to use WEIS (conflict, tension and uncertainty) coded event data as an early warning indicator of major political changes in the Middle East from 1979 to 1996. Schrodt and Gerner (1996) used a statistical cluster algorithm for their analysis and checked the validity of the clustering algorithm with a Monte Carlo analysis[2]. The weighting of the WEIS event categories was optimized using a genetic algorithm[3]. The event data is used as a basis for an early warning system since many structural variables, e.g. ethnic and linguistic differences, do not change at a rate sufficient for use in an early warning system. But if the behaviour of certain actors

[2] Monte Carlo simulations are used in statistics to investigate the properties of a complicated distribution or in models with a complex nondeterministic time evolution, e.g. population growth, or other social phenomena (Madras 2002: 2). Roughly speaking the final output of a Monte Carlo simulation is a random estimate of some unknown object, such as a number, a function or a graph (Madras 2002: 83).

[3] Genetic algorithms are not function approximation techniques like neural networks or fuzzy logic but they are general purpose stochastic optimization methods. They have been inspired by the evolution theory. Genetic algorithms combine the artificial survival of the fittest with genetic operators to form a robust mechanism that is suitable for a variety of optimization problems (Vas 1999: 40-41).

characterize a certain phase in a typology from crisis to conflict, those can be captured by event data.

The approach on state failure by Esty *et al.* (1999) has already been mentioned above. Since his main method is statistical, his results are shown here again. As explained above, he used 75 variables from which 31 were selected as being most important. Esty *et al.* (1999) also tried to identify a statistically significant relation between environmental degradation (deforestation and freshwater supply) and state failure but failed. Esty *et al.* (1999) argued that effects of democratization, trade openness and the quality of life were by far more significant, and masked any impact of environmental deterioration.

The statistical analysis of the event-based approach on the prediction of environmental conflict along international rivers which has been developed by Wolf *et al.* (2003a) is given in Table 14 as well, although some parts of his approach are explained in detail in the next chapter again (see chapter 6.2.9). According to Wolf *et al.* (2003b) with the exception of internationalized basins and unilateral development, no single parameter acts as a strong indicator of water disputes. Therefore, a statistical regression analysis was made and the following indicators were used:

- Friendship/hostility index
- Per capita GDP
- Number of treaties
- Population density
- Freshwater availability per capita

These indicators had a significance of between 5 and 43 %.

Wenche and Ellingsen (1998) tried to prove the link between conflict and the following variables with a Logit model[4]:

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[4] A Logit model is a statistical analysis which among other properties is capable to specify non-linear relationships and can use qualitative variables (Urban 1989).

- Historical conflict (conflict in the last year)
- Land degradation
- Deforestation
- Fresh water availability
- Population density
- Income equality
- Degree of democratization
- Level of economic development
- Degree of political stability

The Logit model's overall performance with a correct prediction rate of 83 % was reasonably high. The findings were that environmental factors did in fact contribute to conflict. Countries suffering from environmental degradation and, in particular, from land degradation (loss of land) are more prone to conflict. However, economic and political factors are far more important. The probability for conflict under the different conditions ranged between below 1% (e.g. only deforestation) and 76% (high land degradation, high population density, high income inequality, poverty, semi-democracy and political instability). Only with a conflict history, it was in a range of 98-99 % (ongoing conflict). Thus, the overall prediction rate has to been seen relative to the prevailing factors. It is worthless that the likelihood of conflict is 98-99 % in the case of an ongoing conflict if an early warning system is to be built.

Toset *et al.* (2000) examined if conflict among countries with shared rivers is more likely. He evaluated 1274 dyads (country pairs) with shared rivers over the period from 1816-1992. His findings were that the relative risk of conflict is higher if countries share rivers or if they have a differing water availability.

Table 14 Comparison of different analysis methods on questions of political sciences

Classification problem	Analytical method	Number of input variables	Number of case studies	Success of analytical method	Reference
State failures	Statistical regression analysis Genetic algorithms Neural network	75 (31)	452	Calculation of the relative risk of state failures from quality of life (factor 3,4), trade openness (factor 1,9) and the level of democracy (factor 3,4)	Esty *et al.* 1999
Correlation between State failures and environmental change				No statistical evidence	
Environmental conflict	Neural network	39	40	Recognition Rate of test cases: 82 %	(this study)
Wars as a follow up of arms races	Statistical regression analysis	2	99	Likelihood that war follows upon an arms race: 55-88 %	Nicholson 1992:179-184
Early Warning Indicators for political	Statistical cluster algorithm	8000 events		Correct Classification of behavioural	Schrodt and Gerner 1996

change in the Middle East and West Africa	Monte Carlo analysis Genetic algorithms			phases: 75-90 %	
Environmental conflict along international rivers	Statistical regression analysis	4	1,831 events	Significance: 5-43 %	Wolf *et al.* 2003b
Environmental conflict	Logit model	9	303	Correct general predictions: 83 % Likelihood of conflict between: 1 and 76 %	Wenche and Ellingsen 1998
Conflict among countries with shared, international rivers	Statistical regression analysis	10	1274 dyads	Relative Risk: 3.2 – 4.0	Toset *et al.* 2000

As a summary on the statistical approaches, the Logit model of Wenche and Ellingsen (1998) seems to best suited for the prediction of the likelihood of environmental conflict. Under certain circumstances (high land degradation, high population density, high income inequality, poverty, semi-democracy and political instability) the probability of conflict is quite high (76%). In comparison with the statistical approaches (see Table 14) a correct classification of 82 % of all cases with the neural network seems quite acceptable considering the fact that the quality and the quantity of the data seems inferior to those used for the statistical aproaches. It would, however, be interesting to test which performance a neural network would have on the data of Wenche and Ellingsen (1998).

6.2.9 An event-based approach for environmental conflict (Time series)

An event-based approach on the prediction of environmental conflict along international rivers has been developed by Wolf *et al.* (2003a) which encompasses an event database containing a comprehensive news file of 1831 reported cases of international water related disputes and dispute resolution from 1950-2000, a treaties database containing over 400 water-related treaties, and an international waters Geographic Information System containing digital thematic maps of the world's international watersheds including climate type, population density, population living with water stress, etc.

His findings are that the number of historical incidents of cooperation over international water resources outnumbers those of conflict in a greater than two to one ratio. Of all 1831 events delineated, 1228 were found to be cooperative, while only 507 were conflictive. In addition most events are mild. 42.8 percent of events fell between mild verbal support (+1) and mild verbal hostility (-1) on the basins at risk (BAR) scale. Only 37 cases of acute conflict, in which violence takes place (-5 to -6 on BAR scale), were identified, and these events were not recent or widespread. In the same time period, 157 treaties were negotiated and signed.

The parameters commonly identified as indicators of conflict (i.e., climate, water stress, dependence on hydropower, dams or development per se, or level of development) are actually only weakly linked to dispute (see also chapter 6.2.1). Instead, the study suggests that institutional capacity within a basin, whether defined as water management bodies or treaties, or generally positive international relations are as important, if not more so, than the physical aspects of a system. It was found that when the rate of change within a basin exceeds the institutional capacity to absorb change, it is likely to find tensions.

Figure 23 shows a composite time series of hydro climatic variables and events of conflict and cooperation over the Senegal River, which is shared by four countries. Droughts and desertification have affected the Sahel region in the past decades, and it is clearly an exceptional example of political tensions following the climatic trend. However, it illustrates the importance of the time context. In several water-scarce regions treaties have been signed during a series of wet years or before major development projects. When water stress later rises during a series of dry years, tensions between the riparians of a shared river become likely.

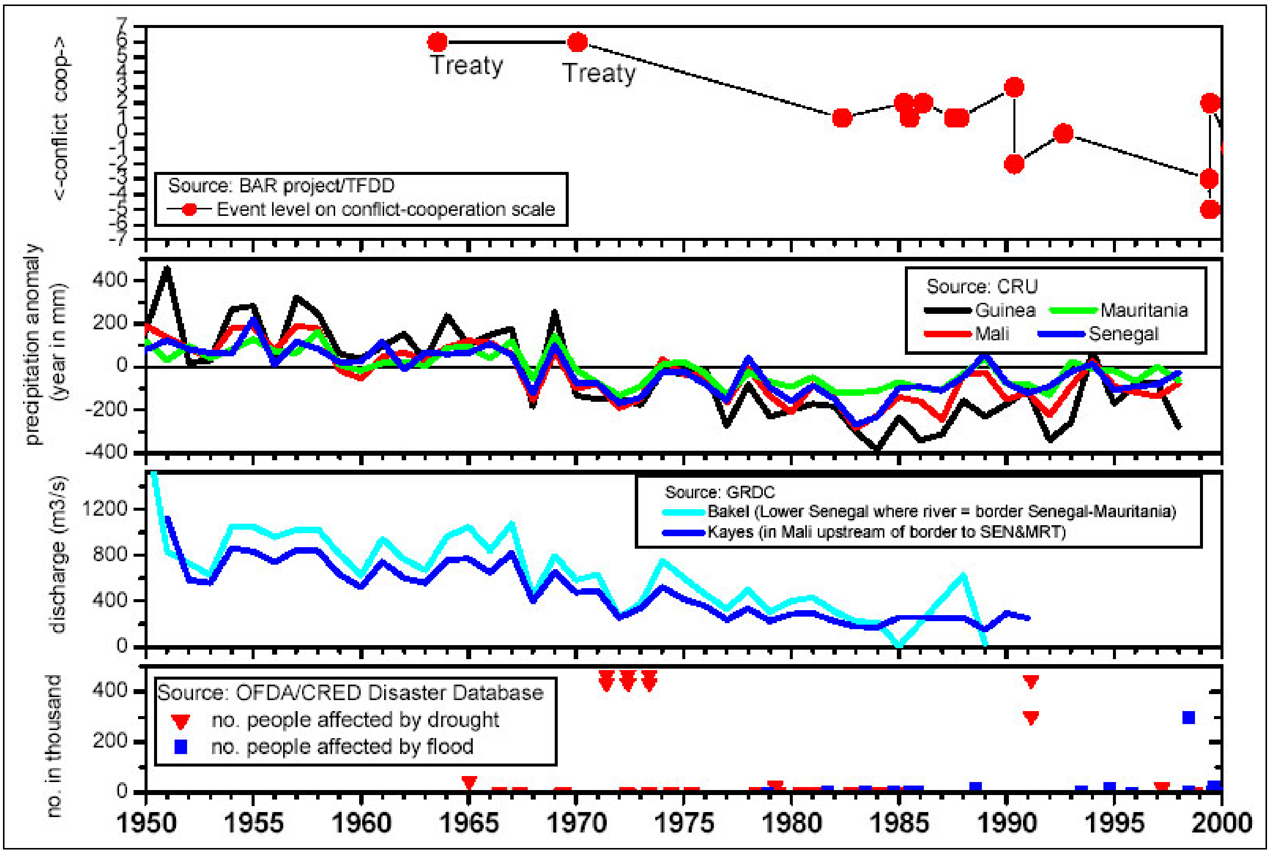

Figure 23 Time series of events of conflict and cooperation, precipitation anomaly, annual mean discharge and the occurrence of natural disasters in the Senegal River basin (adapted from Wolf *et al.* 2003a: 7)

Wolf *et al.* (2003b) argue that the institutional side of the equation is more important than indicators like aridity. Basins without treaties and high dam density are 11% lower in their average conflict/cooperation levels than basins without treaties and low dam density, but the overall level is more conflictive than those basins with treaties.

Looking only at basins with treaties, the cooperation level is actually higher in basins with high dam density than in those with low dam density. Yet the conflict/cooperation level on basins with treaties and high dam density is 40% lower than on similar basins with treaties.

By taking parameters of rapid change as indicators, internationalized basins and major planned projects in hostile and/or institution-less basins, Wolf *et al.* (2003b) tried to identify the basins with settings suggesting a potential for political stresses or conflicting interests in the coming 5–10 years. As Wolf *et al.* (2003b) put it: “The likelihood and intensity of dispute rises as the rate of change within a basin exceeds the institutional capacity to absorb that change.”

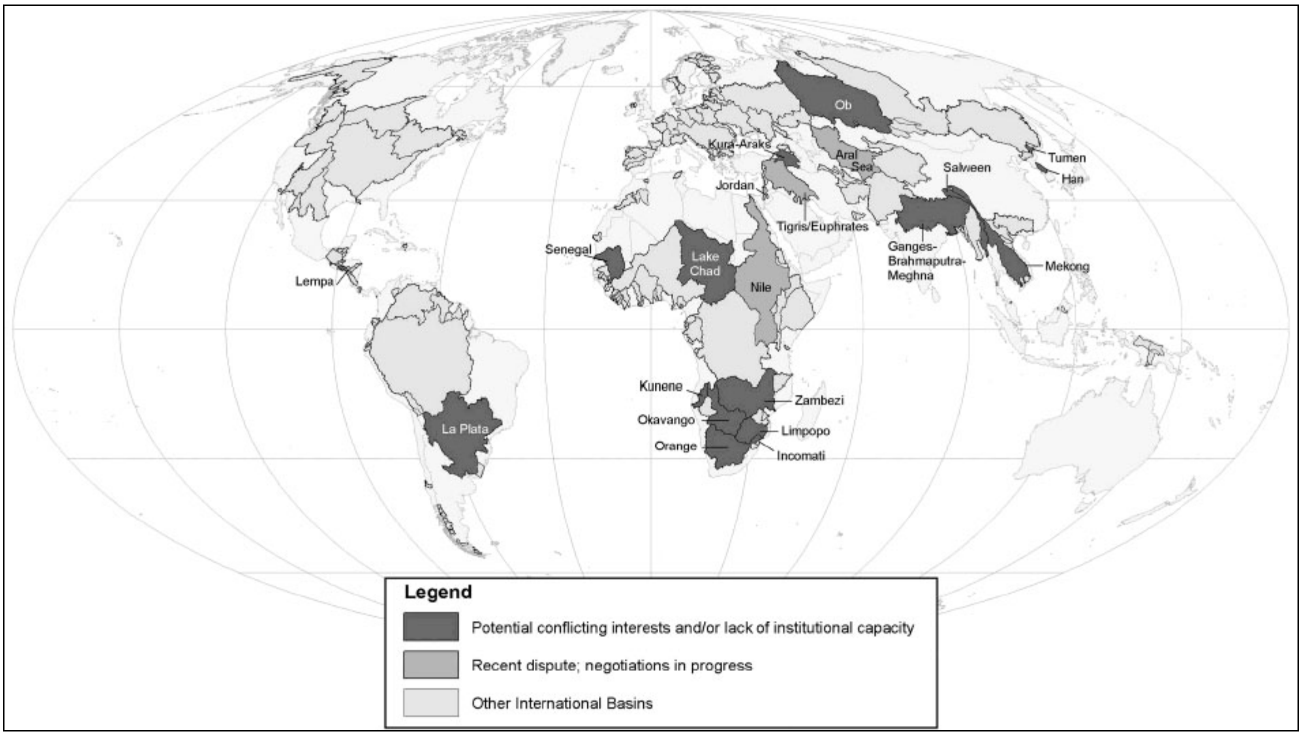

Figure 24 Basis at risk (adapted from Wolf *et al.* 2003b: 47)

However, one must remember that the prediction of the likelihood of environmental conflict based on these rapid change indicators has only been tested against conflict events in a limited way.

6.3 Optimisation and possibilities for further research

As can be seen from the previous chapter, the results of the analysis with neural networks compare with the success of other methods on the field or are even better in some cases. Thus, it seems likely that neural networks can be an important tool for the prediction of the likelihood of environmental conflict. Certain improvements are possible in order to enhance the results further.

Table 15 Improvements for further research

Area of effect	Improvements
Input data	• More case studies should be used to improve the basis for the learning process in an analysis with neural networks. • The case studies should be delineated precisely in time and space. This allows the incorporation of other data sources into the case studies. • Ideally this would lead to the use of quantitative indicators instead of the qualitative factors. Possible data sources should be globally available and may have their origin in official statistics or remote sensing. • An improvement of the finally used indicators is possible with the neural network by checking their weight in the trained network (principal component analysis).
Analytical approach	• In the current study one of the simplest neural network designs has been used. The design of the neural network can most likely be improved so that it gives a better classification. • The value of the analytical approach with neural networks could be compared with statistical methods (e.g. logit models), fuzzy logic, decision tree algorithms, or other analytical approaches in order to determine the most suitable analytical tool.

The result of further research could then be a more precise prediction of the likelihood of environmental conflict. Speaking in the words of Cooley (2000), the raw data and information available on the problems of environmental change would be connected to gain the knowledge where and when the likelihood of environmental conflict will be high or low in particular in light of future development trends be it climate change or population growth (see also Figure 25). Then the next steps can be taken to avert possible environmental conflict with the limited means that will be available. A precise analysis of where and when environmental conflict becomes likely allows for an economic use of scarce resources to avert conflicts.

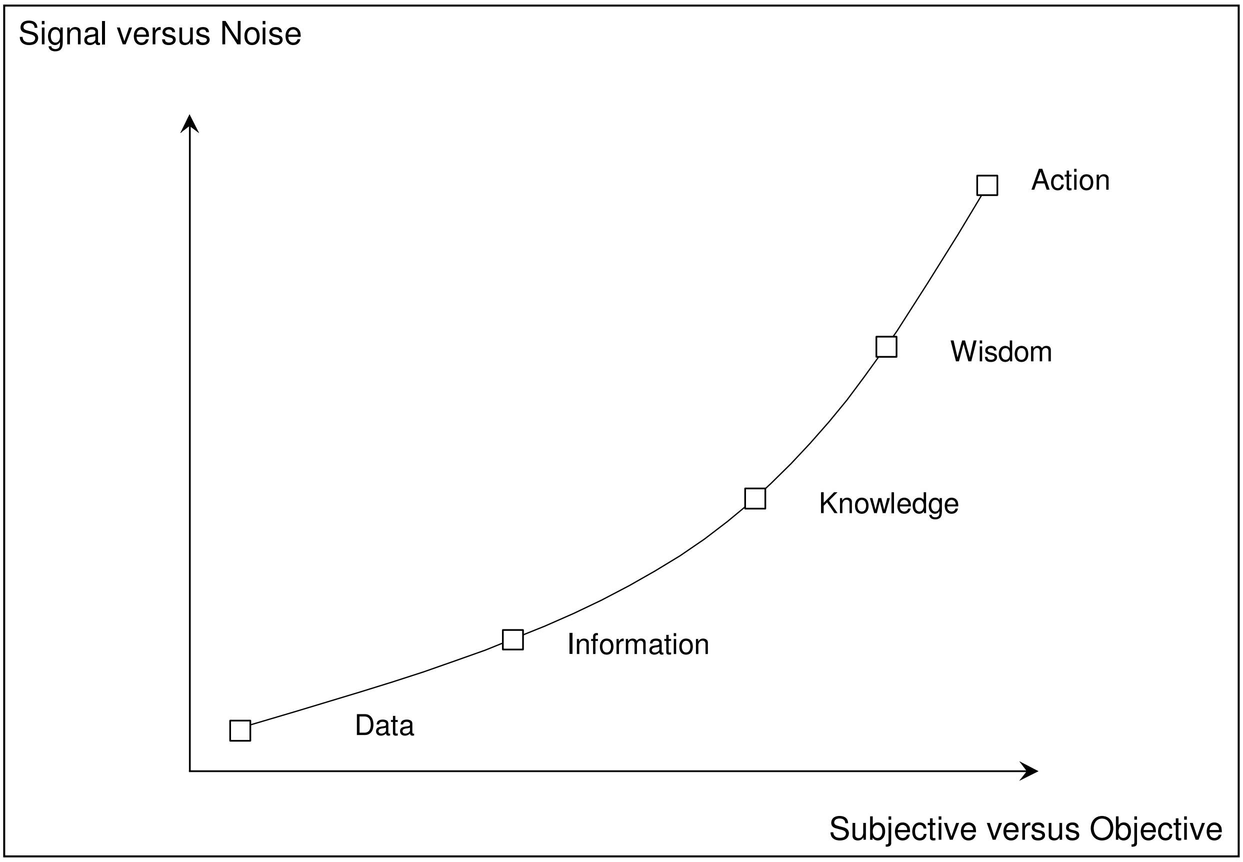

Figure 25 Data, Information, Knowledge, Wisdom and Action (adapted from Colley 2000:126)

The experience with neural networks can also be used in other cases. Thus, knowledge about the method of analysis may be a second major output of further research. An analysis with neural networks could also be used to analyze questions of civil war, state failure or others.

In fact data on the environment, the economy, the social and the political system of the past and the present is used to test and to validate the analytical approach before data on future projections, simulations results and trends can be used for a forecast of the likelihood of environmental conflict.

Table 16 Use of past and present data for a forecast of the likelihood of environmental conflict

	Past and Present	Future
Input data	• Remote sensing data • Statistical information • Field data	• Results from numerical climate models • Economic simulations and trends • Other forecasts
Analysis with a neural network	• Training and validation of neural network • Applicability test	• Forecast of the likelihood of environmental conflict

However, several key questions remain that must be answered in further research.

6.3.1 Precise classification

In this work a very simple classification was used, i.e. “conflict” or “no conflict”. Wolf et al. (2003a) used a more precise scale which covers cooperation and conflict in varying degrees. It would also be possible to classify environmental conflict according to it’s intensity in a logarithmic scale (10, 100, 1000, 10000 deaths etc.). This would allow a better evaluation than a simple differentiation between low and high probability for environmental conflict.

6.3.2 Historical genesis of environmental conflict

Environmental conflict does not manifest itself suddenly because of the emergence of several key factors that lead to conflict. The case studies from Bächler and Spillmann (1996a), Bächler and Spillmann (1996b), and Bächler *et al.* (1996) show how environmental conflict develops. There is always a historical genesis. This historical genesis is not considered in this feasibility study and the question remains if a historical genesis can be analyzed with neural networks. Figure 26 shows how this could work. The historical genesis is reflected in a time series (changing precipitation pattern, changes in productivity / per hectare yields, population growth, economic development, etc.).

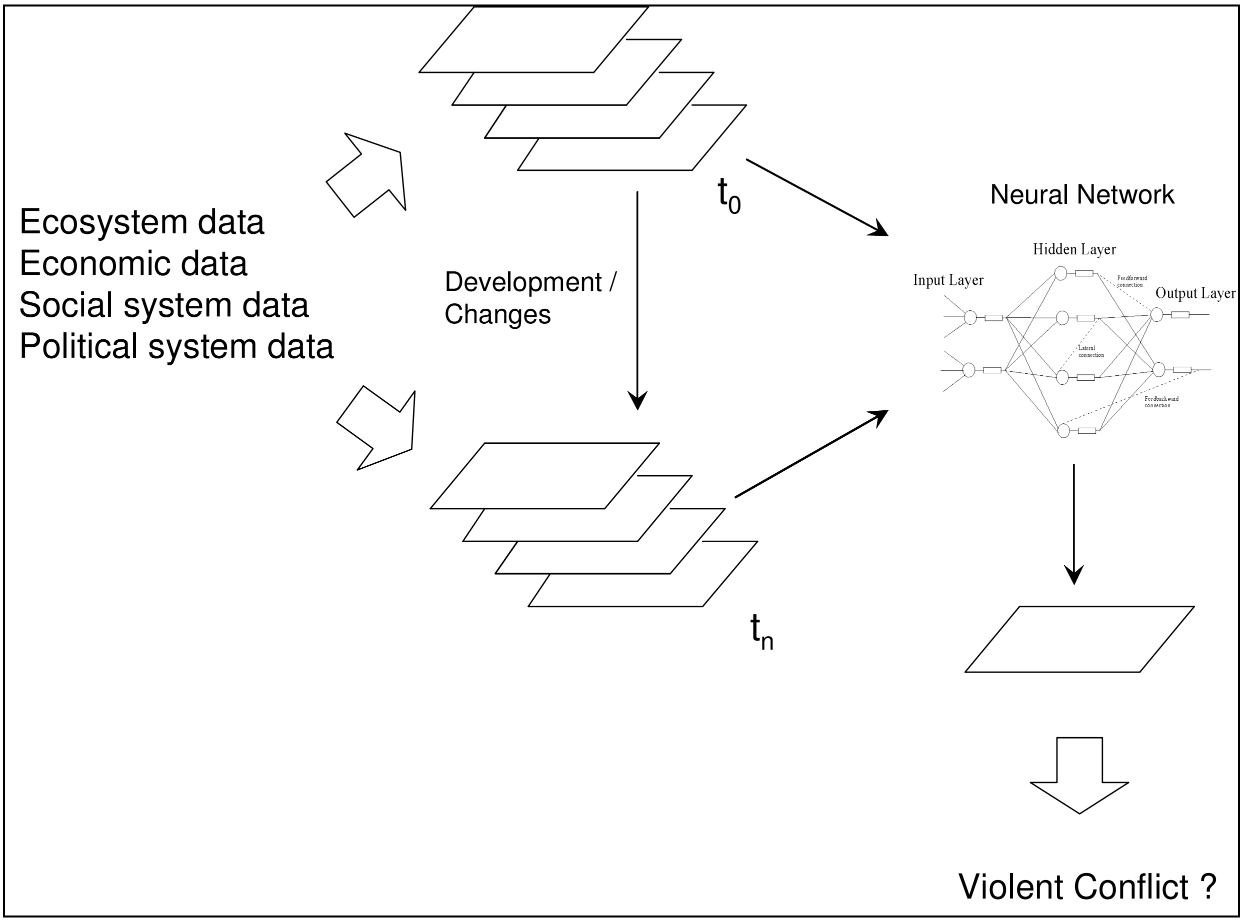

Figure 26 Analysis of a time series with a neural network

It must be noted that other analytical approaches, e.g. statistical approaches, have to deal with the same problem. Gantzel (1981) points out that statistical analysis is limited with respect to the dynamics, to structural changes in the international system, to the states and types of war, etc.

6.3.3 Can historical cases be used for a forecast

A question of principle is if historical case studies of environmental conflict can generally be used for a projection to the future. If we use historical case studies we in fact rule out learning and adaptation effects of society for the future. However, an inherent quality of the socio-economic and political system and its complexity is a certain inertness when it comes to reacting to the phenomena, such as the climatic changes, which will not manifest themselves in the very near future (Baric and Gasparovic 1992). The changes brought about by the greenhouse effect occur slowly, while the socio-political and economic structures are adapted to react only to impending emergencies and dangers. A very complex net of socio-economic structures needs a period of 20 to 50 years to adapt according to present experience (Baric and Gasparovic 1992). Assuming that adaptation and learning with society happens with a time frame of 20 to 50 years, a limited forecast of the likelihood of environmental conflict within an expected error tolerance can be expected.

6.3.4 Indicators for the analysis of environmental conflict

As has been described in chapter 4, the analysis was conducted with simple factors whose values were “Yes” or “No”. For a true prediction of the likelihood of environmental conflict, quantitative indicators for these factors have to be found. Thus, in a future analysis qualitative factors have to be substituted by quantitative indicators. Key indicators have already been listed above and more have been proposed by a range of authors. Schultink (1999) has proposed key indicators which define development potential, environmental constraints, anticipated environmental and economic impacts, public risk tolerance limits, and environmental carrying capacity constraints. According to Schultink (1999) indicators may be grouped together as

- Status indicators
- Need indicators

- Success indicators

Tulbure and Ludwig (2000) suggested the use of the pressure-state-response model of the OECD:

- pressure: Resource consumption, emissions and waste disposal
- state: Quality of the environment, concentration of toxic substances in the air, water and soil
- response Reactions of society, changes in water or energy consumption

In Table 17 some possible indicators have been listed. The list could easily cover more than a hundred entries. Therefore, it is shortened and only covers some variables. As a source of indicators the works of Wolf *et al.* (2003b) or Esty *et al.* (1999) should be mentioned, as well as the World Bank (1997). Even more indicators might be taken from existing peace research. A set of possible analytical categories was e.g. presented by Gantzel (1981). Another valuable source would be Jaggers and Gurr (1995). Their polity III data set contains annual indicators of institutional democracy and regime types in 161 states spanning the years from 1946 to 1994. The democracy and autocracy indicators themselves are constructed based on five different variables: the competitiveness of political participation, the regulation of political participation, the competitiveness of executive recruitment, the openness of executive recruitment and constraints on the power of the Chief Executive.

Table 17 Some qualitative factors for the analysis and their possible quantitative indicators

Area of Effect	**Factor**	**Indicators**	**Reference**
Main Environmental Effects	Population Growth	• Total population • Population density • Population per hectare arable land • Population growth	Schultink 1999 Esty *et al.* 1999

		rate • Ratio of the population in the 15-29-year age bracket relative to that in the 30-54 year age group	
Ecosystem Biosphere	Habitat loss or gain	Land conversion rates: • Deforestation • Wetland conversion • Desertification • Agricultural land conversion • Urbanization • Reserve conversion	Schultink 1999 Esty *et al.* 1999
Economy General	Trade openness	• Value of imports and exports divided by GDP	Esty *et al.* 1999
Social system Income and wellbeing of the population	Population Health	• Child morbidity • Life expectancy • Population nutrition	Schultink 1999 Esty *et al.* 1999
Political system Balance of power and external relations	Differences in military power	• Absolute military spending • Military spending in relation to GDP • Military spending in relation to educational spending	Gantzel 1981 Varshavsky and Varshavsky 1997

6.3.5 Geographic Information Systems

GIS can form the integrating basis for an analysis, i.e. GIS allows a matching of political areas and ecological areas. The analysis in space is particularly important to answer the question WHERE environmental conflict might happen. It is also important because ecological regions (e.g. a watershed) rarely match with political regions (e.g. a state) as Bächler *et al.* (1996) pointed out. A spatial analysis will enhance forecasting. Many factors (degradation, ethnic differences, etc.) develop much earlier than the actual conflict occurs. This offers the possibility that conflicts can be avoided if dangerous developments are recognized at an early non-violent stage of development. Thus, it might be possible to determine WHEN an environmental conflict might occur. It must be noted, however, that human behaviour, motives and interests can hardly be forecast. There always exist a variety of possibilities and options whose likelihood may be estimated but they cannot be forecasted.

6.3.6 Available global data sets of general information

A lot of very useful information is already available as global data sets. These include already highly aggregated information sources such as Bauer *et al.* (2003), Seager (1995), and Kidron and Segal (1992) or first maps of soil degradation, deforestation, over fishing, and expected habitat loss due to global warming (published in National Geographic 09/2002) or official data sources like the UNEP data set “Global Assessment of Human induced soil degradation” (GLASOD) (see Esty *et al.* 1999). And of course the data already assembled by Wolf *et al.* 2003b and Esty *et al.* 1999 could be a source.

6.3.7 Remote Sensing Data

Remote sensing data has the advantage that it is potentially globally available and fairly standardized. Strunz and Güls (1999) and Werner and Kenneweg (1999) have shown that the detection of land use changes with the help of remotely sensed data is possible. This detection of changes is important since changes and the extent of changes are often relevant in the development of environmental conflict. Unchanging circumstances of life seldom lead to conflict, even if life is full of hardship. Ecological models in combination with remote sensing data can be used to obtain more useful information. Heinrich (1999) showed that modelling of land surfaces from digital elevation models and hydrological modelling allowed a calculation of the likelihood of flooding. Meyer *et al.* (1999) developed a model for soil erosion that depends on several more factors like the energy of rain, the soil type, the steepness and the land coverage or the land use.

For the near future, the data assembled under the GMES (Global Monitoring for Environment and Security) project (see www.gmes.info) could be a valuable source.

However, there are also limitations in the use of data from remote sensing. Not all potentially useful information can be easily measured, e.g. pollution from by mines can hardly be detected directly from space born sensors (satellites). Only the effects may be observed (i.e. changes in the vegetation).

6.3.8 Standardization

Clear standards and the integration of different types of data formats will however be needed. Østensen (2001) highlighted the importance of these standardisation aspects. However, today a lot of standards already exist (e.g. ISO 19101 to ISO 19130). The technologies of the SEDRIS project provide the means to represent environmental data (terrain, ocean, air and space), and promote the unambiguous, loss-less and non-proprietary interchange of environmental data (www.sedris.org). The Open GIS Consortium also leads the development of geoprocessing interoperability computing standards (www.opengis.org).

6.3.9 Additional case studies

According to Windfuhr (1998) a huge resource for the identification of environmental conflicts and the generation of cases studies could be the inclusion of data from general conflict databases, like KOSIMO or those provided by AKUF. The approach to use empirical conflict data and case studies is also supported by Rohloff (1998).

Another source is the data assembled under the Correlates of War project (see e.g. Gantzel 1981).

Finally, additional case studies for environmental conflict or refinements on already known cases might be taken from Bächler *et al.* 1996a, BMU 2002, Carius *et al.* 2003a, Carius *et al.* 2003b, Diehl and Gleditsch 2001, Falkenmark 1986, Gleditsch *et al.* 1997, Haftendorn 2000, Halle *et al.* 2002, Homer-Dixon 1994, Markakis 1998, Markakis 1995, Matthew *et al.* 2002, Molvaer 1991, Rogers 1995, Smil 1995, Ohlsson 1999, Val and Homer-Dixon 1998 and WBGU 1998.

6.3.10 Models

Data on future developments is available from simulations with all their limitations. Figure 27 shows a simulation of the atmospheric water cycle which was run with a doubled CO_2 concentration. It shows that differences e.g. in rainfall are to be expected in many parts of world due to climate change (WBGU 1998:69-73).

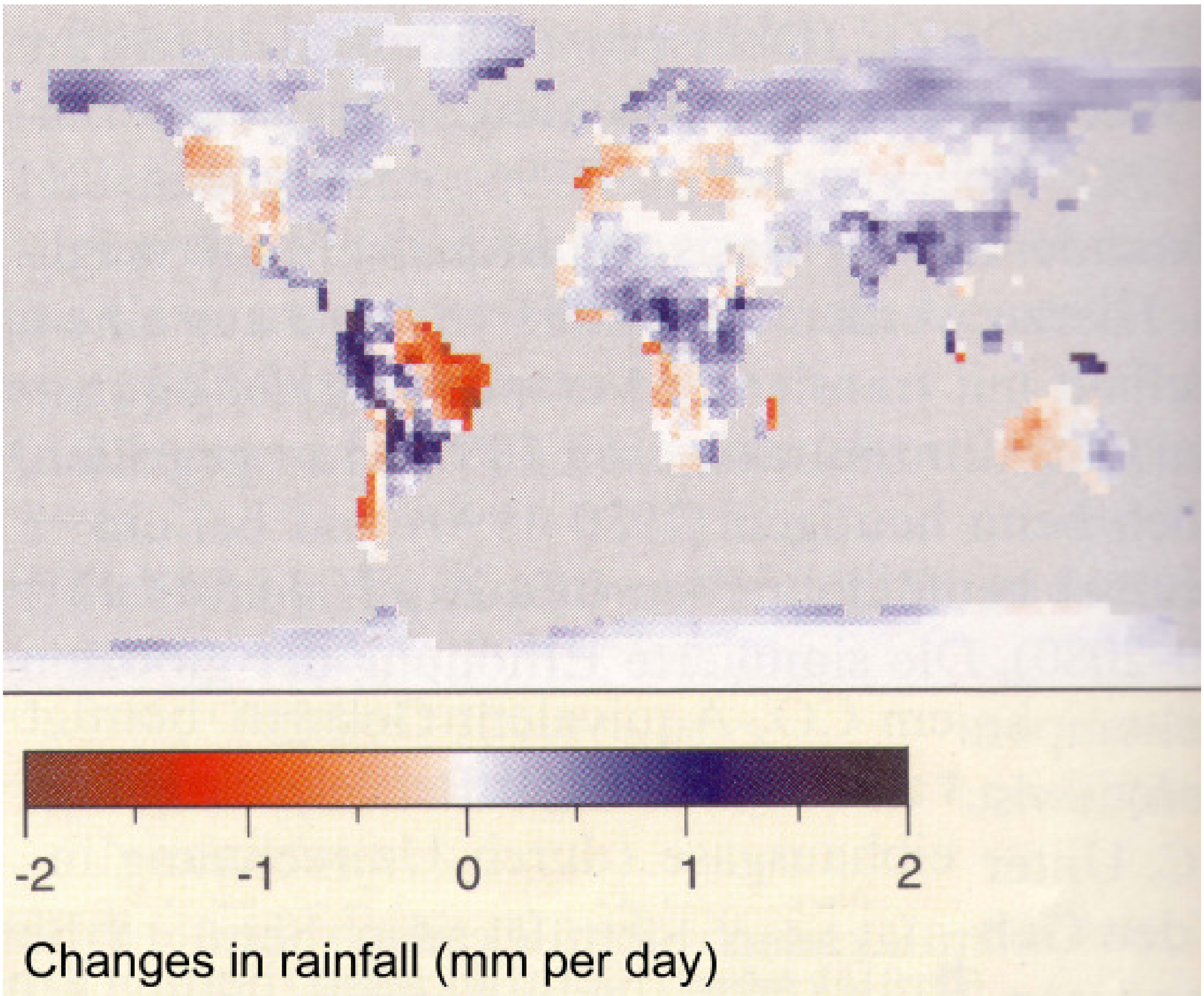

Figure 27 Changes in rainfall in a simulation with a doubled atmospheric CO_2 concentration (adapted from WBGU 1998: 70)

Other models cover other fields. Burroughs (1997: 164-166) mentions the Rosenzweig-Parry model that combined the predictions of three GCMs for the impact of doubling CO_2 levels in the atmosphere by the year 2060. The scenario predicted average changes of global temperature between 4.0-5.2°C. Thus, they are at the top end of IPCC projections. This input was used to predict changes in crop yields. Then economic consequences were simulated in a world food trade model. Not surprisingly there appears to be a large disparity in agricultural vulnerability. At low latitudes yields decline while they rise at middle and high latitudes. This highlights the potential advantages and disadvantages of climatic change. The predicted changes in global grain production were relatively modest of between -10 to -20 % percent when no adaptation in agricultural practice was made, between 0 and -5 % when minor adaptations occur, and +1 and -2.5 % if major adaptations and infrastructure investments are made. This might not seem too worrying but there possibly is an unequal distribution of costs and benefits. The capacity for adaptations and investment possibilities are much higher in developed countries. Another useful model is “WaterGAP” that models the use and water availability in 1162 watersheds and 150 countries, or the FAO Crop suitability model (Alcamo and Endejan 1999).

6.3.11 Design of the neural network

As has been mentioned in chapter 4 the design of the neural network has been kept simple. Advanced neural network designs have not been tested yet. There are for example the possibilities of time-delayed connections (Kung 1993: 30, 203ff) or delay elements that may be incorporated into connections to yield temporal dynamic models, which are more suitable for temporal pattern recognitions. Dynamic time warping techniques could enhance the performance of the neural network further (Kung 1993: 134).

6.3.12 Success metrics or significance of results

The performance of the chosen analytical tool can be measured in different ways. The recognition rate is only one possibility. The minimum sensible recognition rate is 50 %. It is in fact the same as to throw dice. However, other metrics to measure the performance could be used. If not 47.5 % of the used case studies are conflict cases but closer to reality a figure of only 2 - 28 % conflictive events is to be expected (see chapter 6.1.2), the Receiver Operator Characteristic (ROC) could be used as a performance measure. It is used in areas like experimental psychology and radar detection (see Duda *et al.* 2001: 48-50). If the likelihood of environmental conflict is to be determined as a “yes” or “no” the important variable that determines the quality of the analytical tool may not be the recognition rate although it is the easiest metric. The probability of “hits” (correct classifications of environmental conflict) is more important than “false alarms” (incorrect classification as environmental conflict). The “hit” rate obviously has to be optimised. And the rate of “false alarms” has to stay in tolerable limits. This can be evaluated with the Receiver Operator Characteristic.

6.3.13 Other mathematical algorithms

Other mathematical classification algorithm could also be applied to the problem. As one example, decision tree algorithms (see Witten and Frank 2000) have been tested with the same data set that was used for the analysis with the neural network. The J48 algorithm of the Waikato Environment for Knowledge Analysis (WEKA, see www.cs.waikato.ac.nz/ml/weka) software (Version 3.4) was used to classify the data set into conflict and no conflict cases with a recognition rate of 75 %.

7 Summary

Neural networks were successfully tested as an analytical tool to assess the likelihood of environmental conflict. The benefit of the approach with a neural network is that the explicit form of the relationship among the variables, the ecosystem, the economy, the social and the political system does not need to be known. The recognition rate of test cases with 82 % was reasonably high considering the limitations on the available data. Compared with the results from other analytical approaches in political sciences (mainly statistical methods), who yield successful likelihoods for similar questions within a range from 55 to 88 %, the use of neural networks looks promising. It has been pointed out that the quantity of the input data can be increased by using a higher number of suitable case studies. The quality of the input data can be raised by using more variables and by using quantitative indicators which are widely available. In addition, the design of the neural network can be improved in comparison with the simple design that was used in this study.

Therefore, a prediction of the likelihood of environmental conflict in the future, in particular under the conditions of a climate change and population growth, with neural networks seems possible. Figure 28 gives a graphical explanation of the idea. Data from Earth observing satellites, socioeconomic databases and field studies could be combined with the help of GIS (Geographic Information System) software. A neural network could learn from known case studies. Then the neural network could use the results from numerical climate impact models and other (e.g. economic) forecasts to calculate the likelihood for environmental conflict in the future.

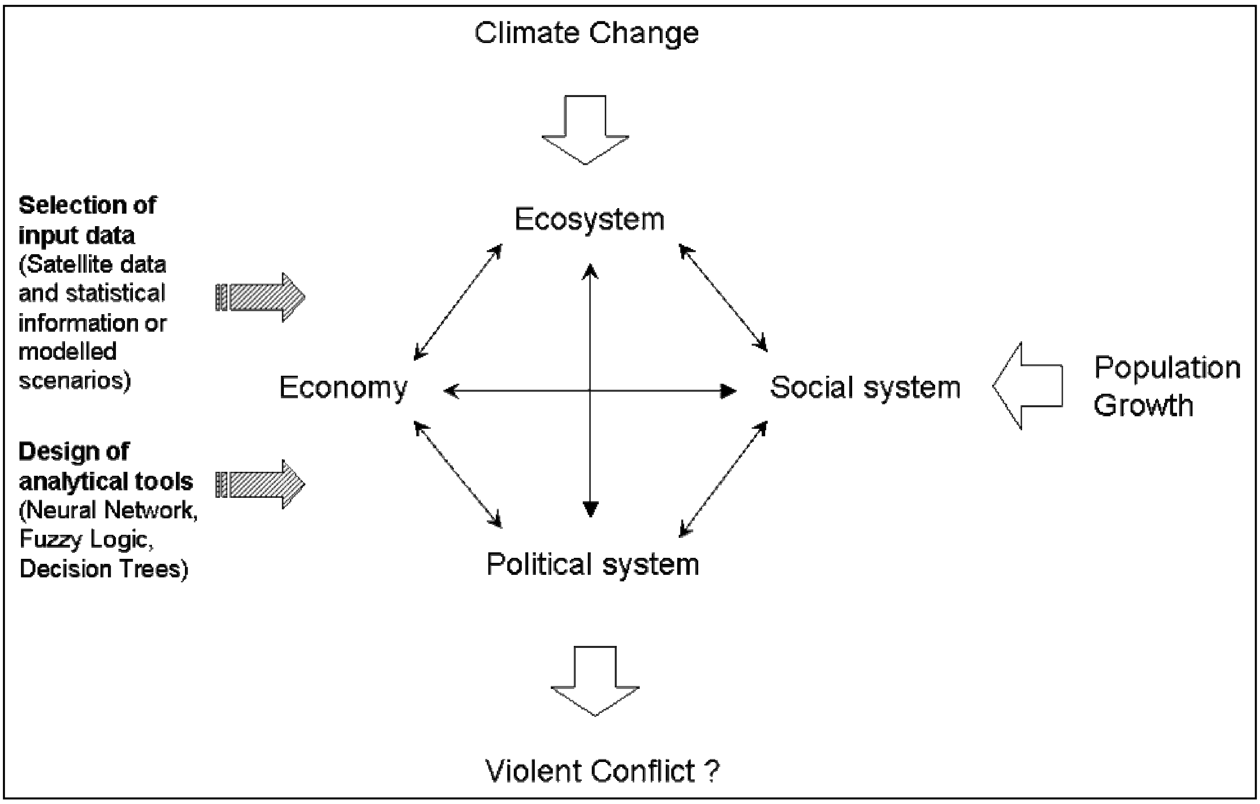

Figure 28 Prediction of the likelihood of violent environmental conflict

8 References

Abe, Shigeo, *Pattern Classification – Neuro-fuzzy Methods and their comparison*, Springer, London, 2001

Acreman, Michael, *Principles of water management for people and the environment*, in: Sherbinin and Dompka 1998, pp. 25-48

Alcamo, Joseph, and Marcel Endejan, *The security diagram: An approach to quantifying global environmental security*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Bächler, Günther, and Kurt R. Spillmann, *Kriegsursache Umweltzerstörung / Environmental Degradation as a cause of war, Band / Volume II, Regional- und Länderstudien von Projektmitarbeitern / Regional and Country Studies of Research Fellows,* (ENCOP Band II), Rüeger, Chur/Zürich, 1996a

Bächler, Günther, and Kurt R. Spillmann, *Kriegsursache Umweltzerstörung / Environmental Degradation as a cause of war, Band / Volume III, Länderstudien von externen Experten / Country Studies of External Experts,* (ENCOP Band III), Rüeger, Chur/Zürich, 1996b

Bächler, Günther, *Rwanda: The roots of tragedy, Battle for elimination on an ethno-political and ecological basis*, in: Bächler and Spillmann 1996a, pp. 461-501

Bächler, Günther, *The anthropogenic transformation of the environment: A source of war? Historical Background, Typology and Conclusions*, in: Spillmann and Bächler 1995, pp. 11-27

Bächler, Günther, *Umweltzerstörung im Süden als Ursache bewaffneter Konflikte*, in: Carius and Lietzmann 1998, pp.111-135

Bächler, Günther, Volker Böge, Stefan Klötzli, Stephan Libiszwewski, and Kurt R. Spillmann, *Kriegsursache Umweltzerstörung, Ökologische Konflike in der dritten Welt und Wege ihrer friedlichen Bearbeitung*, Band I (ENCOP Band I), Rüeger, Chur/Zürich, 1996

Baric A. and F. Gasparovic, *Implications of Climatic Change on the Socio-Economic Activities in the Mediterranean Coastal Zones*, in: Jeftic *et al.* 1992, pp. 129-174

Barnett, Jon, *Security and Climate Change*, Tyndall Centre Working Paper No. 7, Norwich, Tyndall Centre for Climate Change Research, 2001

Bauer, Barbara, Niels Kadritze, and Marie Luise Knott (editors), *Le Monde Diplomatique - Atlas der Globalisierung*, taz-Verlag, Berlin, 2003

Beck, N., and R. Tucker, *Conflict in Space and Time: Time-Series-Cross-Section Analysis with a Binary Dependent Variable*, Paper presented at the American Political Science Association, San Francisco, 28 August - 1 September 1996

Biermann, Frank, *Syndrome des globalen Wandels als Typologie für die Friedens- und Konfliktforschung*, in: Carius and Lietzmann 1998, pp. 137-153

Blaschke T. (editor), *Umweltmonitoring und Umweltmodellierung - GIS und Fernerkundung als Werkzeug*, H. Wichmann, Heidelberg, 1999

Böge, Volker, *Bergbau-Umweltzerstörung-Krieg im Südpazifik*, in: Bächler and Spillmann 1996a, pp. 503-720

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), *Umweltpolitik – Klimapolitik in Deutschland – Erster Bericht der Bundesrepublik Deutschland nach dem Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen*, 1994

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) / Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, *Climate change and conflict, - Can climate change impacts increase conflict potentials - What is the relevance of this issue for the international process on climate change*, 2002

Burroughs, William James, *Does the weather really matter?*, Cambridge University Press, Cambridge, 1997

Carius, Alexander and Kerstin Imbusch, *Umwelt und Sicherheit in der internationalen Politik - Eine Einführung*, in: Carius and Lietzmann 1998, pp. 7-31

Carius, Alexander, Kurt M. Lietzmann (editors), *Umwelt und Sicherheit - Herausforderungen für die internationale Politik*, Springer, Berlin, Heidelberg, 1998

Carius, Alexander, Moira Feil, and Dennis Tänzler, A*ddressing Environmental Risks in Central Asia – Risks, Policies, Capacities – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan*, Environmental Governance Series, OSCE, UNDP, UNEP, 2003b

Carius, Alexander, Moira Feil, Jason Switzer, Philippe Rekacewicz, Ieva Rucevska, Petter Sevaldsen, Otto Simonett, Stephane Kluser, Dominique Del Pietro, and Ron Witt, *Environment and Security - Transforming risks into cooperation - The case of Central Asia and South Eastern Europe*, OSCE, UNDP, UNEP, 2003a

Chattoe, Edmund, Just How (Un)realistic are Evolutionary Algorithms as Representations of Social Processes?, *Journal of Artificial Societies and Social Simulation* 1(3), www.soc.surrey.ac.uk/JASSS/1/3/2.html, 1998 (Online journal, download from 2004-03-20)

Claus, Olaf, *"Batawana say to dredge a river is to destroy it." The case of the southern Okavango integrated water development project*, in: Bächler and Spillmann 1996b, pp. 269-284

Colley, Michael, *The Human Machine Symbiosis*, VDI-Verlag, Paper presented at the World Engineer's Convention, 19 - 21 June 2000

Cooley, John K., The war over water, *Foreign Policy 54*, pp. 3-26, 1984

Czempiel, E.-O., *Internationale Politik: Ein Konfliktmodell*, UTB Ferdinand Schöning, Paderborn, 1981

Dabelko, Geoffrey D., and P.J. Simmons, Environment and Security: Core Ideas and US Government Initiatives, *SAIS Review*, pp. 127-145, Winter-Spring 1997

Demuth, Siegfried, and Kerstin Stahl, Climate variability and drought, *Wasser & Boden 54(10)*, pp. 36-40, 2002

Department of the Environment, Transport and the Regions (DETR), *Potential UK adaptation strategies for climate change*, 2000

Diehl, Paul F., Environmental conflict: An introduction, *Journal of Peace Research* 35(3),1998

Diehl, Paul Francis, and Nils Petter Gleditsch (editors), *Environmental conflict*, Westview Press, Boulder, 2001

Duda, Richard O., Peter E. Hart, David G Stork, *Pattern Classification*, 2nd edition, John Wiley & Sons, New York, 2001

Dyer, Hugh C., *Theoretical aspects of environmental security*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Esty, Daniel C., Jack A Goldstone, Ted Robert Gurr, Barbara Harff, Marc Levy, Geoffrey D. Dabelko, Pamela T. Surko, and Alan N Unger, State Failure Task Force Report: Phase II Findings, *Environmental Change and Security Project (ECSP) Report 5*, Woodrow Wilson Center, Summer, 1999

European Commission, *European Security – The external economic dimension, Environmental security: Just another green fashion?*, 1999

Faath, Sigrid, *Umweltprobleme und Bevölkerungsdruck: Eine Ursache Politischer Konflikte in Algerien*, in Bächler and Spillmann 1996b, pp. 203-268

Falkenmark, M., The massive water scarcity now threatening Africa—why isn't it being addressed? *Ambio 18 (2)*, pp. 112–118, 1989

Falkenmark, Malin, *Fresh waters as a factor in strategic policy and action*, in: Westing 1986, pp. 85-113

Fariz, Ghaith H., and Alia Hatough-Bouran, *Case Study: Jordan – Population Dynamics in Arid Regions: The Experience of the Azraq Oasis Conservation Project*, in: Sherbinin and Dompka 1998, pp. 105-135

Fausett, Laurene, *Fundamentals of neural networks: Architectures, algorithms, and applications*, Prentice Hall, Englewood Cliffs, 1994

Gantzel, Klaus-Jürgen, Another Approach to a theory on the Causes of War, *Journal of Peace Research 18(1)*, pp. 39-56, 1981

Gimblett, H. Randy (editor), *Integrating Geographic Information Systems and Agent-based Modeling Techniques for Simulating Social and Ecological processes*, Oxford University Press, New York, 2002

Gimblett, H. Randy, *Integrating geographic Information Systems and Agent-based Technologies for Modeling and Simulating Social and Ecological Phenomena*, in: Gimblett 2002, pp. 1-20

Gleditsch, Nils Petter, Armed conflict and the environment: A critique of the literature, *Journal of Peace Research* 35(3),1998

Gleditsch, Nils Petter, *Environmental Conflict: Symptons and Causes*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999b

Gleditsch, Nils Petter, Lothar Brock, Thomas Homer-Dixon, Renat Perelet, Evan Vlachos (editors), *Conflict and the Environment*, Proceedings of the NATO

Advanced Research Workshop on Conflict and the Environment Bolkesjø (Norway) 11.-16. June 1996, NATO Advanced Sciences Institutes Series 2: Environment - Vol. 33, Kluwer Academic Publishers, Dordrecht, 1997

Gleditsch, Nils Petter, *Resource and Environmental Conflict: The state of the art*, paper presented at the NATO Advanced Research Workshop (ARW) “Responding to Environmental Conflicts: Implications for Theory and Practice”, Budapest, Hungary, 21-23 January 1999a

Gleick, Peter H., *Fresh Water: A source of conflict or cooperation? A survey of present developments*, in: Bächler and Spillmann 1996b, pp. 1-25

Gleick, Peter H., The implications of global climatic changes for international security, *Climatic Change 15*, pp. 309-325, 1989

Goldstone, Jack A., Ted Robert Gurr, Barbara Harff, Marc A. Levy, Monty G. Marshall, Robert H. Bates, David L. Epstein, Colin H. Kahl, Pamela T. Surko, John C. Ulfelder Jr., Alan N. Unger, *State Failure Task Force Report: Phase III Findings*, Science Applications International Corporation (SAIC), McLean, 2000

Hafiz, M. Abdul and Nahid Islam, *Environmental Degradation and Intra/Interstate conflicts in Bangladesh*, in: Bächler and Spillmann 1996a, pp. 1-108

Haftendorn, Helga: Water and international conflict, *Third World Quarterly 21(1)*, pp. 51-68, 2000

Halle, Mark, Jason Switzer, and Sebastian Winkler, *Trade, Aid and Security: Elements of a Positive Paradigm - A Working Paper*, IISD, IUCN, CEESP, 2002

Hauff, Volker, *Unsere gemeinsame Zukunft, Der Brundtland-Bericht der Weltkomission für Umwelt und Entwicklung*, Eggenkamp Verlag, Greven, 1987

Heinrich, U., *Angewandte ökologische Modellierung für die Umweltplanung - Entwicklungsstand, Anwendungsprobleme, Perspektiven*, pp. 111-119, in: Blaschke 1999, pp. 111-119

Hoerling, Martin, James W. Hurrell, and Taiyi Xu, Tropical origins for recent North Atlantic climate change, *Science 292(5514)*, pp. 90-92, 2001

Homer-Dixon, T. F., Environmental Scarcities and Violent Conflict, Evidence from Cases, *International Security 19 (1)*, pp. 5-40, 1994

Homer-Dixon, T. F., On the Threshold, Environmental Changes as Causes of Acute Conflict, *International Security 16 (2)*, pp. 76-116, 1991

Ierland van, Ekko C., Marcel G. Klaassen, Tom Nierop, and Herman v.d. Wusten, *Climate Change: Socio-Economic impacts and violent conflict*, Dutch National Research Programme on global air pollution and climate change, LU Wageningen, 1996

Intergovernmental panel on climate change (IPCC), *Climate Change 2001: Impacts, Adaptation, and Vulnerability - Summary for Policymakers*, 2001

Isaac, Jad, *Core issues of the Palestinian-Israeli water dispute*, in: Spillmann and Bächler 1995, pp. 57-74

Jaggers, Keith, and Ted Robert Gurr, Tracking Democracy's Third Wave with the Polity III Data, *Journal of Peace Research 32(4)*, pp. 469-482, 1995

Jeftic L., J. D. Milliman, and G. Sestini (editors), *Climatic Change and the Mediterranean*, Volume 1, Edward Arnold, London, 1992

Johannessen, Ola M., Lennart Bentsson, Martin W. Miles, Svetlana I. Kuzmina, Vladimir A. Semenov, Genrikh V. Alekseev, Andrei P. Nagurnyi, Victor F. Zakharov, Leonid Bobylev, Lasse H. Pettersson, Klaus Hasselmann, and Howard P. Cattle, *Arctic Climate Change – Observed and Modeled Temperature and sea ice variability*, Nansen Environmental and Remote Sensing Center, Technical Report No. 218, Bergen, 2002

Kidron, Micheal, and Ronald Segal, *Der politische Weltatlas*, Dietz, Bonn, 1992

Kliot, Nurit, *Milk and Honey but no water: Scarce water resources in the Israeli-Palestinian Jordanian Realm*, in: Spillmann and Bächler 1995, pp. 43-56

Klötzli, Stefan, *The Water and soil crisis in central Asia- a source for future conflict*, in: Bächler and Spillmann 1996a, pp. 247-335

Kollman, K., J. H. Miller, and S. E. Page, *Computational Political Economy*, Paper presented at the American Political Science Association, San Francisco, 28 August - 1 September, 1996

König, Thomas, *Environmental Issues in Thailand – A case study with special reference to the struggle about Eucalyptus Plantations*, in: Bächler and Spillmann 1996b, pp. 149-174

Kotov, Vladimir, and Elena Nikitina, *Environmental security in Russia: Crisis of protective instruments*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Kung, S. Y., *Digital Neural Networks*, PTR Prentice Hall, Englewood Cliffs, New Jersey, 1993

Libiszewski, Stephan, *Water disputes in the Jordan Basin and their role in the resolution of the Arab-Israeli conflict*, in: Bächler and Spillmann 1996a, pp. 337-460

Libiszewski, Stephan, *What is an Environmental conflict?*, ENCOP Occasional Paper Nr. 1, Swiss Peace Foundation/Swiss Federal Institute of Technology, Zürich/Bern, 1992

Lomborg, Bjørn, *Resource constraints or Abundance*, in: Diehl and Gleditsch 2001, pp. 125-152

Lonergan, Steve, *The* role of environmental degradation in population displacement, *Environmental Change an Security Project (ECSP) Report* 4, Woodrow Wilson Center, Spring, 1998a

Lonergan, Steve, *The role of environmental degradation in population displacement, Global environmental change and human security project*, International Human Dimensions Programme on Global Environmental Change, Research Report 1, 1998b

Lonergan, Steve C. (editor), *Environmental change, adaptation, and security*, Proceedings of the NATO Advanced Research Workshop on Environmental change, adaptation, and security, Budapest (Hungary), 16.-18. October 1997, NATO Advanced Sciences Institutes Series 2: Environment - Vol. 65, Kluwer Academic Publishers, Dordrecht, 1999

Lume, William, *The ecological background to the struggle between the Tuaregs and the central government of Niger*, in: Bächler and Spillmann 1996b, pp. 175-202

Madras, Neal, *Lecture on Monte Carlo Methods*, Fields Institute Monographs, American Mathematical Society, Providence Rhode Island, 2002

Markakis, John, *Environmental Degradation and social conflict in the Horn of Africa*, in: Spillmann and Bächler 1995, pp. 110-115

Markakis, John, *Resource conflict in the horn of Africa*, Sage Publications, London, 1998

Matthew, Richard, Mark Halle, and Jason Switzer, *Conserving the Peace: Resources, Livelihoods and Security*, IISD, IUCN, CEESP, Foreign & Commonwealth Office, 2002

McCormack, Michael D., *A review of automated first break picking and seismic trace editing techniques*, in: Sandham and Legget 2003

McKenzie, Hedger M., Gawith M., Brown I., Conell R., and Downing T.E. (editors), *Climate change: Assessing the impacts – identifying responses. The first three years of the UK Climate Impacts Programme*, DETR, Wetherby, 2000

McNeill, *Something new under the sun – An environmental history of the twentieth-Century World*, Norton & Company, New York, 2000

Meyer, Martin, Ernst-Walter Reiche, and Ilka Dibbern, *Verfahren und Probleme zur Parametrisierung am Beispiel der Bodenerosionsmodellierung*, in: Blaschke 1999, pp. 153-162

Molvaer, Reidulf, K., Environmental Cooperation in the Horn of Africa – A UNEP Perspective, *Bulletin of Peace Proposals 21(2)*, pp. 135-142, 1990

Molvaer, Reidulf, K., Environmentally induced conflicts? A discussion based on studies from the Horn of Africa, *Bulletin of Peace Proposals 22 (2)*, pp. 175-188, 1991

Münchner Rückversicherung / Munich Re, *TOPICSgeo - Jahresrückblick Naturkatastrophen*, München, 2003

National Intelligence Council (NIC), National Intelligence Estimate: The global infectious disease threat and its implications for the United States, *Environmental Change an Security Project (ECSP) Report 6*, Woodrow Wilson Center, Summer, 2000

Nicholson, N., *Rationality and the Analysis of International Conflict*, Cambridge Studies in International Relations Nr. 19, Cambridge University Press, Cambridge, 1992

Oberthür, Sebastian, *Preventing environmentally induced conflicts through international environmental policy*, paper presented at the NATO Advanced Research Workshop (ARW) “Responding to Environmental Conflicts: Implications for Theory and Practice”, Budapest, Hungary, 21-23 January 1999

Ohlsson, Leif, *Environment, scarcity and conflict – A study of Malthusian concerns*, Göteborg University, Göteborg, 1999

Okoh, Peter B., *Environmental Degradation, Conflicts and peaceful resolution in Nigeria and between Nigeria and Neighboring States*, in: Bächler and Spillmann 1996a, pp. 181-245

Oren, Ram, David S. Ellsworth, Kurt H. Johnson, Nathan Phillips, Brent E. Ewers, Chris Maier, Karina V.R. Schäfer, Heather McCarthy, George Hendrey, Steven G. McNulty, and Gabriel G. Katul, Soil fertility limits carbon sequestration by forest ecosystems in a CO_2-enriched atmosphere, *Nature 411(6836)*, pp. 469-472, 2001

Organisation for Economic Co-operation and Development (OECD), *The DAC Guidelines - Helping Prevent Violent Conflict - International Development*, 2001

Østensen, Olaf, The expanding agenda of Geographic information standards, *ISO Bulletin 32(7)*, pp. 16-21, 2001

Pesonen, Mauno, Arto Kettunen, and Petri Räsänen, *Non-industrial private forest landowners' choices of timber management strategies: Genetic algorithm in predicting potential cut*, Acta Forestalica Fennnica 250, The Finnish Society of Forest Science, Helsinki, 1995

Pinter, Nicholas, Nancy S. Phillipe, and Russell Thomas, *Side-Stepping Environmental Conficts: The role of natural-hazards assessment, planning and Mitigation*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Piotrowski, Ralph, *Mit Sicherheit in den Umweltkrieg – Wie gut erfassen Theorien internationaler Beziehungen das Phänomen umweltverursachter Gewaltkonflikte*, Diplomarbeit, Universität Konstanz, 1997

Radkau, Joachim, *Natur und Macht – Eine Weltgeschichte der Umwelt*, C.H. Beck, München, 2002

Reid, Keith, and John P. Croxall, Environmental response of upper trophic-level predators reveals a system change in an Antarctic marine ecosystem, *Proceedings of the Royal Society of London – Biological Sciences 268(1465)*, pp. 377-384, 2001

Rogers, Katarina, *Environmental conflict and cooperation between Mexico and the United States*, in: Bächler and Spillmann 1996b, pp. 27-64

Rogers, Katrina S., *River Disputes as source of environmental cooperation – Environmental cooperation and integration theory*, in: Spillmann and Bächler, 1995, pp. 116-137

Rohloff, Christoph, *Konflikforschung und Umweltkonflikte: Methodische Probleme*, in: Carius and Lietzmann 1998, pp. 155-175

Sandham, William, and Miles Legget (editors), *Geophysical applications of artificial neural networks and fuzzy logic*, Kluwer Academic Puplishers, Dordrecht, Boston, London, 2003

Scheffran, Jürgen, *Umweltkonflikte und nachhaltige Entwicklung – ein Konfliktmodell und seine Anwendung in der Klima- und Energiepolitik*, in: Carius and Lietzmann 1998, pp. 209-232

Schönenberg, Regine, *Environmental conflicts in the Amazon region of Brazil*, in: Bächler and Spillmann 1996b, pp. 315-357

Schrodt, P. A., and D. J. Gerner, *Using Cluster Analysis to Derive Early Warning Indicators for Political Change in the Middle East 1979-1996*, Paper presented at the American Political Science Association, San Francisco, 28 August - 1 September, 1996

Schultink, G., *Comparative environmental policy and risk assessment: Implications for risk communication and international conflict resolution*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Schwark, Rainer, *Environment and Development in Chile: Future social conflict potential of the dams project at the bio-bio river – A case study*, in: Bächler and Spillmann 1996b, pp. 359-407

Schwartz, Peter, and Doug Randall, *An Abrupt Climate Change Scenario and Its Implications for United States National Security*, US Department of Defense (DoD), 2003

Seager, Joni, *Der Öko-Atlas*, 1st edition of new version, Dietz, Bonn, 1995

Sherbinin, Alex de, and Victoria Dompka (editors), *Water and Population Dynamics: Case Studies and Policy Implications,* American Association for the Advancement of Science (AAAS), Washington, 1998

Sherfedinov L.Z., *Central Asia: Irrigation-Power Engineering "Conflict"*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Smil, Vaclav, *China's Environmental Refugees: Causes, Dimensions and Risks of an emerging problem*, in: Bächler and Spillmann 1996b, pp. 127-148

Smil, Vaclav, *China's Environmental Refugees: Causes, Dimensions, and Risk of an emerging Problem*, in: Spillmann and Bächler 1995, pp. 75-91

Soromenho-Marques, Viriato, *Culture, Environment and the challenge of peace*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Soros, Marvin S., *The turbot war: Resolution of an international fishery dispute*, in: Gleditsch *et al.* 1997, pp. 235-252

Spillmann Kurt R., and Günther Bächler (editors), *Environmental Crisis: Regional Conflicts and Ways of Cooperation*, ENCOP Occasional Paper No. 14, Zürich/Bern: Swiss Peace Foundation/Swiss Federal Institute of Technology, 1995

Sprinz, Detlef, F., *Die Modellierung umweltbedingter Konflikte*, in: Carius and Lietzmann 1998, pp. 195-208

Strunz, G., and I. Güls, *Einsatz von Fernerkundungsmethoden für das Monitoring im Naturschutz*, in: Blaschke 1999, pp. 69-81

Stuttgart Neural Network Simulator (SNNS), *User Manual*, Version 4.1, Stuttgart, 1995

Suhrke, Astri, *Environmental degradation, migration, and the potential for violent conflict*, in: Gleditsch *et al.* 1997, pp. 255-272

Sukosd, Miklos, *The sloval-hungarian conflict over the Gabcikovo-Nagymaros dam system on the Danube*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Suliman, Mohamed, *Civil War in Sudan – The Impact of ecological degradation*, in: Bächler and Spillmann 1996a, pp. 109-144

Suliman, Mohamed, *War in Darfur or the desert versus the oasis syndrome*, in: Bächler and Spillmann 1996a, pp. 145-180

Switzer, Jason, Saule Ospanova, and Alexander Carius, *Environment and Security: A Framework for Cooperation in Europe*, Draft Background Paper, ENVSEC Initiative, OSCE, UNDP, UNEP, 2002

Thomas, Caroline, *Water: A focus for cooperation or contention in a conflict prone region? The example of the lower Mekong Basin*, in: Bächler and Spillmann 1996b, pp. 65-126

Tir, Jaroslav, and Paul F. Diehl, Demographic pressure and interstate conflict: Linking population growth and density to militarized disputes and wars, 1930-1989, *Journal of Peace Research* 35(3),1998

Toset, Hans Petter Wollebæk, Nils Petter Gleditsch, and Håvard Hegre, Shared river and interstate conflict, *Political Geography 19*, pp. 971-996, 2000

Trombetta, Maria Julia, *A global environmental security regime: The changes in international environmental politics from Stockholm to Kyoto*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

Tulbure, Ildiko, and Bjørn Ludwig, Umweltindikatoren – Schlüssel zu Sustainable Development, *Umwelt 30 (4/5)*, April/Mai 2000

United Nations (UN), *World Population Prospects - The 2002 Revision – Highlights*, United Nations Population Division, 2002

United Nations Development Programme (UNDP), *Human Development Report 2002 - Deepening democracy in a fragmented world*, 2002

Urban, Dieter, *Binäre Logit-Analyse: ein statistisches Verfahren zur Bestimmung der Abhängigkeitsstruktur qualitativer Variablen*, Duisburger Beiträge zur soziologischen Forschung, No. 3, Universität Duisburg, 1989

Val, Percival, and Thomas Homer-Dixon, Environmental scarcity and violent conflict: The case of South Africa, *Journal of Peace Research* 35(3),1998

VanDeveer, Stacy D., and Geoffrey D. Dabelko, *Debating regional security around the Baltic: The Environmental Dimension*, paper presented at the NATO Advanced Research Workshop (ARW) "Responding to Environmental Conflicts: Implications for Theory and Practice", Budapest, Hungary, 21-23 January 1999

VanDeveer, Stacy D., Environment and Security Policy, *Foreign Policy in Focus 4(2)*, January 1999

Varshavsky, Alexander E., and Leonid E. Varshavsky, *Conflicts and Environmental Change: Models and Methods*, in: Gleditsch *et al.* 1997, pp. 109-125

Vas. Peter, *Artificial-Intelligence-Based Electrical Machines and Drives – Application of Fuzzy, Neural Fuzzy-Neural, and genetic-algorithm-based techniques*, Monographs on Electrical and Electronic Engineering, Oxford University Press, New York, 1999

Walther, Gian-Reto, Eric Post, Peter Convey, Anette Menzel, Camille Parmesan, Trevor J.C. Beebee, Jean-Marc Fromentin, Ove Hoegh-Guldberg, and Franz Bairlein, Ecological Responses to recent climate change, *Nature 416(6879)*, pp. 389-395, 2002

Wegemund, Regina, *Ethnic and transborder conflicts in the senegambian region caused by environmental degradation*, in: Bächler and Spillmann 1996b, pp. 315-358

Wenche, Hauge, and Tanja Ellingsen, The causal pathway to conflict: Beyond Environmental scarcity, *Journal of Peace Research* 35(3),1998

Werner, Claudia and Hartmut Kenneweg, *Aktualisierung und Ergänzung der biotoptypen- und Nutzungsartenkartierung in Sachsen-Anhat mit IRS-1C-Satellitendaten*, in: Blaschke 1999, pp. 99-108

Westing, Arthur (editor), *Global Resources and International Conflict - Environmental Factors in Strategic Policy and Action*, Oxford University Press, Oxford, 1986

Wigley, T.M.L., M.J. Ingram, and G. Farmer, *Climate and History - Studies in past climates and their impact on Man*, Cambridge University Press, Cambridge, 1981

Windfuhr, Michael, *Die Rolle der Umweltpolitik in der Friedens- und Konfliktforschung*, in: Carius and Lietzmann 1998, pp. 57-91

Winkler, Gerhard, *Image Analysis, Random Fields, and Markov Chain Monte Carlo Methods – A mathematical introduction, Applications of mathematics – Stochastic modelling and applied propability*, 2nd edition, Springer, Berlin, Heidelberg, New York, 2003

Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU), *Welt im Wandel – Strategien zur Bewältigung globaler Umweltrisiken, Jahresgutachten 1998* , Springer-Verlag, Berlin, 1999

Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU), *Welt im Wandel – Wege zu einem nachhaltigen Umgang mit Süßwasser, Jahresgutachten 1997* , Springer-Verlag, Berlin, 1998

Witten, Ian H., and Eibe Frank, *Data Mining: Practical machine learning tools with Java implementations*, Morgan Kaufmann, San Francisco, 2000

Wöhlke, Manfred, *Umwelt und Sicherheit: Die demographische Dimension*, in: Carius and Lietzmann 1998, pp. 93-107

Wolf, Aaron T., Kerstin Stahl, and Marcia F. Macomber, Conflict and cooperation within international river basins: The importance of institutional capacity. *Water Resources Update 125*, Universities Council on Water Resources, 2003a

Wolf, Aaron T., Shira B. Yoffe, and Mark Giordano, International waters: identifying basins at risk, *Water Policy 5*, pp. 29-60, 2003b

World Bank, *Expanding the measure of Wealth: Indicators of environmentally sustainable development*, Environmentally sustainable development studies and monograph series No. 17, 1997

World Wildlife Fund (WWF), *Climate Change & Global Glacier Decline*, Berlin, 2003

Zaba, Basia, and Ndalahwa Madulu, *A drop to drink ? Population and water ressources: Illustrations from Northern Tanzania*, in: Sherbinin and Dompka 1998, pp. 49-86

Zeng, L., *Prediction and Classification with Neural Network Models*, Paper presented at the American Political Science Association, San Francisco, 28 August - 1 September, 1996

Zhang, Lin, and Mary Poulton, *Neural Network inversion of EMD39 induction log data*, in: Sandham and Legget 2003

9 Some useful internet links

www.ihdp.uni-bonn.de

www.gechs.org

www.transboundarywaters.orst.edu

www.wilsoncenter.org/ecsp

www.cidcm.umd.edu/inscr/stfail

www.envirosecurity.net

www.globalgovernance.de