COMBINING GEOMORPHIC AND SOCIAL APPROACHES FOR IMPROVED FLOOD RISK MANAGEMENT

Data-Rich versus Data-Scarce Areas:

the Cases of the Tagliamento (Italy) and Limpopo River Basins (Southern Africa)

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(met een samenvatting in het Nederlands)

THESIS

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by

MATHIAS SPALIVIERO

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PROEFSCHRIFT

Proefschrift aangeboden tot het behalen van de graad van
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door

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Dedication

To Maisha and Leandro, thanking them for their patience with me, and wishing them a fantastic existence, with all my heart…

Dad will always be there for you.

I love you.

Preface

The long road from the Tagliamento River, Italy, to the Limpopo River, southern Africa

This PhD thesis is the result of 15 years of research and work on rivers and flood risk reduction. Its foundations were laid when I started working on the definition of fluvial corridors of the Tagliamento River, northern Italy, in September 1997. The latter research served to conclude a 5-years course on Environmental Sciences with specialisation in Land and Regional Planning at the Ca' Foscari University of Venice, Italy, in April 1999. From that experience I started developing a growing interest for flood risk management from all its angles, combining different disciplines and fields of knowledge from both human and natural sciences. I was trying to introduce innovative analysis by reinterpreting existing historic data in literature into cartographic outputs to obtain a better understanding of the river's evolution, and consequently infer on the intrinsic territorial vulnerability to flooding.

From September 1999 to August 2000 I followed a master specialisation course in Water Resources Management using Geographic Information System (GIS) and remote sensing techniques at the International Institute of Geo-Information Science and Earth Observation (ITC) in Enschede, the Netherlands. The latter formally became a Faculty of the University of Twente in 2010. As part of my final assignment I coupled aerial photo-interpretation for defining mapping terrain units with a spatial model in a GIS environment. During the following 2 years I taught fundamentals of GIS, remote sensing, aerial photo-interpretation and environmental modelling at the Water Resources Department at ITC. I was working under the supervision of Dr. Chris Mannaerts, PhD, Associate Professor in Satellite and Environmental Hydrology, who is one of the two co-promoters of this PhD work.

While being at ITC, I continued to study the Tagliamento River and, with the support of Prof. Allard Meijerink, former Head of the Water Resources Department, ended up with a paper entitled: *Historical fluvial development of the Alpine-foreland Tagliamento River, Italy, and consequences for floodplain management*, published in GEOMORPHOLOGY in 2003 (vol. 52, n. 3-4, pp. 317-333). This paper constitutes Chapter 2 of this research. It is at that time, also considering that I grew up in Africa, that the following question came to my mind: would it be possible to apply a similar research methodology in a data-scarce area, which is typically the case of river basins in developing countries?

Joining the United Nations Human Settlements Programme (UN-Habitat) in October 2002 represented a big turn in my career. I was based in Mozambique until end of 2009 and Dr Antonio Yachan, PhD, Senior Human Settlements Adviser, who is the other co-promoter of this PhD thesis, was my supervisor for few years. During that period I was responsible for several projects dealing with flood risk reduction issues.

In November 2003 I was invited to the international conference organised by the International Association of Geomorphologists (IAG) in Mexico City, Mexico, in which I presented the paper: *Vulnerability Reduction Strategies in Flood Prone Areas: the case of Mozambique*. In that occasion

I met with Prof. dr. Morgan De Dapper from the Department of Geography, Faculty of Sciences at the Ghent University in Belgium, specialised in Regional Geomorphology and Geo-archaeology. When I presented him the intended topic of my PhD thesis in 2004 and asked if he could be my promoter, Prof. De Dapper accepted with enthusiasm and actively supported me in making progress and conclude this important work ever since.

As result of the first 3 years of work in Mozambique, I wrote a paper entitled: *Integrating Slum Upgrading and Vulnerability Reduction in Mozambique*, which was published in the special issue: "Managing Urban Disaster" of OPEN HOUSE INTERNATIONAL in 2006 (vol. 31, n. 1, pp. 106-115), which constitutes Chapter 5 of this thesis. Meanwhile, between 2004 and 2007, I have coordinated the implementation of an initiative in the Limpopo River basin funded by the Global Environment Facility (GEF), which concerned the four riparian countries: Botswana, Mozambique, South Africa and Zimbabwe. The main findings of this project were used to produce the paper: *Participatory Approach for Integrated Basin Planning with Focus on Disaster Risk Reduction: the Case of the Limpopo River*. The latter was published in 2011 in vol. 3 of WATER, an open access scientific journal (www.mdpi.com/journal/water), which represents Chapter 4 of this thesis.

In October 2009 Prof. De Dapper led the fieldwork that we carried out in the lower Limpopo River, determining Chapter 3: *Analysis of the territorial vulnerability to flooding in the Limpopo basin through the description of the past river's evolution and geomorphological approach.* In this way, I could apply a similar analytical process than the one use in the Tagliamento River, but this time in a data scarce area. This chapter also constitutes a scientific paper which was recently submitted to GEOMORPHOLOGY.

Since January 2010 I have been working in the Regional Office for Africa at UN-Habitat in Nairobi, Kenya, where I function as Disaster Risk Reduction and Climate Change Adaptation focal point. I supervise activities in several countries in the region. My rather loaded working schedule made the road between Tagliamento to Limpopo a bit longer than originally planned. However, it also gave me a fantastic opportunity to continue applying my scientific knowledge regarding flood risk management, and learn from concrete field experiences in different countries.

Acknowledgements

There are many persons that I need to thank for allowing me finishing this work.

First of all, I would like to thank Morgan De Dapper, who immediately accepted to be my supervisor when I first presented him the idea of this PhD in 2004. Several times I thought of stopping along the way, as carrying out this kind of research while working as intensively as I did in the past 12 years can really be a challenge. Morgan, I sincerely enjoyed the moments we spent together, and I hope we will keep in touch. You have always been there to support me, and thanks to you I can finally hand over this manuscript today. I will never be sufficiently grateful to you for having achieved this result: thank you my friend!

Another important person who provided me with constant assistance, consistent comments and precious inputs to my draft chapters, who made me thinking through again and again before making statements, is Antonio Yachan, my co-supervisor. Antonio, you are more than a friend to me, you are almost like a second father. Thank you for all your advice which allowed me refining this work, and improving myself as a professional and as a human being. It has been deeply appreciated, always. Muchas gracias!

My other co-supervisor, Chris Mannaerts, is another great character. You were my supervisor, Chris, during my first professional assignment. I will never forget that. I thank you for all your help, kindness and friendship, for assisting me in drafting the PhD proposal and the work plan in the very beginning, and for having accompanied this work all the way despite your heavy schedule. Obrigado!

I would also like to thank all the friends and colleagues who were around me along these years, who encouraged me in carrying on this PhD. In trying to mention all of them, I would surely forget some...

A special thank goes to my family, to my parents Gianni and Françoise who gave me the opportunity to continue my studies and follow the life I wanted, and to my brother Fabio and my sister Rosa, for always being there when I needed them most.

Last but not least, I would like to thank the person who has been closed to me in the last 9 years, with whom we went through difficult moments but also had a lot of joy like when we decided to have a family… Thank you, Paula, thank you for always supporting me in my decisions, and for taking so good care of our beautiful kids, Maisha and Leandro. I will always be there for you.

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List of Acronyms

CGIAR	Consultative Group on International Agricultural Research
C-S Axis	Ciskei-Swaziland Axis of crustal flexure
CSO	Civil Society Organisation
DINAGECA	*Direcção Nacional de Geografía e Cadastro* (National Directorate of Geography and Cadastre, Mozambique)
DINAPOT	*Direcção Nacional de Planeamento e Ordenamento Territorial* (National Directorate of Territorial Planning, Mozambique)
DNA	*Direcção Nacional de Águas* (National Directorate of Water Affairs, Mozambique)
DNDA	*Direcção Nacional de Desenvolvimento Autárquico* (National Directorate for Autarchic Development, Mozambique)
DNHU	*Direcção Nacional da Habitação e Urbanismo* (National Directorate of Housing and Urban Development, Mozambique)
EGT Axis	Etosha-Griqualand-Transvaal Axis of crustal flexure
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Development Product
GEF	Global Environment Facility
GIS	Geographic Information System
GWP	Global Water Partnership
HIV/AIDS	Human immunodeficiency virus / acquired immunodeficiency syndrome
HYCOS	Hydrological Cycle Observing System
IAG	International Association of Geomorphologists
INGC	*Instituto Nacional de Gestão de Calamidades* (National Institute for Disaster Management, Mozambique)
ITC	Faculty of Geo-Information Science and Earth Observation, Twente University, The Netherlands
LBPTC	Limpopo River Basin Permanent Technical Committee
LIMCOM	Limpopo Watercourse Commission
LBSP	Limpopo Basin Strategic Plan
MICOA	*Ministério para a Coordenação da Acção Ambiental* (Ministry for Coordination of Environmental Affairs, Mozambique)
MOPH	*Ministério das Obras Públicas e Habitação* (Ministry of Public Works and Housing, Mozambique)

NGO	Non-Governmental Organisation
OCHA ROSA	United Nations Office for the Coordination of Humanitarian Affairs - Regional Office for Southern Africa
OKZ Axis	Ovambo-Kalahari-Zimbabwe Axis of crustal flexure
PGIS	Participatory Geographic Information System
PRA	Participatory Rural Appraisal
PRSP/PARPA	Poverty Reduction Strategy Paper / *Plano de Acção para a Redução da Pobreza Absoluta*
RP	Return-period
SADC	Southern Africa Development Community
UEM	*Universidade Eduardo Mondlane* (Eduardo Mondlane University, Mozambique)
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UN-Habitat	United Nations Human Settlements Programme
UNISDR	United Nations International Strategy for Disaster Reduction
WCED	World Commission on Environment and Development
WMO	World Meteorological Organisation

Abstract

Rivers have always played a crucial role in the development process of human society, influencing the spatial distribution of settlements and land use. For studying rivers one needs to analyse the complex human-river relationship. This requires the combination of natural and social sciences, which is the field of geography. In this research, focus is put on the role of floods in this relationship, especially from a spatial point of view. The aim is to contribute to more holistic and improved flood risk management that can be applied in both data-rich (typically in developed countries) and data-scarce areas (typically in developing countries). The main research question thus is: can people improve flood risk management based on geomorphological knowledge and participatory land use planning?

After the introductory chapter, which defines the problem, justifies the research, describes the aim, structure and relevance of this work and explains the used methodology, the second chapter analyses the fluvial geomorphological development of the Tagliamento River, located in northern Italy, and its flooding history. In this study case, which is typical of a data rich area, it is observed that flood hazard concentrates in those areas where flooding occurred during historical times, denoting a cyclical behaviour of the river. It is further noted that during the last century land use pressure led to a confinement of the river by dikes to such an extent that flood risk in downstream areas has increased and represents nowadays a major territorial planning issue. Fluvial corridors are proposed in the lower and middle stretches of the basin, which are defined based on the historic flooding and fluvial evolution.

The third chapter consists also in a thorough geomorphologic analysis to reconstruct the past evolution of the Limpopo River located in southern Africa, hence a typical data-scarce area. Similarly to the study carried out in the Tagliamento River, the objective is to analyse the territorial vulnerability to floods in the Limpopo basin based on a better understanding of the past fluvial dynamics, which have been deeply influenced by successive tectonic events. In fact, it is demonstrated that the apparently abandoned drainage conformation of the palaeo-Limpopo River constitutes today preferential flood-prone areas in case of major rainfall events. An important palaeo-delta is identified in the lower Limpopo which imposes a particular drainage pattern to the floodplain in Mozambique and influences, still today, the floods dynamics. Therefore, the description of the past river's evolution and the adoption of a geomorphological approach is proved to be helpful in identifying areas under endemic flood risk which are not suitable for human settlements development.

The fourth chapter proposes to adopt participatory approach for preparing a strategic plan of the Limpopo River basin with focus on disaster risk reduction, mainly regarding floods and drought. It explains the benefits of combining different types of activities following a bottom-up logic, despite an institutional context which operates through traditional top-down mechanisms. In particular, the *"Living with Floods"* experience implemented in Mozambique is highlighted as a concrete example of a successful disaster adaptation measure. The chapter concludes by formulating recommendations for potential replication of the same approach in other basins of the developing world.

The fifth chapter describes the vulnerability of the urban slums in Mozambique to flooding. It presents a review of the different project activities developed by the United Nations Human Settlements Programme aiming to identify applicable strategies for reducing this vulnerability. These activities counted with the active involvement of the government, local authorities and communities at each implementation stage, from decision-making to practical implementation, based on an integrated bottom-up approach. They consisted of three main components: (i) support to policy-making to ensure sustainable urban development; (ii) delivery of training and capacity building based on the mainstreaming concept of *"Living with Floods"*; and (iii) facilitation of participatory land use planning and upgrading interventions at the local level through community empowerment.

We conclude with an analytical synthesis which, after a short discussion, provides elements to answer the main research question. In particular, this concluding chapter derives lessons from the combination of geomorphic and social approaches to obtain a more holistic approach to flood risk management, and suggests a way forward.

Samenvatting

Rivieren beïnvloeden het landgebruik en de ruimtelijke verspreiding van nederzettingen en hebben aldus steeds een cruciale rol gespeeld bij de ontwikkeling van menselijke gemeenschappen. Dientengevolge vergt de studie van rivieren een analyse van de complexe relatie mens-rivier en deze behelst zowel factoren uit de natuurwetenschappen als uit de sociale wetenschappen; de combinatie van beiden is een typisch geografische benadering. Voorliggende doctoraatsstudie focust op de rol van overstromingen binnen deze complexe relatie, waarbij vooral het ruimtelijk aspect ervan bekeken wordt. Het doel is bij te dragen tot een meer holistisch en aldus verbeterd beheer van het risico op overstromingen dat zowel in data-rijke (typisch voor ontwikkelde landen) als in data-arme (typisch voor ontwikkelingslanden) streken kan toegepast worden. De voornaamste onderzoeksvraag is: kan de mens het beheer van overstromingsrisico's in een streek verbeteren door een betere kennis van de geomorfologische ontwikkeling ervan en een landgebruik gebaseerd op groepsoverleg.

Het eerste inleidend hoofdstuk omvat een definitie van het probleem, een rechtvaardiging van het onderzoek, een beschrijving van het doel, structuur en relevantie van het werk en een verklaring van de gebruikte methodologie. In het tweede hoofdstuk wordt de fluviale geomorfologische ontwikkeling van de Tagliamento, een rivier in noordelijk Italië, bestudeerd; meer in het bijzonder wordt zijn overstromingsgeschiedenis geanalyseerd. In deze gevalsstudie, typisch voor een data-rijk gebied, stelt men vast dat het overstromingsgevaar zich concentreert in deze delen van het bekken waarin overstromingen reeds in historische tijden voorkwamen en dat volgens een cyclisch patroon. Er werd tevens vastgesteld dat de druk op het landgebruik gedurende de laatste honderd jaren leidde tot een bedwingen van de vrije rivierloop door bedijking, wat aanleiding gaf tot een verhoogd overstromingsrisico in het benedenstroomse gedeelte van het bekken; deze ontwikkeling is heden ten dage één van de grootste bekommernissen bij de territoriale planning. Als oplossing plant men voor het midden- en mondingsgebied van het bekken het vrijmaken van fluviale corridors waarbij rekening gehouden wordt met de historische overstromingen en de geomorfologische ontwikkeling van de rivier.

Ook het derde hoofdstuk behelst een grondige analyse van de geomorfologische geschiedenis van een rivierbekken, ditmaal echter in een data-arm gebied: de Limpopo rivier in zuidelijk Afrika. Net als bij de studie van de Tagliamento is het objectief het inschatten van de territoriale kwetsbaarheid voor overstromingen gebaseerd op het beter begrijpen van de fluviale dynamiek welke, in het geval van de Limpopo, fundamenteel beïnvloed wordt door opeenvolgende tektonische gebeurtenissen. Er wordt aangetoond dat de drainagestructuur van de paleo-Limpopo van deze aard is dat in geval van periodes met overvloedige regens, 'dode' stroomkanalen gereactiveerd worden wat aanleiding geeft tot overstromingen in welbepaalde gebieden. Tevens kon aangetoond worden dat een belangrijke paleo-delta in de benedenloop van de Limpopo een specifiek drainagepatroon a.h.w. 'opdringt' aan de overstromingsvlakte van de Limpopo in Mozambique en aldus ook nog heden ten dage de overstromingsdynamiek beïnvloedt. Ook in dit geval zien we dat de combinatie van een geomorfologisch-historische benadering toelaat zones met hoog overstromingsrisico, ongeschikt voor menselijke bewoning, te identificeren.

Teneinde een strategisch plan, wat betreft de reductie van de risico's gebonden aan overstromings- en droogterampen, voor het bekken van de Limpopo uit te werken, wordt voorgesteld te werken via een methode waarbij groepsoverleg een primordiale rol speelt; dit is het onderwerp van het vierde hoofdstuk. Het plan pleit voor het combineren van verschillende activiteiten via een 'bottom-up' logica, en dit ondanks een institutionele context die werkt via de traditionele 'top-down' mechanismen. In het bijzonder wordt de actie "Living with Floods", die uitgevoerd werd in Mozambique, belicht als een concreet voorbeeld van een succesvolle aanpassing aan overstromingsrampen. Als besluit worden in dit hoofdstuk een aantal aanbevelingen geformuleerd die moeten toelaten deze actiemethode toe te passen in andere rivierbekkens in ontwikkelingsgebieden.

Het vijfde hoofdstuk beschrijft de kwetsbaarheid voor overstromingen in de stedelijke slums van Mozambique. De verschillende projectactiviteiten van het 'United Nations Human Settlements Programme (UN-Habitat)' betreffende het identificeren van geschikte strategieën om deze kwetsbaarheid te reduceren worden overlopen. Deze activiteiten werden uitgevoerd met de actieve deelname van zowel de nationale als lokale stakeholders en dit op elk niveau van implementatie, van besluitvorming tot toepassing; daarenboven waren ze gebaseerd op een geïntegreerde 'bottom-up' benadering. De activiteiten omvatten drie hoofdcomponenten: (1) steun aan de 'policy-making' teneinde een duurzame stedelijke ontwikkeling te verzekeren; (2) training en capaciteitsopbouw gebaseerd op het "Living with Floods" concept; (3) bewerkstelligen van landgebruiksplanning via groepsoverleg en versterken van lokale interventie door meer inspraak te geven aan de basisgemeenschap.

In het concluderend hoofdstuk wordt een analytische synthese gemaakt en wordt een kritisch antwoord gegeven op de voornaamste onderzoeksvraag: 'kan de mens het beheer van overstromingsrisico's in een streek verbeteren door een betere kennis van de geomorfologische ontwikkeling ervan en een landgebruik gebaseerd op groepsoverleg'. In het bijzonder worden lessen getrokken uit de combinatie van geomorfologische en sociale factoren om tot een meer holistische benadering van het beheren van overstromingsrisico's te komen; ook worden suggesties geformuleerd voor een verdere uitwerking van dit concept.

Some definitions

Adaptation: transformation of one or more system features which permits the reestablishment of equilibrium so that the individual, household or community is able to respond to hazard in the short, medium and long term (Hogan and Marandola, 2007).

Disaster: serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources. Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences (UNISDR, 2007).

Disaster risk: potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period (UNISDR, 2009).

Disaster risk management: the systematic process of using administrative directives, organisations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster (UNISDR, 2007).

Disaster risk reduction: the concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (UNISDR, 2007).

Flood risk: in its most essential form, it is the product of probability of a particular flood event times the consequence that event would have. In another form, flood risk is described as a function of the flood hazard (probability of occurrence of a particular flood event), the exposure of human activity to the flood (flood damage potential) and the specific vulnerability of the community affected by the flood (WMO/GWP, 2007).

Hazard: a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage (UNISDR, 2007).

Mitigation: the lessening or limitation of the adverse impacts of hazards and related disasters. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness (UNISDR, 2007).

Preparedness: the knowledge and capacities developed by governments, professional response and recovery organisations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions. Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response through to sustained recovery (UNISDR, 2007).

Prevention: the outright avoidance of adverse impacts of hazards and related disasters through action taken in advance. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high risk zones, and seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake. Very often the complete avoidance of losses is not feasible and the task transforms to that of mitigation (UNISDR, 2007).

Public awareness: the extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards. It is a key factor in effective disaster risk reduction (UNISDR, 2007).

Recovery: the restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors. The recovery task of rehabilitation and reconstruction begins soon after the emergency phase has ended, and should be based on pre-existing strategies and policies that facilitate clear institutional responsibilities for recovery action and enable public participation. Recovery programmes, coupled with the heightened public awareness and engagement after a disaster, afford a valuable opportunity to develop and implement disaster risk reduction measures and to apply the "build back better" principle (UNISDR, 2007).

Resilience: the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (UNISDR, 2007).

Risk assessment: a methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios (UNISDR, 2007).

Risk management: the systematic approach and practice of managing uncertainty to minimise potential harm and loss. It comprises risk assessment and analysis, and the implementation of strategies and specific actions to control, reduce and transfer risks (UNISDR, 2009).

Structural and non-structural measures: (i) structural measures: Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems; (ii) non-structural measures: Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education (UNISDR, 2007).

Vulnerability: degree to which a socio-economic system is susceptible or resilient to the impact of flood hazards. While this definition can also include flood damage, resilience includes the aspect of how well the system is coping and is as such influenced by community's combination of prevailing social conditions and factors such as poverty and livelihoods. It is essential to take count of flood vulnerability as part of overall flood risk in land use-planning and regulation (WMO/GWP, 2007).

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1. Introduction

Rivers have always played a crucial role in the development of human society, influencing the spatial distribution of settlements and land use. By flowing at the earth's surface, rivers represent an important and easily accessible source of fresh water, a natural resource which is necessary to life. They also constitute important transport axes. Fertile soils and morphological flatness of their floodplains provide excellent conditions for agriculture and their waters allow fishing. According to Priscoli (2000), "the history of social organisation around river basins and watersheds is humanity's richest record of our dialogue with nature".

The greatest civilisations and cities have developed along rivers. Ancient Mesopotamia developed between the Tigris and the Euphrates Rivers, while Ancient Egypt flourished along the Nile River. A third of China's population lives within the Yang Tse River basin, which ends up in Shanghai. What about the importance of the Mississippi-Missouri River in the United States of America, and of the Volga River in Russia? The Tiber, the Thames and the Seine Rivers cross Rome, London and Paris respectively. The economic importance of the Rhine River in Europe is well known. There are also amazing transboundary rivers such as the holy Ganges basin in Asia used by almost half a billion people, the Amazon River basin which covers half of southern America's surface, the Mekong River linking several countries in the Far East, the Congo and Niger Rivers in Western and Central Africa, just to mention a few. As stated by Boon et al. (2000), rivers are the lifeblood of nations and the control of their waters has been fundamental to the building of human civilisations. When looking at history, it is clear that river floodplains represented preferential areas for establishing human settlements (WMO/GWP, 2007).

For studying rivers in a comprehensive manner one needs to take into account the human-environment relationship. This requires the combination of natural and social sciences, which is the field of geography. In the particular case of this research, it concerns the use of geomorphology as a natural science discipline and participatory land use planning as a social science discipline, with a specific focus on *flood risk management*.

1.1. Problem definition and justification

1.1.1. Rivers dynamism: the role of floods

Rivers are dynamic ecosystems (Harper and Everard, 1998) influenced by natural and/or anthropogenic factors, according to different time and spatial scales. In particular, morphological river changes are mainly determined by the variations in sedimentation, transportation and erosion processes. Among the natural factors responsible for these changes we can cite: climate (precipitation influencing discharge; this factor can determine seasonal changes, for example), tectonics (important changes at the geological scale) and relative sea level changes, type of soil (e.g. varying erodibility characteristics) and vegetation cover (Blum and Tornqvist, 2000; Straffin and Blum, 2002; Wallick et al., 2007).

Flood events, in particular, can provoke important spatial changes of river courses (Newson, 1980; Slezak, 1980; Miller, 1990; Newson, 2002; US Department of the Interior, 2004; Twidale, 2004; Wallick et al., 2007). For example, the following rivers lateral migration rates were recorded in alluvial plains: the Brahmaputra River shifted 10 km in 150 years, the Kosi River 113 km in 228 years, etc. (Osborn and du Toit, 1990). Sedimentation processes produce other striking results related to fluvial dynamics: the Shantung Peninsula in China was a former island that has been linked to the mainland as a consequence of alluviation of the Yellow River (Twidale, 2004). Similar dynamics are documented for the Tagliamento River in Italy since the Roman Empire (Spaliviero, 2003). Hence there is an intimate linkage between fluvial changes and flooding phenomena.

Furthermore, the flood pulse concept (introduced by Junk et al., 1989) describes rivers and their fringing floodplains as components of a single dynamic system which are linked by strong interactions between hydrological and ecological processes (Tockner et al., 2000). The area of influence of rivers covers both terrestrial and aquatic units, and should be considered during the preparation of land use plans. The river corridor concept (Gardiner, 1991; Govi and Turitto, 1994; Arnaud-Fassetta et al., 2009) is meant to reserve sufficient space for the river to fulfil its ecosystemic functions within the floodplain, hence to guarantee a more sustainable spatial equilibrium between river and man.

Therefore, it becomes evident, based on the above, that Man needs to obtain a proper historic and multi-disciplinary understanding of the inherent fluvial dynamism before undertaking river management decisions. Steinberg (2004) acknowledges that, unfortunately, Man's perception of the river flow is limited and not consistent with a river's dynamic flooding and meandering history. This is precisely one of the main issues that the present research aims to explore: the analysis of the complex relationship between Man and river, especially from a spatial perspective, in which floods play a major role. That is where the combination of geomorphic and social approaches can play a role in improving flood risk management.

1.1.2. Human intervention and increased vulnerability to floods

The degree of anthropogenic intervention on rivers varies with the level of industrialisation, urbanisation and human density. Typically, human-induced alterations of river floodplains (such as deforestation, grazing, cropping, urbanisation, etc.) reduce their ecological functions and shift affected streams away from natural equilibrium conditions (Warner, 1984; Hupp et al., 2009). River regulation works are found predominantly in developed countries (Dynesius and Nilsson, 1994). With growing economies and the emergence of wealthier societies, Man puts more pressure on river floodplains so that the flood damage potential increases (WMO/GWP, 2007; Kundzewicz et al., 2002). In addition, flood protection gives a false sense of security and brings more development (Bakker, 2006; Steinberg, 2004). In this context, society has to take decisions on the level of flood risk it is willing to accept (WMO/GWP, 2007).

Recent scientific literature is full of examples of poor river management interventions (such as dams, levees or channelization) which, combined with human pressure on what could be considered "river's land", have actually triggered more flood damage than fulfilling their function of protecting human assets and investments (Spaliviero, 2003; US Department of the Interior, 2004; Steinberg, 2004; Gregory, 2006; Weng, 2007; James & Singer, 2008; Osti, 2008). Among other possible aspects, this can be explained by: (i) the combined effect of channelization and decrease in soil infiltration capacity, especially in urban areas (WMO/GWP, 2007); and (ii) rapid sedimentation leading to “perched” riverbeds above the surrounding floodplain (Shu and Finlayson, 1993; Calvet et al., 2002).

While this research makes reference to either rural or urban settlements, it puts emphasis on the effects of uncontrolled urban development on increased vulnerability to floods. Today, urbanisation is a dominant demographic trend and a major factor in land transformation (Grimm et al, 2000). The fastest urbanisation is observed in developing countries (UN-Habitat, 2010), where rural-urban migration combined with natural growth of cities are producing more and more informal settlements in vulnerable areas, mainly located in the periphery of the main cities (Kamanga et al., 2003; WMO/GWP, 2007). Hence, there is a direct nexus between poverty and increased flood risk (Hogan and Marandola, 2007; Osti, 2008). In addition, many cities in the developing world were established in naturally hazardous or environmentally sensitive areas (Gupta and Ahmad, 1999). As explained by Hogan and Marandola (2007), “what generally prevails is the adjustment of the environment to the city, not the contrary, a process which is at the root of many urban hazards, especially floods”. Therefore, urban vulnerability to floods, especially for the poor, represents an increasing concern which needs to be addressed urgently.

Floods increased in frequency in the last 25 years and developing countries are the most affected (Bakker, 2006). It is now well-accepted that there are causal links between environmental degradation, land use and vulnerability to disaster (WMO/GWP, 2007), which need to be further explored. For example, the livelihood of local people is greatly affected in case of floods (Osti, 2008) and this increases their vulnerability. What strategies could be adopted to manage flood risk in a more sustainable manner in developing countries, especially in data-scarce areas? Here again, the combination of the geomorphic and social approaches could probably help in obtaining a greater understanding of the flooding phenomenon and identify adequate risk management solutions.

1.1.3. Flood risk management at the basin scale

Fluvial areas require more space and continuity, and less static regulations (Ureña and Ollero, 2001) which are typical of human administrative frameworks. According to Harper and Everard (1998), management issues need to reconcile the dynamic reality of rivers within a structural framework for decision making. These considerations lead to the paradigm of considering the river basin as a territorial planning and management unit (Newson, 1997; Barrow, 1998; Kauffman, 2002). The same river basin, thus, should be considered for managing flood risk in a sustainable and sound manner. Despite making a lot of sense, especially from an ecosystemic perspective, this approach has proven to be difficult to implement (Koppel, 1987), especially for transboundary river basins, as it requires an enabling technical, institutional and political environment as well as proper communication and cooperation between riparian countries in terms of river basin management. It is a real challenge to obtain such conducive environment, especially in developing countries, which makes them even more vulnerable (Hogan and Marandola Jr., 2007).

According to the author, the complexity of fluvial dynamics and of the morphological settings of any river basin, as well as the difficulty to reproduce the effects of anthropogenic intervention and of extreme flood events, are factors that limit the adoption of spatially distributed dynamic modelling for improving flood risk management at basin level. Developing models for simulating such complexity requires gathering a huge amount of data (Parker et al., 2008) during a consistent number of years, as well as many variables (Hickin, 1983). In addition, access to accurate data is often a problem (Fohrer, 2003), especially in poor countries. There are high costs involved in data collection, and simulation results become difficult to control as the level of complexity increases (Kauffman, 2002; Parker et al., 2008).

Therefore, alternative flood risk assessment and management approaches need to be explored at river basin level, especially for data-scarce areas. This justifies once again the adoption of a mixed approach, enhancing the use of geomorphic observation and evidence to compensate for the lack of data, and of participatory land use planning as a practical method to cater for the territorial complexity. As stated by Holling (1978): "where data are a problem, approaches should be flexible and adaptive".

1.2. Research objective

The main objective of this research is ***to contribute to a more holistic and improved flood risk management by combining geomorphic and social approaches***, for both data-rich and data-scarce areas.

Reaching this objective entails the analysis on how the following two dimensions relate to each other: (i) floods, as a physical phenomenon which needs to be understood in its dynamism and complexity (related to the geomorphic approach); (ii) the way human society occupies and manages the territory under risk of flooding (related to the social approach). Firstly, within the scope of this research, flooding is not only considered as a natural hazard but also as a dynamic factor producing territorial changes and influencing the spatial distribution of human settlements. Secondly, socio-economic and managerial aspects related to the human occupation of the river's territory or of the area under flood risk are considered. Finally, the need to reach a "spatial consensus" between these two dimensions (Floods and Man) is addressed through appropriate territorial planning.

Therefore, *flood risk management* in this research comprises:

- risk assessment, through historical and geomorphological spatial analysis;
- preparedness, through participatory planning and the elaboration of appropriate didactic and communication tools for increasing public awareness;
- mitigation, by referring to structural and non-structural measures;
- adaptation, such as "living with floods" as alternative to massive resettlement operations, for example; and
- vulnerability reduction, especially for the communities living in the lower parts of a river basin or, more in general, in areas at risk, through appropriate territorial planning.

1.3. Research questions and thesis structure

The Main Research Question of this thesis is the following: ***can people improve flood risk management based on geomorphological knowledge and participatory land use planning?***

In terms of structure, after the introductory chapter, this thesis is organised in four main chapters and a conclusion. Each chapter attempts to respond to a specific research sub-question.

First Research Sub-Question: *How has anthropogenic intervention determined fluvial changes and influenced the flood dynamics of the Tagliamento River, a fluvial system typical of the developed world?* (Corresponding to Chapter 2)

In this chapter, the historic fluvial development of the Tagliamento River in northern Italy is described, by combining geomorphological interpretation and historic literature review. In particular, the way Man has been influencing the river's morphology during the last two centuries, especially through land use change and dyke construction, is analysed. Interestingly, it is observed that in the lower stretch of the river flood hazards concentrate at those places and zones where flooding occurred during historical times, or where the river was flowing before, following a cyclical behaviour. Similar observations were made by the US Department of the Interior (2004) while studying the Gila River in Arizona, USA. Conclusions are derived for improving structural flood mitigation measures, with as main recommendation to reduce the anthropogenic pressure on the lower river basin and provide more space to the fluvial system. For this purpose, river corridors are defined, for which different land use regulations apply. Shu and Finlayson (1993), the US Department of Interior (2004) and Steinberg (2004) make similar recommendations. The situation of the Tagliamento River basin is typical of developed countries, showing a high population density. A rich data set is available allowing for the combination of results obtained using different analytical methods.

Second Research Sub-Question: *Do clear relationships exist between past fluvial changes, identified through geomorphologic analysis, and territorial vulnerability to floods in the Limpopo River basin, a typical transboundary basin of the developing world?* (Corresponding to Chapter 3)

The geomorphologic analysis carried out while developing this chapter includes an extensive literature review coupled with field work activities undertaken in October 2009. The idea is to analyse the territorial vulnerability to floods in the Limpopo River basin, an important drainage system located in south-eastern Africa, through a better understanding on how this system has evolved in the past. In fact, as described for the Tagliamento River by Spaliviero (2003), it is demonstrated in this chapter that for the upper and middle fluvial stretches, the drainage conformation of the palaeo-Limpopo River (i.e. before it was modified by successive tectonic events) provides today preferential flood-prone areas or channel flow reactivation in case of major rainfall events. Consequently, areas prone to endemic flooding and not suitable for human settlements are identified. As for the lower Limpopo River, a huge palaeo-delta is described, which imposes a particular drainage pattern to the floodplain in Mozambique and influences, still today, flood dynamics. This is a typical case of a data-scarce area, in which the description of the past river's evolution and the adoption of a geomorphological approach prove to be helpful in determining territorial vulnerability to floods.

Third Research Sub-Question: *How can participatory approach lead to a more integrated (land and water) planning of the Limpopo River basin, and which flood risk reduction strategies can be derived?* (Corresponding to Chapter 4)

This chapter explains how participatory planning can be used for integrated river basin planning with focus on disaster risk reduction. Again, we consider the case of the Limpopo River basin. An in-depth analysis of the institutional settings and policy framework is undertaken, and the relationship between the local and the basin scales mainstreamed during the planning exercise. Special emphasis is put on awareness raising for disaster preparedness and the implementation of innovative adaptation measures for Mozambique, such as *Living with Floods*. The chapter derives recommendations for replicating the same approach in other developing countries.

Fourth Research Sub-Question: *How can participatory slum upgrading be used in Mozambique to reduce the vulnerability of poor urban dwellers to flooding?* (Corresponding to Chapter 5)

This chapter describes the impact of the uncontrolled growth of informal urban areas in terms of increased vulnerability to flooding. It focuses on Mozambique, a country which is particularly exposed to natural hazards and where slums represent approximately 70 to 80 per cent of the urban population. Unsafe areas are often the only affordable option for new settlers coming to the cities from rural areas, and for the urban poor in general. Participatory approaches, awareness raising, institutional capacity building and integrated water and sanitation activities are the proposed components for upgrading informal settlements and, thus, reducing the vulnerability of slum dwellers to flooding.

The concluding chapter makes a synthesis analysis of the research, by inter-relating the conclusions of the different chapters and thus answering the main research question. In particular, evidence is provided on how this work contributes to scientific knowledge by combining geomorphic and social methodologies to obtain a more holistic approach to flood risk management, whereas suggestions for follow-up research activities are made.

1.4. Relevance

As underlined by Baker (1994): "floods are the most globally pervasive, environmentally diverse and continually destructive of all natural hazards". Flooding is a topic under continuous scientific investigation, causing increased damage around the world, especially in poor countries. Despite the paradigm shift from flood control to flood management, there is still lack of appropriate science to integrate human and environmental water needs (Petts and Kennedy, 2005).

Probably one of the most relevant aspects of this research is its contribution to scientific knowledge. After years of investigation and practical work around the same subject, i.e. flood risk, the author tried to combine both natural (especially geomorphology) and human sciences (especially participatory land use planning) to fulfil the research objective. Therefore, several fields of investigation were explored while undertaking this research, to obtain a more holistic understanding of flood risk management, with the possibility to contribute to its improvement. Of particular relevance is how knowledge of past morphologic evolution of a river can help in determining the territorial vulnerability to floods at present (Chapters 2 and 3). As complementary approach, it also appears relevant to adopt participatory planning for identifying sustainable and feasible flood risk mitigation measures (Chapters 4 and 5). In fact, new ways of studying rivers and their related flood risk should be explored, so that better disaster risk reduction strategies can be identified, tested and adopted.

The second main contribution to be highlighted in this research is the attempt to identify flood risk management strategies suitable to the developing world, where data is scarce. As mentioned earlier, poor countries are generally much more vulnerable to the impact of changing fluvial dynamics than developed nations. From this perspective, it is this research's clear interest to concentrate on a Third World region to contribute, up to a certain extent, to increasing sustainable development knowledge. Therefore, the case of Limpopo River basin was used for Chapters 3 and 4, located in the south-eastern part of the African continent. The main challenges in this river basin are: (i) the difficulty to take sound basin management decisions, as it often occurs in the case of international watercourses; and (ii) the general lack of data and capacity (both human and infrastructural), which characterises developing countries.

This research highlights other relevant aspects, which contribute to the on-going debate regarding modern flood management approach. It emphasises the importance of adopting non-structural solutions such as zoning (ref. to the river corridors mentioned in Chapter 2), adapted building codes (Chapter 4), participatory planning, *Living with Floods*, awareness raising and local capacity development (Chapters 4 and 5), water and sanitation activities for reducing the vulnerability to floods in informal urban areas (Chapter 5), among others. This is especially relevant considering the costs involved in structural solutions which cannot guarantee full security for large and complex river basins, and also with the expected increased impact of climate change. As observed by Bakker (2006), flood management has gone through 4 successive phases: (i) do nothing; (ii) keep the river away from the people; (iii) keep the people away from the river; and (iv) "living with floods". Therefore, this research is rightly contributing to further developing this field by promoting alternative solutions adapted to the current flood risk management trends.

1.5. Methodology

Methodology is concerned with the particular means by which a researcher gains knowledge on a selected subject (Yachan, 2002). Different methodologies were used for each of the main chapters or scientific papers (from II to V) composing this research.

Before entering into the description of the specific methodology used for each paper, it is important to underline that, in general, we adopted a qualitative approach for this research. Qualitative research is a method of inquiry employed in many different academic disciplines, but more traditionally in the social sciences (Denzin and Lincoln, 2005). Shank (2002) defines qualitative research as "a form of systematic empirical inquiry into meaning". This means a planned and ordered (systematic) inquiry method which is grounded in concrete experience or observations (empirical) for improving the level of understanding (meaning) of the subject under investigation. Different methodologies and disciplines are combined in this thesis. This makes sense within a qualitative research context, considering the complexity and the multi-dimensional nature of the topic under investigation.

In particular, the author, after having studied and taught spatially distributed dynamic modelling during some years, came to the conclusion that it is difficult to describe quantitatively or simulate accurately the spatial dynamics of an ecosystem with the dimensions of a river basin. This view is supported by several authors, such as Baker and Twidale (1991) who affirm that “theoretical models may fail to account for the field evidence and the larger spatio-temporal domain”. Baker (1994) explains how conventional flood science has been devoting increasing attention to the mathematics of physics theory which, through the manipulation of idealised parameters that are assumed to have flood-like properties, has resulted in the design of engineered river control solutions that were imposed on society with sometimes catastrophic consequences. Pilkey and Pilkey-Jarvis (2007) have a similar line of thought. One should also consider the multiplicity of factors that determine socio-economic decisions influencing land use and river management options in a confined geographical area. As underlined by Wu et al. (2008), the true effects from socio-political drivers on land use/cover change are difficult to distinguish due to the multiplicity of interactions and inter-correlations between different variables and the deficiency of available the socio-political information with an appropriate spatial resolution.

In addition, there is the problem of multiple temporal and spatial scales needed to describe the dynamic human-environment relationships. As indicated by Parker et al. (2008), while many of these relationships operate at similar scales, many feedbacks are indirect and may operate at different spatial and temporal scales. Specifically regarding rivers, Wallick et al. (2007) and Pahuja and Goswami (2006) explain that in large basins channel response to a particular impact in a given time period is contingent upon all previous events. Threshold phenomena, which cause a rapid and often unpredictable change of state in systems, as it occurs for river channels (Newson, 2002), provide additional levels of complexity (Parker et al., 2008).

To manage rivers and their related flood risk adequately, we first need to understand their evolution and nature, which can be done by investigating their history. That is why one of the main scientific disciplines used in this research, especially in Chapters 2 and 3, is geomorphology from a purely interpretative and, thus, qualitative angle. Geomorphology rests on the interpretation of processes from form through careful observation across the whole system under study, together with the application of well-established principles (Thorne et al., 1996). Geomorphological understanding of floods results from a long tradition of studying real processes operating in historical times, which are recorded in the sediments, landforms and erosional scars of past floods (Baker, 1994). As indicated by Gilvear (1999), fluvial geomorphology has the ability to recognise the significance of both ancient and active landforms as indicators of levels of landscape stability.

Meanwhile Chapters 4 and 5 adopt a social approach. They focus on aspects related to the reduction of a population’s vulnerability to floods and on improved river basin management, especially looking at policy and institutional issues. One of the main methodological paradigms linking both these chapters is the extensive use of participatory land use planning at different levels (local, national and sub-regional), which was identified as a key aspect to ensure sustainability of decisions taken to reduce flood risk. Relevant scientific bibliography on participatory approach is provided in both Chapters 4 and 5.

1.5.1. Methodology used in Chapter 2

The geomorphological behaviour of the Tagliamento River during the past 2,000 years is studied through a combination of literature review, the analysis of land use and topographic maps, aerial photos and satellite images, the use of hydrological data and fieldwork validation. The aim is, firstly, to gain knowledge on past river dynamics and on the recurrence of flood hazards in different locations along the middle and lower stretches of the river; and, secondly, to relate land use changes with fluvial changes and analyse the evolution of the anthropogenic pressure on the river.

For this purpose, historical descriptions of flooding found in literature are digitised, positioned in existing maps and overlaid to a satellite image. The latter is displayed using a band combination which maximises the visibility of hydrological and geomorphological features. Preliminary conclusions are then validated through geomorphological observations made during a short field work along the middle and lower Tagliamento River. Therefore, by using different sources of recent and historic data and analytical approaches, spatial relationships among the findings are derived in the form of maps, which allowed interpreting past river dynamics with a certain degree of accuracy. A similar approach was followed by Pearce and Grossinger (2004). This method is possible to be applied for a data-rich area such as the Tagliamento River.

Of particular methodological interest is the definition of fluvial corridors as an attempt to reflect the historical fluvial geomorphological developments and the areas where floodwaters found their way. The author defines as fluvial corridor a zone that belonged in historical times to the active part of the fluvial ecosystem and that appears to be still under the rivers' influence when analysing flood dynamics. As explained by Arnaud-Fassetta et al. (2009) fluvial risk can be anticipated by identifying reaches characterised by active channel shifting and define policy regulations to restrict their anthropogenic use and occupation. Therefore, in this chapter, the land use zoning approach was adopted by defining fluvial corridors according to different levels of flood risk for which, ideally, specific land use regulations should be developed. This reflects a modern flood management approach in which regulatory land use plans need to define a territorial balance between "the space for human development" and "the space for water/rivers" to keep flood damage potential to acceptable levels (WMO/GWP, 2007).

1.5.2. Methodology used in Chapter 3

Chapter 3 investigates, using a geomorphological approach, the role played by tectonics (as underlined by Blum & Tornqvist, 2000) in determining major changes of the Limpopo River in the past. The aim is to demonstrate that the palaeo-morphology of the river heavily influences the flood susceptibility of the basin today.

Firstly, thanks to an extensive literature review regarding the geological evolution of southern Africa since the late Jurassic - Early Cretaceous period, the historic development of the river is reconstructed. The literature review is combined with the use and interpretation of several historic and thematic maps as well as satellite images of southern Africa.

Secondly, the participatory land use planning exercises undertaken in the upper-middle Limpopo (in Botswana and Zimbabwe) between 2005 and 2007, and the geomorphological observations made in the lower Limpopo during a field visit carried out in October 2009, provide evidence that palaeo drainage patterns are often re-activated by floods at present. As for the lower river stretch, a geomorphological interpretation is reproduced in a shaded relief map derived from an existing 90 m. resolution digital elevation model.

Finally, a radar image taken during the 2000 floods is used to assess the geographical extension of the 2000 floods, and compared to the recent floods which occurred in February 2013. Linkages with the historic geomorphological evolution of the complex lower Limpopo floodplain are made. Similar flood risk mapping methods were described by Baker (1988) and Kenny (1990) for data scarce areas.

1.5.3. Methodology used in Chapter 4

The qualitative approach adopted in this chapter is based on the social sciences. A scientific literature review is carried out, complemented with information collected throughout the work undertaken in the Limpopo River basin by a multidisciplinary team between 2004 and 2007.

The main methodological tool used is participatory planning at different scales (local, national and sub-regional), with aim at preparing a river basin plan with focus on disaster risk reduction. This tool represents a concrete answer to data scarcity, complex environmental conditions and weak institutional capacity. It enables people to conduct their own analysis of the reality they live in, and take action to change it. This approach was successfully applied by several authors (Freire, 1970 and 1974; Absalom et al., 1995; Brace, 1995; Binns et al., 1997; Chambers, 1998).

At the local level, several stakeholders are consulted from the different sectors including the targeted communities, while at the national and sub-regional levels inter-sectoral and inter-country coordination activities were organised. Such consultative work is complemented by a legal and policy framework analysis carried out at both national and sub-regional levels.

As a result a Limpopo Basin Strategic Plan is derived focusing on flood and drought risk reduction, which are two interrelated types of natural hazards regularly affecting the basin. Sustainable strategies to reduce the vulnerability are then designed and tested. These include *Living with Floods*, innovative awareness raising tools and the construction of pilot public buildings which can be used as safe haven in case of disaster.

1.5.4. Methodology used in Chapter 5

This chapter provides an overview of the urbanisation challenges in Mozambique and their consequences in terms of vulnerability, particularly to flooding. The analytical method used belongs to the sphere of social sciences, within the field of human settlements studies.

Firstly, a policy and institutional review of the urban sector in Mozambique is carried out. This is done to identify capacity gaps and functional overlaps between various institutional bodies at different hierarchical levels dealing with urban management (i.e. different ministries at government level, municipal authorities and neighbourhood structures). Consequently, recommendations for improving the policy framework are formulated, and training and capacity building activities proposed. As for

Chapter 6, these included the design of innovative awareness raising materials promoting the idea of *Living with Floods*.

Secondly, the participatory land use planning method is applied to informal neighbourhoods of selected cities and towns. Consequently, priority water and sanitation interventions are identified on a consensual basis with all the stakeholders for reducing the vulnerability to floods. These interventions are then implemented through community involvement to increase their sense of ownership during the slum upgrading process. Finally, mechanisms for replicating similar bottom-up methodologies in other Mozambican cities and towns are analysed and proposed.

Hence the multi-fold methodology adopted during this investigation reflects the ambition of getting the most comprehensive picture possible regarding flood risk management for both data-rich and data-scarce areas. This resulted in exploring different fields of research in both natural and social sciences. Lessons learned are highlighted in the concluding chapter.

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2. Historic fluvial development of the Alpine-foreland Tagliamento River, Italy, and consequences for floodplain management

Mathias Spaliviero (2003); Published in GEOMORPHOLOGY, vol. 52, n. 3-4, pp. 317-333

2.1. Abstract

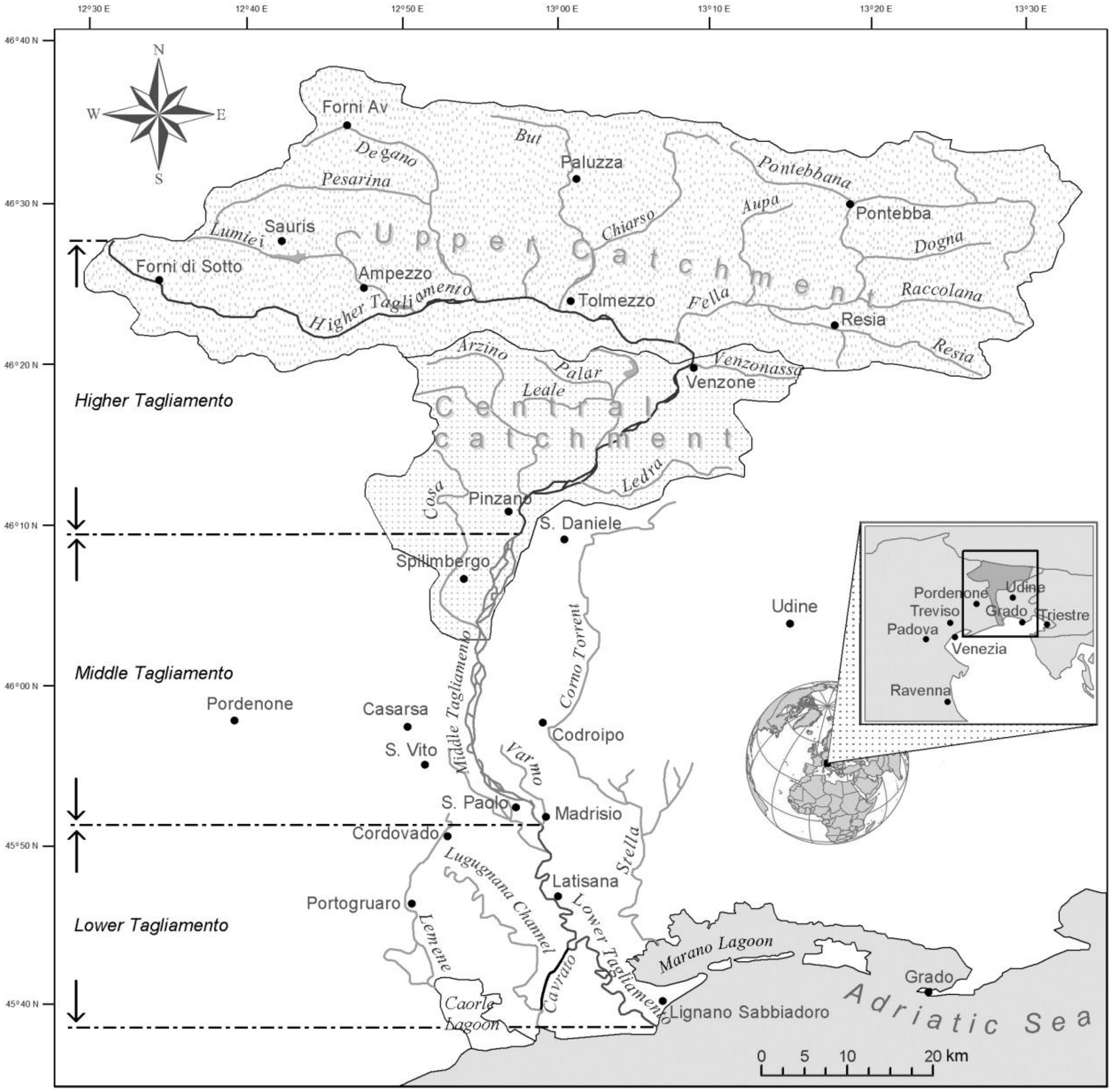
The fluvial geomorphological development of the Tagliamento River and its flooding history is analysed using historical documents and maps, remote-sensed data and hydrological information. The river has been building a complex alluvial fan starting from the middle part of its alluvial course in the Venetia-Friuli alluvial plain. The riverbed is aggrading over its entire braided length. The transition from braiding to meandering near Madrisio has shifted downstream where the river width determined by the dikes becomes narrower, causing major problems. The flood hazard concentrates at those places and zones where flooding occurred during historical times. Prior to the agrarian and industrial revolution, land use was adjusted to the flooding regime of the river. Subsequent land use pressure led to a confinement of the river by dikes to such an extent that the flood risk in the floodplain downstream of Madrisio has increased consistently, and represents nowadays a major territorial planning issue. The planned retention basins upstream of the middle Tagliamento will alleviate the problem, but not solve it in the medium and long term. Therefore, fluvial corridors in the lower-middle parts (from Pinzano to the sea) have been identified on the basis of the flooding history in relation to fluvial development during historical times. The result should be used for hydraulic simulation studies and land use planning.

Keywords: Flood events; Historical analysis; Fluvial dynamics; Fluvial corridors

2.2. Introduction

Flooding damage caused by the Tagliamento River has been reported since historical times. Meteorology, a large area of the upper catchment and steep slopes confer to the river a torrential regime that generates flash flood events of considerable size in the alluvial plain. Alluvial fan deposition by braided rivers takes place due to large sediment loads entering the foreland. This situation is typical of the Po foreland, but a parallel situation is found, for example, in the Himalayan range and the Gangetic foreland. Furthermore, the anthropogenic interventions of the last centuries, such as the construction of dikes and draining of existing wetlands in the lower lands, have severely reduced the river's space, causing highly critical hydraulic conditions in the lower part of the floodplain where the river changes from braiding to meandering (Fig. 2.1).

Figure 2.1: The Tagliamento River basin



(Source: Basin Authority for the North Adriatic Rivers)

In this context, a number of questions arise. First, how does the geomorphological setting influence the overall hydraulic morphology of the river? Second, what evidence is available to analyse and map changes of the river since historical times? Third, what has been the role of human activity on the river? Finally, can likely near future developments of the river be described and taken into account to work out measures for flood control?

To understand the existing flood hazard, it is useful to study the behaviour of the river in the past. For this purpose, different approaches were adopted that produced new findings concerning the dynamics of the Tagliamento River. Historical descriptions of flooding were positioned on a map base. A land-use map of 1833, which forms the first reliable cartographic data, was compared with topographic maps of 1899, 1925 and other recent maps to relate land-use changes with channel changes. Aerial photos from different periods (1953–1955, 1966 and 1997) as well as recent satellite images were interpreted to retrieve geomorphological observations concerning the river's evolution, which were then related to existing hydrological data.

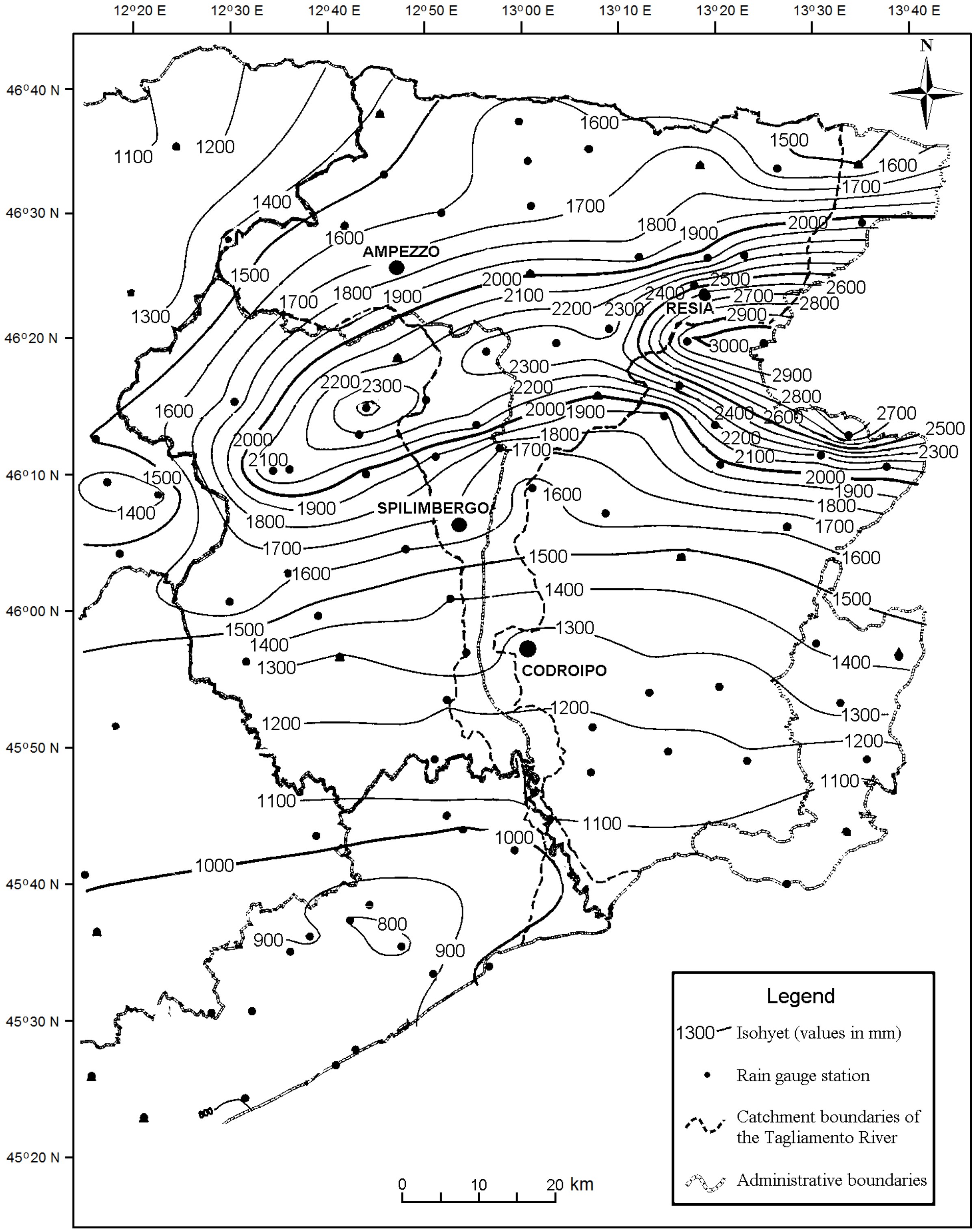
2.3. Description of the present situation

The Tagliamento River originates from Mauria Mountain at 1,195 m and is 175 km long. It has a catchment area of 2,871 km^2 (Basin Authority for the North Adriatic Rivers, 1997), which shows a funnel shape with a wide and mountainous upper part, a smaller and hilly central part, and a long and narrow band in the floodplain (Fig. 2.1). The catchment includes 60 towns with a total population of approximately 180,000 inhabitants.

The principal tributaries of the upper catchment, the Lumiei, the Degano, the But and the Fella, converge and join the Tagliamento River forming a palmate pattern. Their basins are characterised by steep slopes and lie in one of the wettest regions of Italy, where annual precipitation can reach 3,000 mm (Fig. 2.2). Rainfall is concentrated mainly in heavy and erosive showers determining the torrential regime of the river. Furthermore, the mountain basin is seismically active and has a dense distribution of landslides, resulting in much bed load and a braided nature of the river downstream.

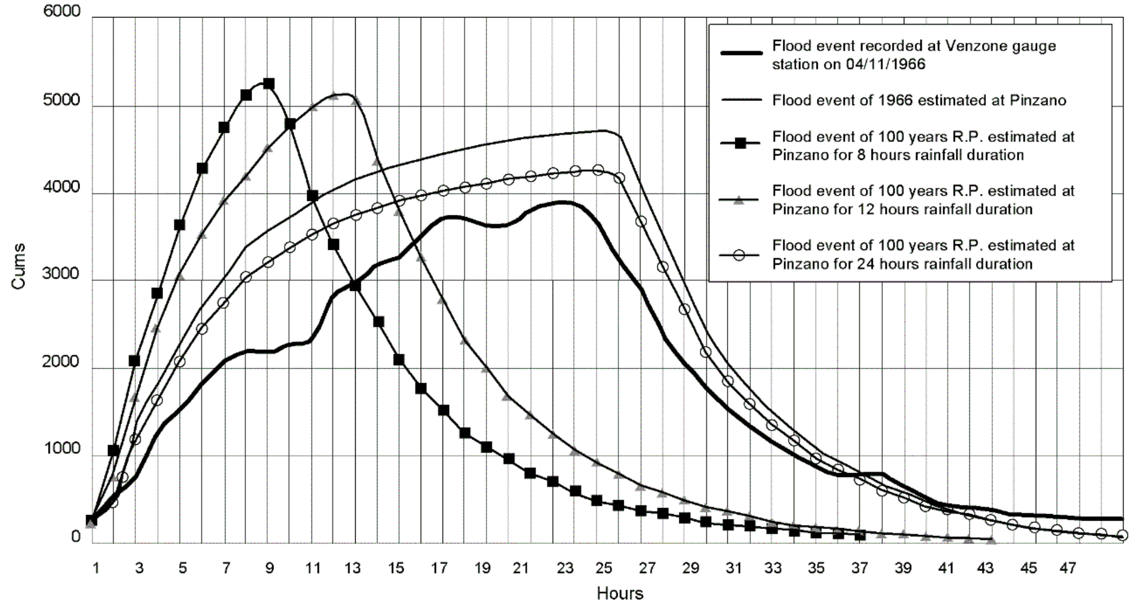
Although this paper focuses on the relation between historic fluvial changes and flooding risk, it is valuable to provide the main hydrological data. The rainfall characteristics cause high peak flows in the central and lower part of the basin. The crest of the peak flow propagates rapidly downstream. The difference in arrival times of the peak between the upstream Venzone gauging station and the downstream Latisana gauging station (Fig. 2.1) is generally 12-16 h. Since the distance between the two gauging stations is 75 km, the crest propagates with a speed of 1.75 m/s. The annual average discharge is approximately 100 m^3/s, while the 50-year return-period (RP) peak discharge is 3,500 m^3/s. For 100 years RP, 4,300 m^3/s, and for 500 years RP, over 6,000 m^3/s (Maione and Machne, 1982). Fig. 2.3 reports the hydrograph of the exceptional 1966 flood recorded at Venzone and the estimated hydrographs at Venzone and Pinzano of flood events of 100 years RP for different rainfall durations, according to the Basin Authority for the North Adriatic Rivers (1997). A linear trend line fitted on a plot with the annual maximum water levels recorded at Venzone gauging station between 1886 and 1996 shows a slight long-term increase (Fig. 2.4). It is difficult to identify how much this increase is due to aggradation of the riverbed or to the increases of discharge; furthermore, in the latter case, it has to be considered that flood discharges are based on extrapolation of rating curves and not on direct measurements.

Figure 2.2: Average annual precipitation for the period 1961- 1990



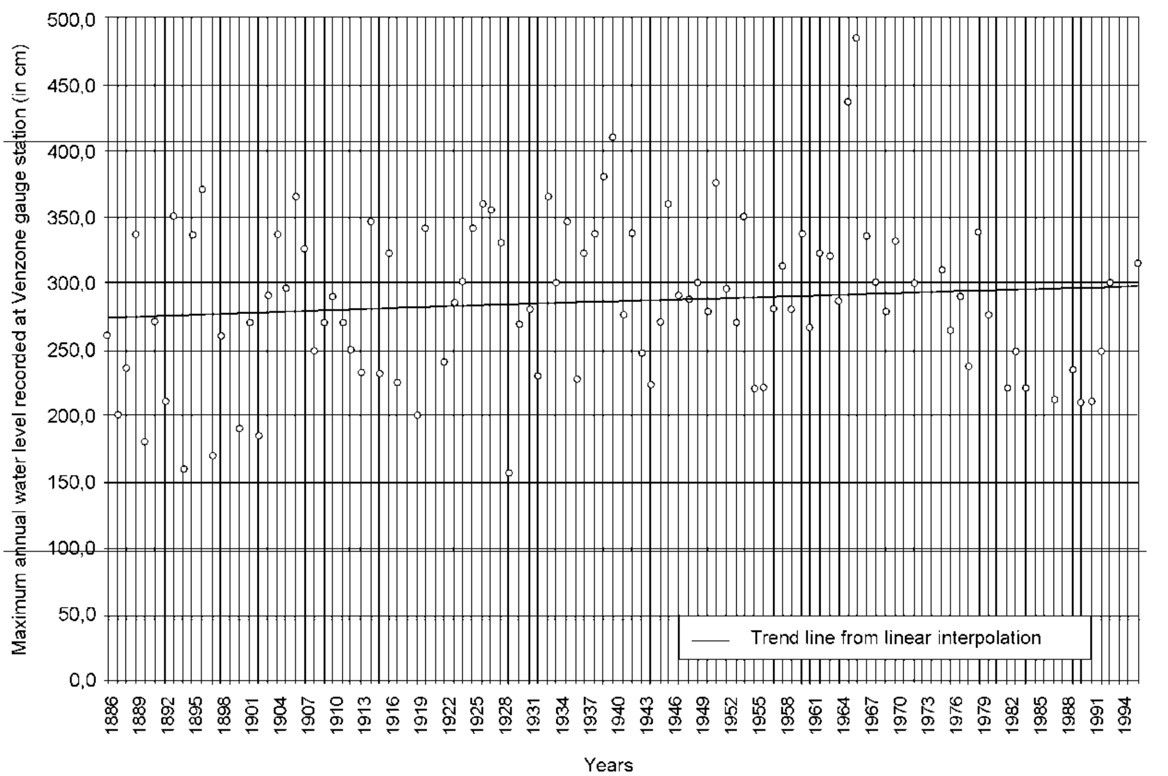
(Source: Basin Authority for the North Adriatic Rivers)

Figure 2.3: Recorded and estimated hydrographs of major flood events of the Tagliamento River



(Source: Basin Authority for the North Adriatic Rivers)

Figure 2.4: Maximum annual water levels recorded at Venzone gauge station for the period 1886-1996



(Source: Basin Authority for the North Adriatic Rivers)

The study area, which starts from Pinzano and reaches the outlet in the Adriatic Sea, is represented by the middle and lower Tagliamento (Fig. 2.1). From the Pinzano gorge to the confluence with the Cosa tributary, the river is confined between two high Quaternary terraces and can reach a maximum width of 3 km near Spilimbergo during periods of high water. There starts the large S. Vito alluvial fan of the river (Figs. 2.5 and 2.7), which has an area of 500 km^2.

The riverbed in the middle part is fully braided, as would be expected under conditions of irregular discharge, high bed load and associated relatively steep gradient of the alluvial fan. Because the braided reach is wide and shallow and the channel banks are unstable, the rate of sediment transport per unit width of channel may be relatively low (Leopold et al., 1964). In this river stretch, the average width of the active riverbed is about 1 km and is aggrading, as discussed below. The cross-section in Fig. 2.6 shows the riverbed at the highest position on the San Vito cone. Dry season flows infiltrate fully.

The lower Tagliamento starts near Madrisio, where the river changes to a single channel showing a semi meandering pattern. This change is accompanied by a less steep gradient and finer grained sediments in the riverbed. The river width reduces drastically and measures 175 m at Latisana. At this location, as an average, the river bottom is 14 m deeper than the immediate surroundings, while the dikes are on average 6 m higher. Latisana, located 25 km from the coast, was an estuarine settlement in the past; at this distance, the river is under a tidal backwater effect. This factor caused overflow in front of the town during the last major flood event, in 1966, when a peak discharge greater than 4,000 m^3/s was estimated at Latisana gauging station. During the second half of the 19th century, the Cavrato channel was built 10 km downstream of Latisana to dissipate the high water. Its capacity has been recently enlarged to 2,500 m^3/s and it starts to function once the Tagliamento reaches a discharge of 2,000 m^3/s (Foramitti, 1990).

Figure 2.5: Alluvial fans of the rivers Tagliamento, Corno and Meduna

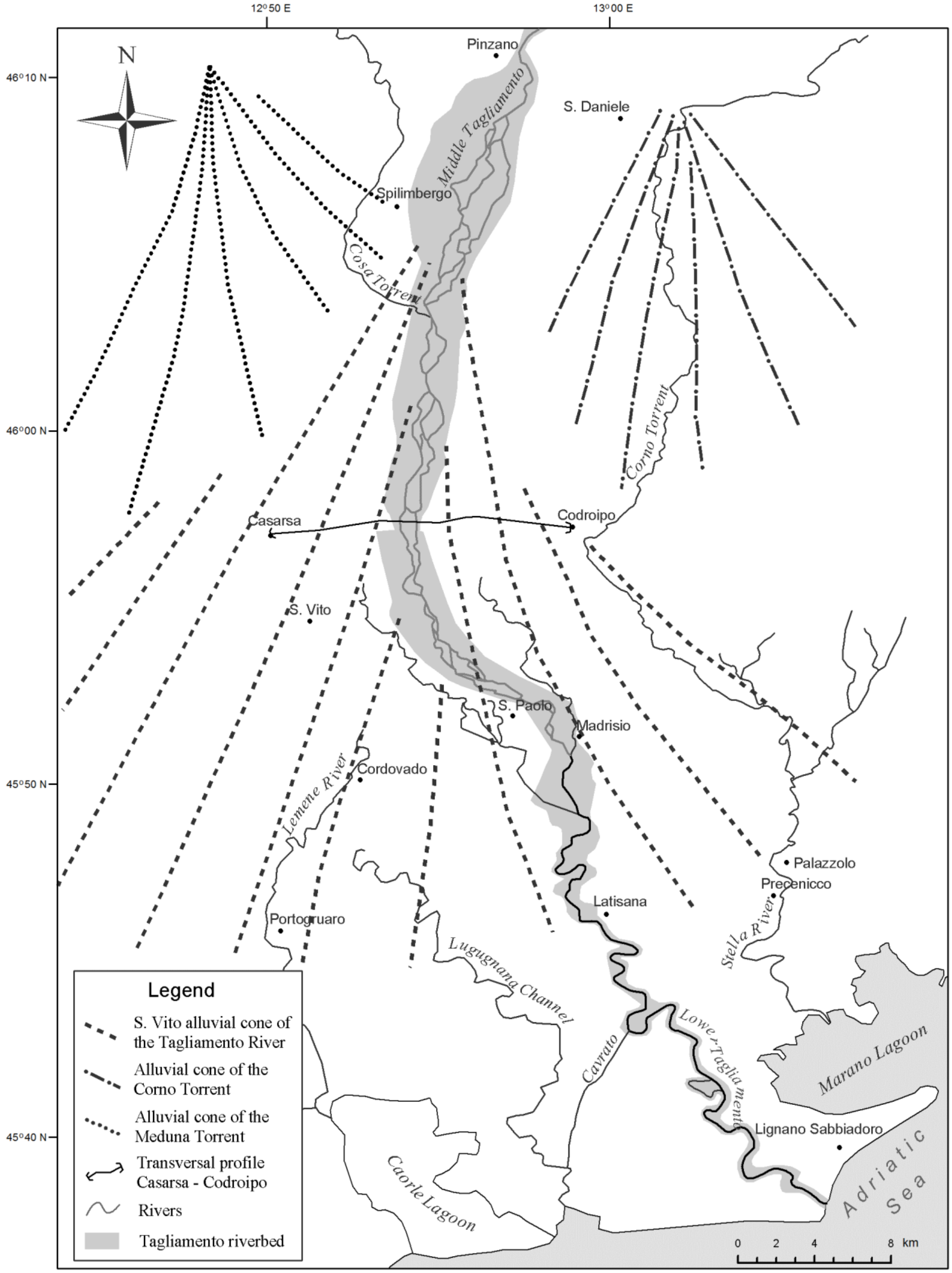
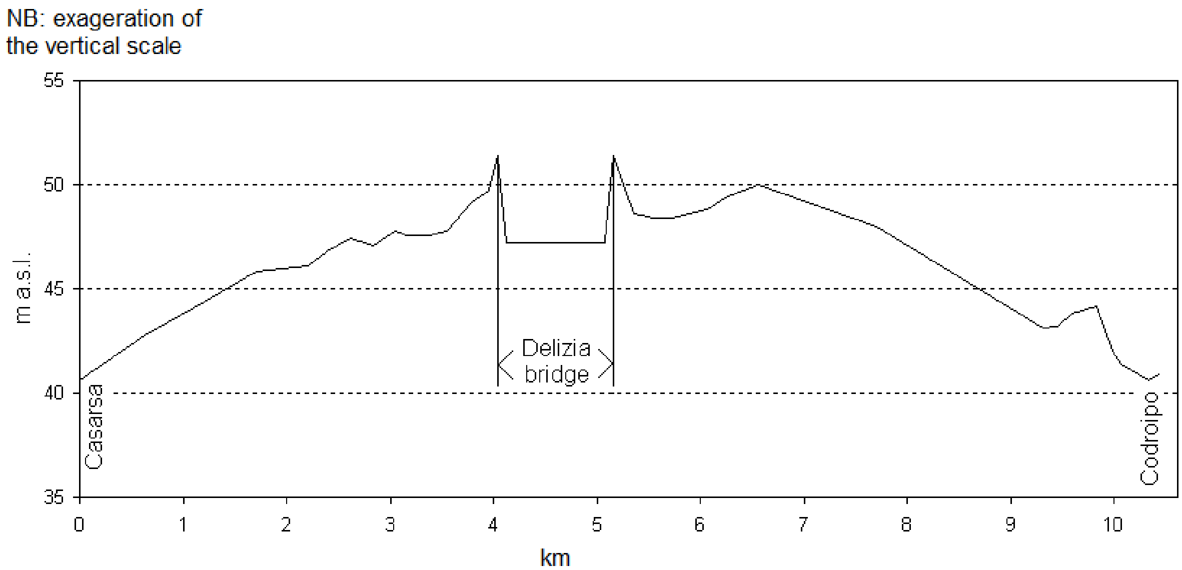


Figure 2.6: Transversal profile Casarsa-Codroipo extracted from topographic map 1:10,000



2.4. Historical evolution of the fluvial dynamics

Historical documents were used to reconstruct and map the evolution of the Tagliamento during the past centuries. Of particular interest is to analyse the location and area of the floodplain, the flood and sediment regime and to define fluvial corridors.

The overall setting of the lower and middle Tagliamento catchment is shown on LANDSAT Thematic Mapper false colour composite of Fig. 2.7. The band combination used for the false colour image is a result of experimentation to obtain an image with most hydrological and geomorphological information.

The older Quaternary deposits can be recognised by the large alluvial fan of the ancestors of the Tagliamento River: the Udine fan. It stretches from the city of Udine in the east to Pordenone in the west, where the wide Meduna and Cellina braided riverbeds are deflected along the old fan to the southwest. As mentioned, the upstream part of the middle Tagliamento River is incised in the older fan deposits. The zonation of decreasing grain sizes of the Udine fan is reflected in the land use pattern, as indicated by four zones in the image. At the start of the Holocene, the Tagliamento River occupied the western part of the old fan and formed during the period 18,000-6,000 BP the San Vito alluvial fan (Fantin, 1990), shown also in Fig. 2.5. The western position is probably due to the complex configuration of the glacial deposits within the Osoppo amphitheatre that obliged the river to pass through the Pinzano gorge. It is also possible to delineate the fluvial deposits from the coastal plain sediments on the image, as shown. The partial on-lap of the Tagliamento fluvial deposits on the coastal plain sediments south of Latisana can be noted, as well as the redistribution of the sands by long shore transport in the small and young delta, which has grown beyond the coastal plain. Before the 10th century, there was an uninterrupted lagoon between Ravenna in the south and Grado in the north (Fantin, 1990). This important water body was divided in the lagoons of Comacchio, Venice, Caorle, Marano and Grado between the 10th and the 14th centuries by intense alluvial depositions of the north

Adriatic rivers, in particular the Tagliamento River, due to deforestation in the Alpine region (Fantin, 1990).

During the Roman Empire, the Tagliamento River flowed in two main branches: *Tiliaventum Maius*, which had approximately the present position, and *Tiliaventum Minus* (TM in Fig. 2.7) that most probably was more in the east, where the rivers Corno and Stella are located (Averone, 1911). The rivers Lèmene and Stella and the Lugugnana channel were all Tagliamento's riverbeds (A, B, C and D in Fig. 2.7) during the past centuries (Averone, 1911); at present, only groundwater is discharged in these beds (Stefanini and Cucchi, 1977, 1978). In fact, the diverging branches mark active fan formation downstream of the incised part of the Tagliamento River. These ancient branches were often reused during the main flood events (Scimone, 1927; Ciconi, 1855; Rinaldi, 1870; Castellarin, 1990) and urban settlements like Portogruaro, Palazzolo or Precenicco, which are located relatively far from the Tagliamento, were flooded repeatedly (Figs. 2.8 and 2.9) until the dikes for the middle Tagliamento were completed, after 1850 (Fig. 2.10).

During the period 1400–1599 (Fig. 2.8), the middle Tagliamento flowed more to the west compared to its present position (Rinaldi, 1870), i.e., in alignment with its ancient riverbeds A, B and C (Fig. 2.7). Therefore, the towns of Cordovado and Portogruaro were flooded several times.

From 1600 to 1799 (Fig. 2.9), an eastwards migration took place and, consequently, the ancient riverbed D was reoccupied several times during the inundations (Castellarin, 1990). Even the *Tiliaventum Minus* was used twice (Fig. 2.10).

Figure 2.7: Interpretation of the study area using a LANDSAT Thematic Mapper 5 image

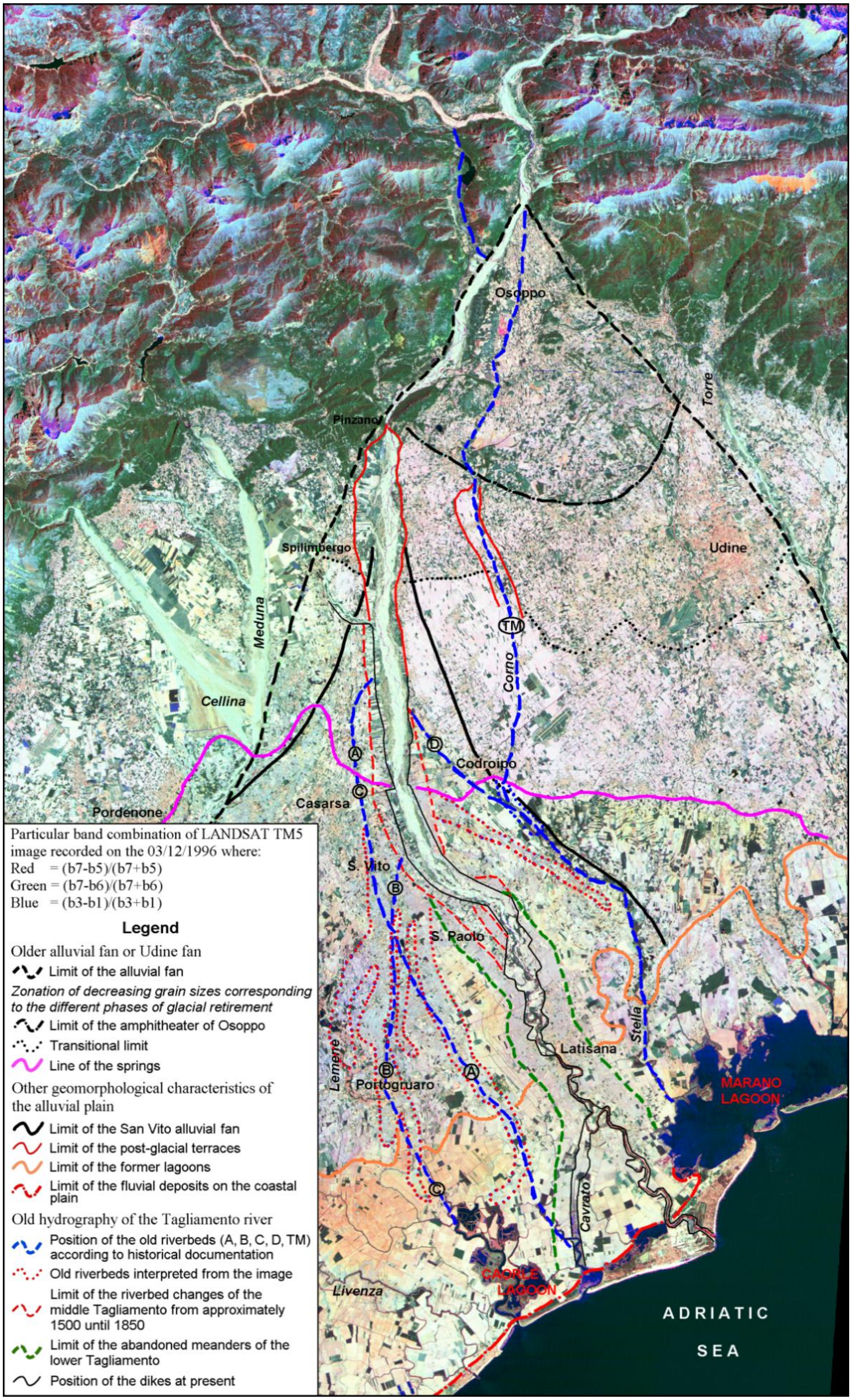


Figure 2.8: Fluvial dynamics for the period 1400-1599

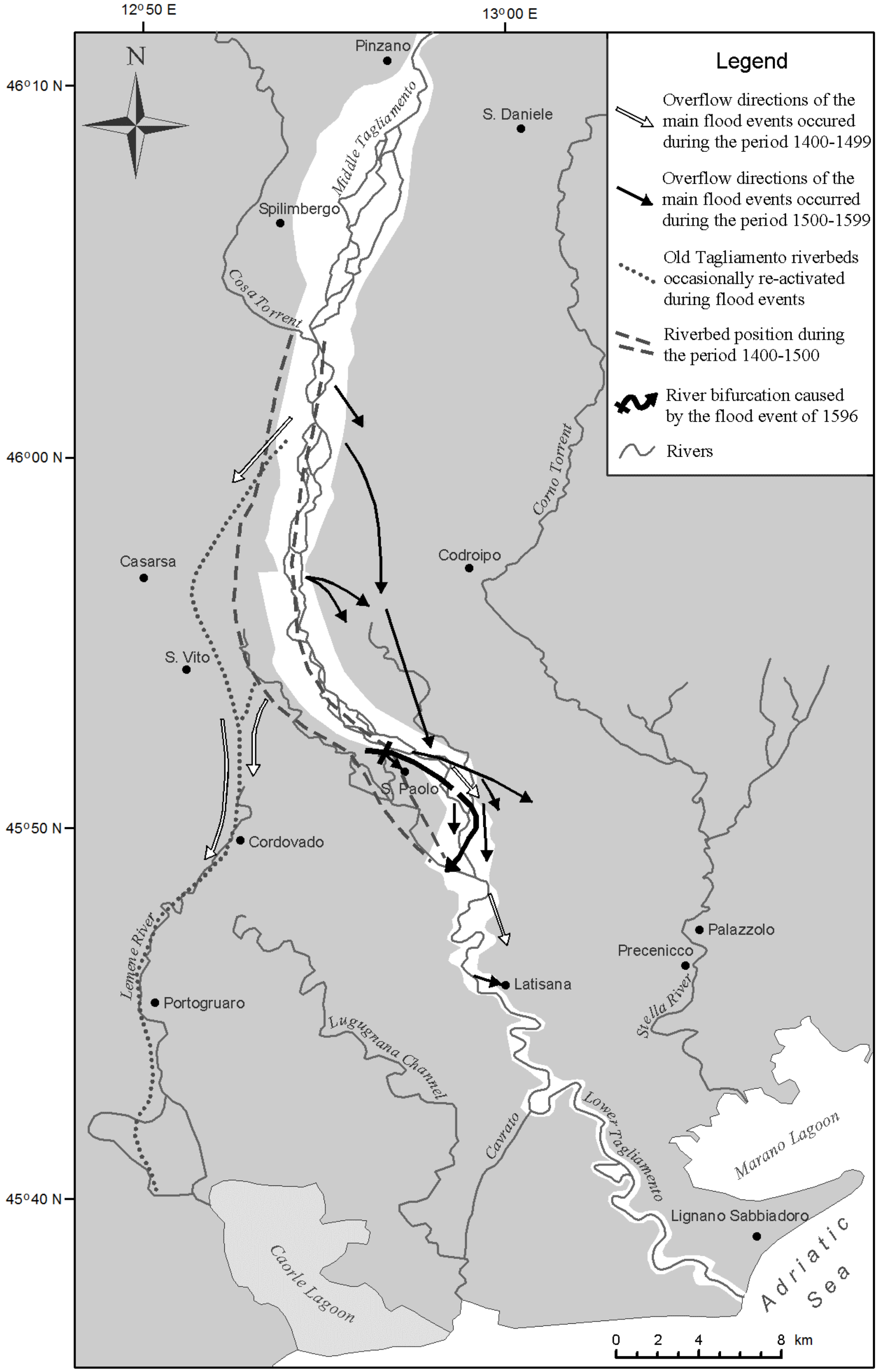
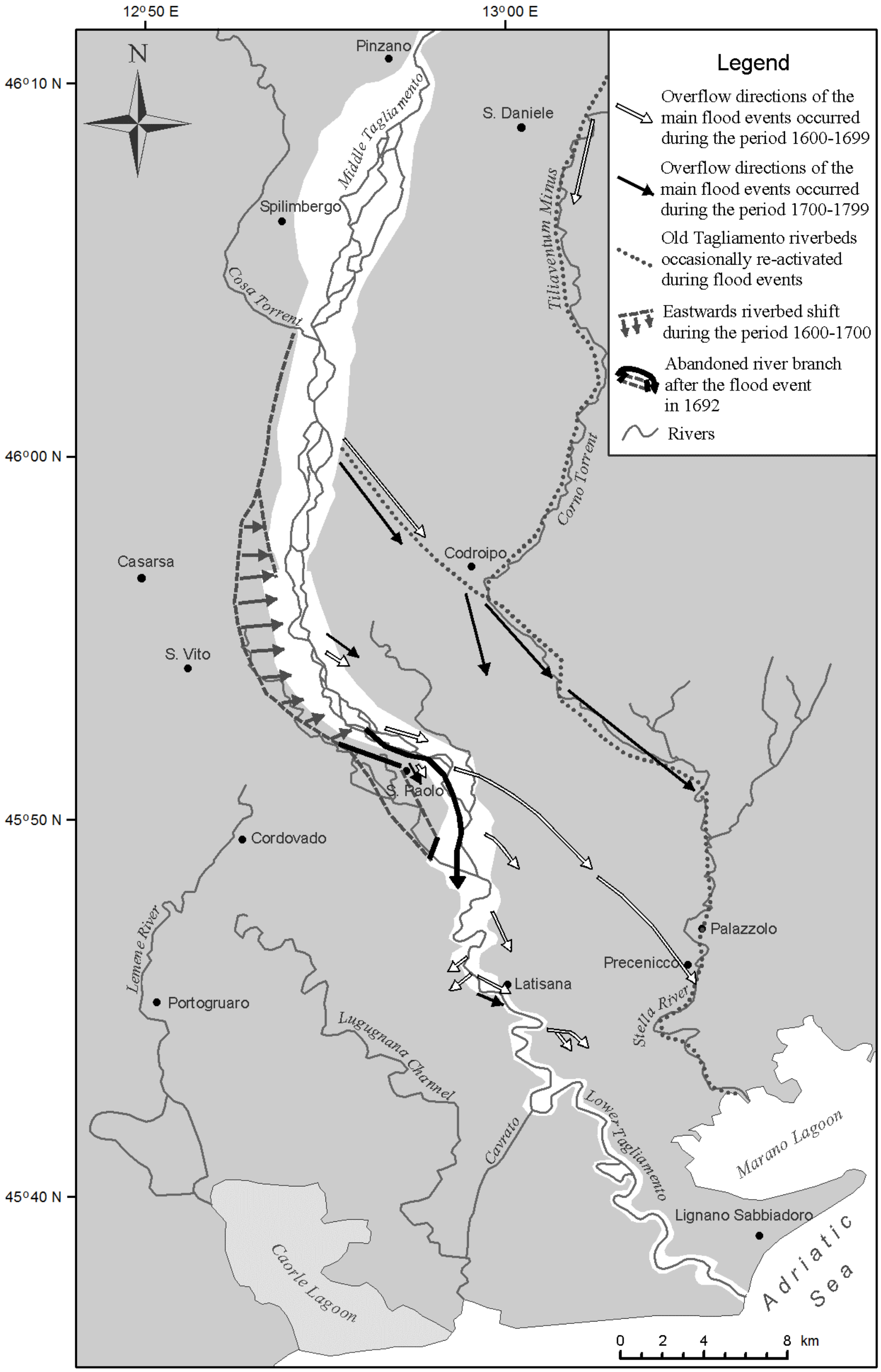
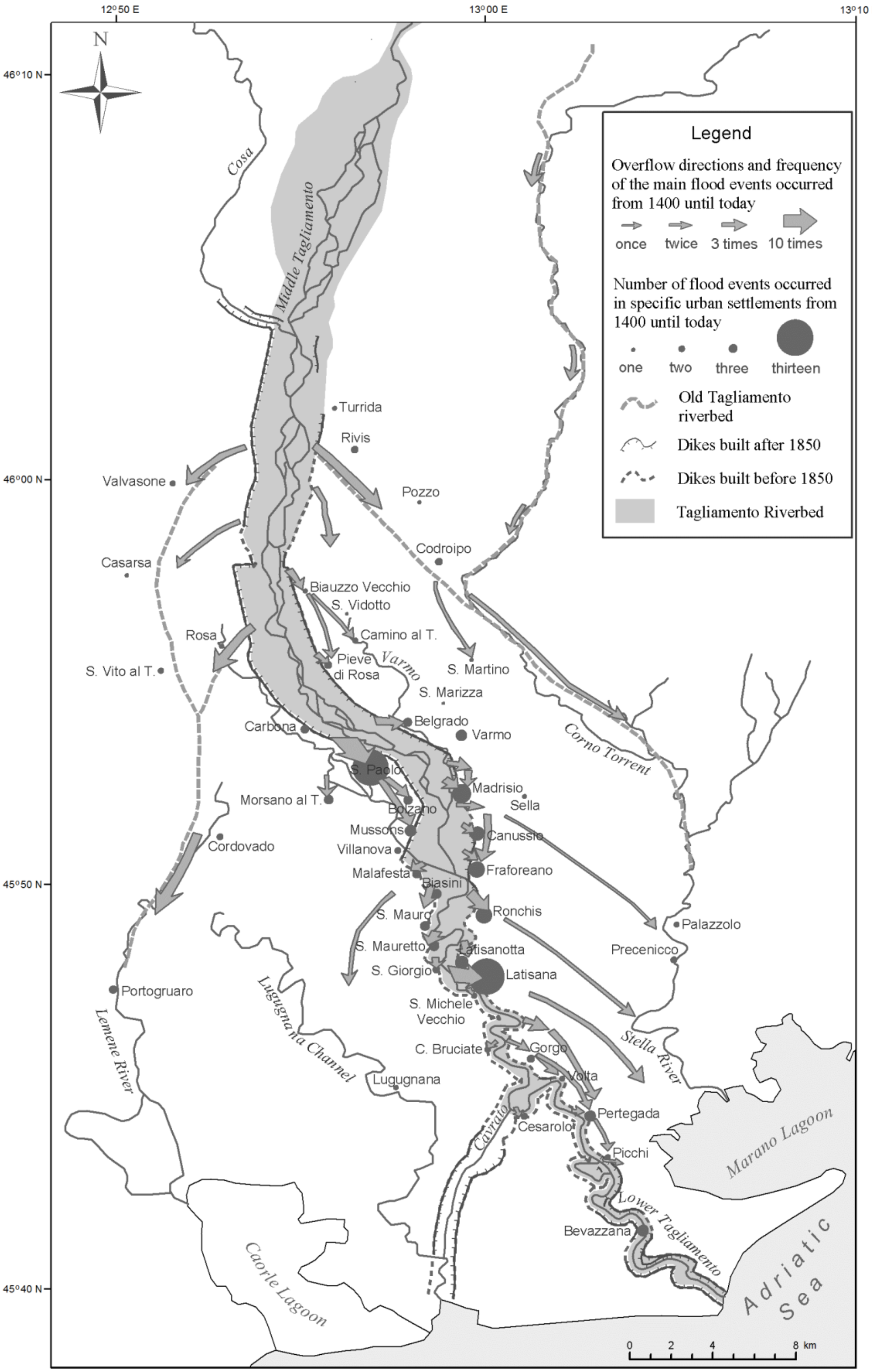


Figure 2.9: Fluvial dynamics for the period 1600-1799



<u>Figure 2.10</u>: Synthesis of the historical dynamics of the Tagliamento River



In particular, from 1596 to 1692, the river bifurcated at the transition between the medium and the lower Tagliamento, forming an island where the settlements of San Paolo, Bolzano and Mussons were located (Castellarin, 1990). After an important flood in 1692, the river occupied the eastern branch, its present position. However, since that time, the abandoned western branch was used several times during the flood events (even during the last one in 1966), causing important damage in particular to the city of San Paolo (Fig. 2.10).

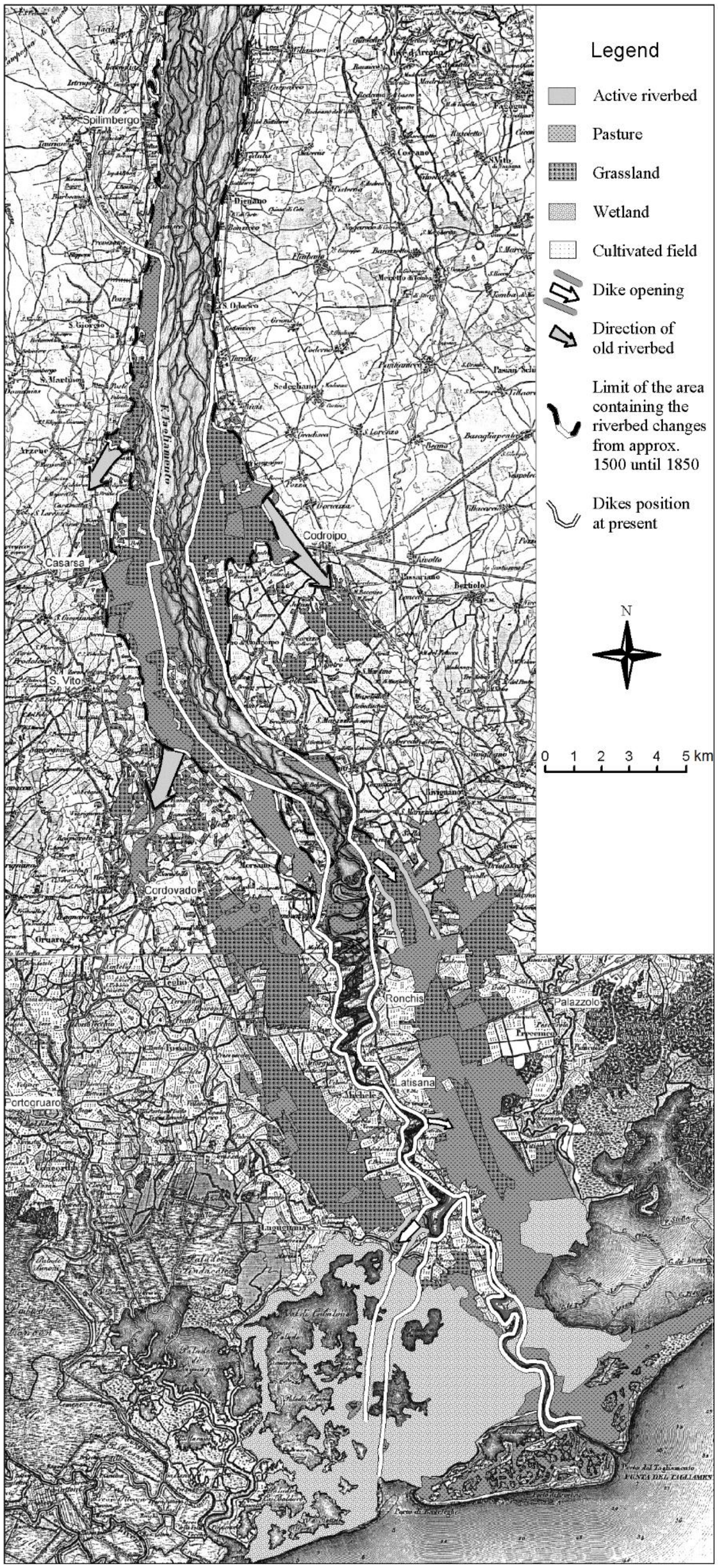
During the flood events of the first half of the 19th century, when the middle Tagliamento was still free to migrate eastwards or westwards at the top of its alluvial fan, the old riverbeds of both sides were re-used. With the growth of the population after the industrial and agrarian revolution, the pressure on the riparian lands increased and agricultural practices changed. The information reproduced in Fig. 2.11 was derived from the land use map of 1833 made by official surveyors of the Austrian Empire, which shows the situation before the major pressure developed. Areas prone to inundation were grasslands, wetlands or were used for pastures. In the middle Tagliamento, these uncultivated areas clearly indicate that the old river courses (A, B, C and D) and the bifurcation close to San Paolo were left as they were for centuries; however, patches of cultivated areas along the edges of the floodplain witness the attempt to occupy what was fluvial space in favour of agriculture. The town of Latisana, being a major stakeholder and at the most vulnerable position, played a role in maintaining the status quo flood protection in a natural manner. The uncultivated lands of the lower Tagliamento served as overflows during major flood events through openings in the dikes. These areas were part of a large lagoon (Fig. 2.7). This technique of dissipation was applied to protect the important settlements and the cultivated fields located in the riparian zones of the lower floodplain (Scimone, 1927; Castellarin, 1990).

After 1850, dikes were completed for both the middle and the lower parts of the river (Fig. 2.10). Meanwhile, the openings in the dikes were closed (Croci, 1899), the wetlands adjacent to the lower Tagliamento were drained for cultivation purposes, as well as significant parts of the lagoons of Marano and Caorle, and the grasslands and pastures were progressively converted into cultivated fields. Thus, during the second half of the 19th century, the hydraulic regime of the Tagliamento River was drastically modified by man. Instead of the former situation where the floodwaters had space to spread out over a wide floodplain and over several branches and overflows, they were now contained by dikes in a narrowed floodplain. Consequently the frequency and the magnitude of overflows increased in the lower Tagliamento and, in particular, in the stretch where the river changes from braiding to meandering, upstream of Latisana town (Fig. 2.10). Even if the reliability of historical records depends on the potential for channel changes that could alter stage-discharge relations at the site (Cook, 1987), Table 2.1 seems to confirm that in Latisana, significantly higher water levels were recorded after 1850. It can be expected that the situation will get worse, since the downstream part is the narrowest, as it is still adjusted to the earlier conditions where the flood peaks were attenuated by upstream storage over a wide floodplain and branches, and the coarse bed load was laid down in the upstream parts. The channel patterns of the area upstream Latisana were interpreted using aerial photos of 1953 and 1997, and it was found that traces of meanders are present in stretches where the river is now braiding. Therefore, we can conclude that sediment wedge associated with the aggradation of the middle section was curtailed by the dikes and has moved downstream; this process may have contributed to the trend shown in Table 2.1.

Table 2.1: High water levels recorded since 1800 in Venzone gauging station and in Latisana gauging station during the major flood events

Major flood events after 1800	High water level in Venzone (m)	High water level in Latisana (m)
15/10/1823		8.1
02/11/1851		8.2
28/10/1882	3.9	8.76
21/10/1896	3.7	9.88
02/09/1965	4.37	10.5
04/11/1966	4.85	10.88

Figure 2.11: Interpretation of the land cover map of 1833



(Source: Land-use map made by the official surveyors of the Austrian Empire, 1833)

There is no reason to expect that either the flood produced by rainfall or the sediment yield of the upper mountain catchment will reduce in the near future, so the sediment wedge will continue to migrate downstream. From a geomorphological point of view, the river will tend to maintain a steep gradient as an adjustment to the high sediment load and irregular discharges (Schumm et al., 1987), which it can achieve by extending the braided course ultimately to the sea. Similar narrowing of braided rivers (e.g. the Agri River in South Italy) by dikes has led to substantial increases of the absolute level of the bed, with the consequence that flood discharges cannot be contained by the cross-sectional area between the dikes (Meijerink, 1984). Breakthrough of the dikes can then be expected and in the worst case, the river finds a new course in the adjoining, topographically lower areas.

The map in Fig. 2.10, which synthesises the fluvial dynamics resulting from the historical analysis, confirms this tendency. It can be observed that the river overflowed mainly at the same locations, in particular, close to San Paolo where, as mentioned above, the river bifurcated for almost one century, and downstream where the transition from braided streams to a single meandering channel engenders a much narrower river section.

This paper does not provide a full understanding of the fluvial dynamics, which would require further investigation. Other natural factors could be considered, such as tectonic movements determining uplift or subsidence processes, changes in sea level and changes in rainfall regime. For example, the possible effects of the little Ice Age on the bed load are unknown. Little information exists on the frequency of landslide contribution to the sediment load, a part from some reports by Ciconi (1855) concerning the flood events of 1851, which caused the bifurcation near San Paolo as did that of 1962. Detailed topographic surveys, such as longitudinal profile and cross-sections, would be needed to document the process of river aggradation since the 19^{th} century.

2.5. Planned measures for flood mitigation

The only remediation so far for the problems created by the interventions of the 19^{th} century was to increase the height of the dikes and to maintain the Cavrato channel as the only diversion for floodwaters.

At present, a plan to construct three interlinked retention basins between Pinzano and Spilimbergo is under discussion for approval. The attenuation of the flood peaks by channel, floodplain storage and transmission losses in the middle Tagliamento would be modified by the basins; they are designed for a capacity of 30 million m^3 that should reduce the peak discharge from 4,600-5,000 to 4,000 m^3/s at Latisana (Foramitti, 1990). It is planned to construct the basins in the western part of the post-glacial valley, nowadays intensely cultivated. Their construction would cause severe reduction of the riverbed width with consequences for the erosion-sedimentation regime of the river, as well as rapid groundwater seepage because of the coarse gravels below the retention basins, with dikes of 10 m height (Foramitti, 1990). Furthermore, in light of this research, that project does not solve the risk of aggradation in the downstream stretch between San Paolo and Latisana in the medium to long term.

Concerning the area where it is planned to construct the basins, a progressive expansion of Spilimbergo City close to the western terrace of the post-glacial valley has occurred since the beginning of the 20^{th}

century, while the Tagliamento River was shifting eastwards. New settlements were built in an area that had been actively occupied by the riverbed a few decades earlier. Even if at present the river is flowing more than 2 km away from these settlements, close to the eastern terrace, the valley was entirely occupied by the riverbed less than two centuries ago and has been regularly flooded during important flood events (the last time was in 1998).

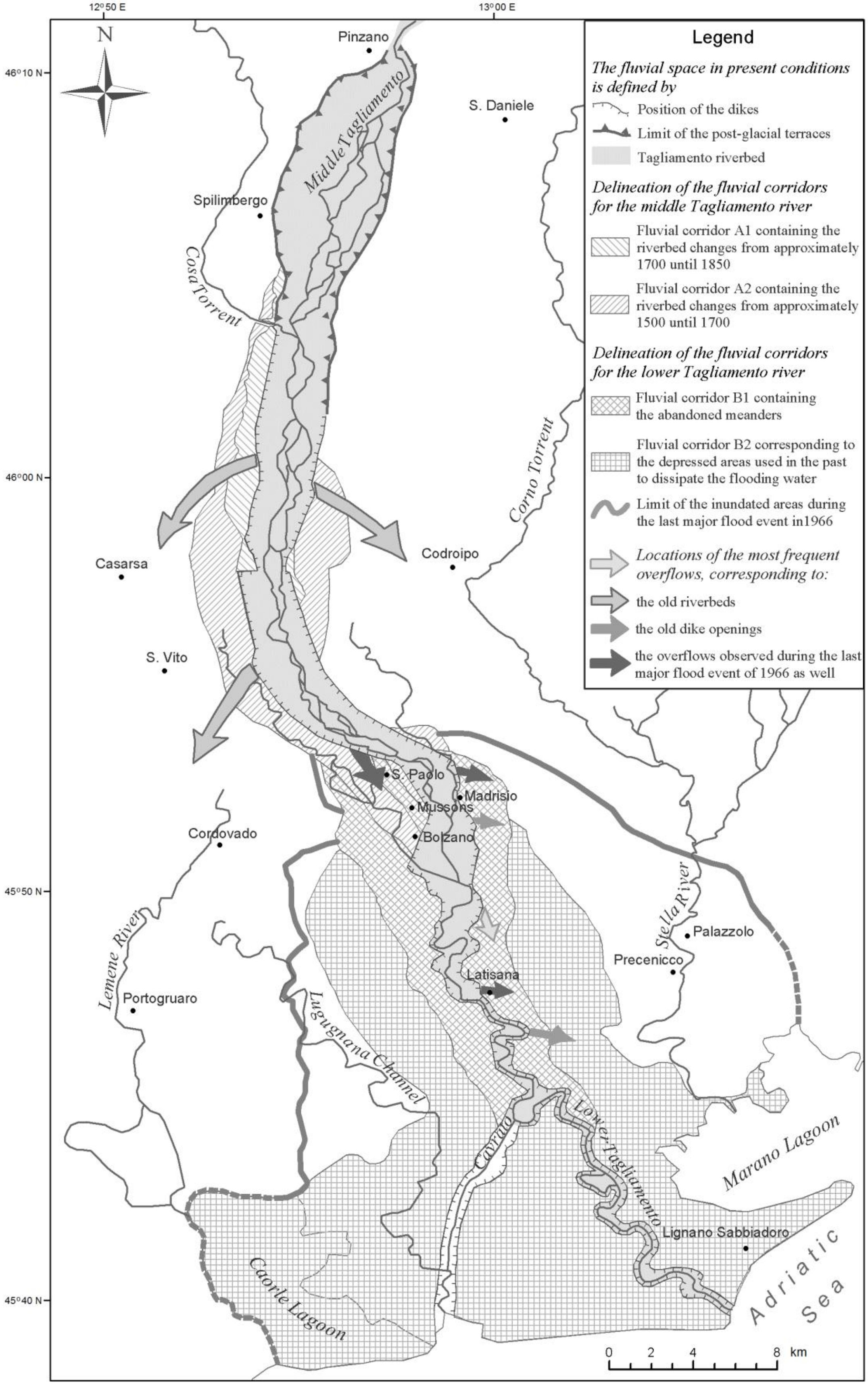
2.6. The option of fluvial corridors

The medium to long term prospects necessitate to develop options other than solely retention basins. First of all, floods larger than the 1966 event may be expected, not only on statistical grounds, but also because most climatic change models agree that rainfall extremes will increase. Even with an attenuation of the flood peak by the planned retention basins by some 15-20%, the effects of the moving sediment wedge towards Latisana will still cause a dangerous situation.

One option was building a dam in the narrow gorge of Pinzano in order to create a reservoir upstream of
50 million m^3, but it met strong opposition from the local communities (Foramitti, 1990).

Another option left is to consider fluvial corridors (Gardiner, 1990; Govi and Turitto, 1994) in the middle to lower Tagliamento. The corridors should reflect the historical fluvial geomorphological developments and the areas where floodwaters found their way. In that perspective, a fluvial corridor is described here as a zone that belonged in historical times to the active part of the fluvial ecosystem and that appears to be still under the rivers' influence when analysing flood dynamics. The map of Fig. 2.12 shows fluvial corridors by taking into account the past dynamics of river shifts and locations of frequent overflows. The map provides the background information as a starting point for further working out expansion of the present Tagliamento corridor, which has too limited capacity. Widening the river by shifting the dikes downstream of the transition between middle and lower Tagliamento would provide an obvious corridor, but the presence of significant urban settlements at both river edges, such as Latisana and S. Michele, causes problems. In this sense, the map can be used for the planning of urban expansion and infrastructure to avoid developments that may form additional burdens in the near future.

Figure 2.12: Definition of the fluvial corridors



The middle Tagliamento has two categories of corridors corresponding to different stages of the river's evolution. The *fluvial corridor A1* includes more recent changes in the riverbed width, approximately between 1700 and 1850. During flood events, the dikes are subject to the lateral erosion of the river trying to reoccupy its former corridor. Particularly dangerous is the section narrowed by the dikes of the two Delizia bridges. The *fluvial corridor A2* contains the riverbed migrations approximately during the period 1500–1700. Since the construction of the dikes, this area has been relatively stable, except at places of the former courses indicated by arrows in Fig. 2.12. During the last major flood event of 1966, near San Paolo, the right bank dike was overtopped and damaged.

The abandoned meanders of the lower Tagliamento were detected by aerial photo interpretation. Their spatial pattern and distribution density allowed the definition of the *fluvial corridor B1*. It is interesting to notice that the old meanders are more concentrated where the river overflowed frequently in the past, e.g. in front of Latisana. Several abandoned meanders were found upstream of the place where the river starts to meander nowadays. Thus, as mentioned above, the sediment wedge associated with the braiding-meandering transition has moved downstream, but the floodplain confined by the dikes is narrowing, which creates hydraulic instability.

For the zone B2, the limit of the depressed areas used in the past for the dissipation of the flood is taken as corridor receiving the floodwaters from zone B1. Because of the downstream shift of the braiding-meandering transition and the confined narrow width of the lower Tagliamento, this zone will remain a vulnerable zone in the medium to long term. The map shows also the limit of the inundation of 1966, when the river overflowed at the same locations as the historical events.

The number, delimitation and dimensions of the corridor(s) should be based on hydraulic modelling, assuming a further rise of the braided riverbed, detailed topography and according to the land use and land ownership within potential delimitations.

Finally, concerning the future evolution of the riverbed's position, it seems that the lower Tagliamento tends to shift eastwards since a greater frequency of damage was suffered by the eastern riparian territories during the last major inundations. On the other hand, the middle Tagliamento pushes westwards to reoccupy its former riverbeds A, B and C (see Fig. 2.7).

2.7. Conclusion

The fluvial geomorphological development of the Tagliamento River and flooding history are described and analysed using historical documents and interpretation of satellite images and aerial photographs. The geologic and climatic conditions of the upper catchment determine a hydraulic regime with high sediment load and irregular discharges, which led to the formation of a complex geomorphology of the alluvial plain. The riverbed of the middle course is aggrading and the transition from braiding to meandering is shifting downstream. These natural processes favour the flood risk, which was increased by the confinement of the river by dikes after 1850. The historical analysis confirmed that the flood hazards tend to concentrate in the same locations where historic fluvial changes occurred, allowing the delineation of the areas under major risk. Therefore, since the planned retention basins will not solve the problem in the medium-long term, fluvial corridors were defined. The results of the approach adopted in this study could be integrated with hydraulic studies that are commonly carried out, in order to obtain more information on the complexity of fluvial dynamics. For example, modelling the propagation of flash floods should be extended to include the use of corridors, to develop a plan for flood containment. The effects of further aggradation of the riverbed should be included in the modelling. It will be wise policy to start considering restrictions on land use and infrastructural development in the zones of anticipated future fluvial corridors.

2.8. Acknowledgements

I would like to especially thank late Prof. Mario Govi for the important scientific contribution to this research, Prof. A.M.J. Meijerink for the precious support in writing this article and improving its scientific contents, Prof. E. Kosters for the pertinent advice he gave me after reading it, Prof. A.M. Harvey and Prof. W.A. Marcus who carefully reviewed the paper, resulting in significant improvements, and Ir. Lluis Barcons for the technical support in map digitising and map editing.

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3. Analysis of the territorial vulnerability to flooding in the Limpopo basin through the description of the past river's evolution and geomorphological approach

Mathias Spaliviero, Morgan De Dapper, Sérgio Maló; submitted to GEOMORPHOLOGY on 16 February 2013 (feedback from peer-reviewers received on 1 June 2013)

3.1. Abstract

In this paper a reconstruction of the past evolution of the Limpopo River, a transboundary drainage system located in south-eastern Africa, and a geomorphologic approach are carried out through an extensive literature review and field work activities. The main purpose is to analyse the territorial vulnerability to floods in the basin. Major changes have occurred since the late Jurassic - Early Cretaceous period due to successive tectonic events. This paper demonstrates that the apparently abandoned drainage conformation of the palaeo-Limpopo constitutes today preferential flood-prone areas in case of major rainfall events in the upper and middle stretches of the river. An important palaeo-delta is identified in the lower Limpopo which imposes a particular drainage pattern to the floodplain in Mozambique and determines the floods dynamics at present. The adopted method proves to be helpful in determining the territorial vulnerability to floods in a data scarce-area which shows complex fluvial dynamics, and allows identifying unsuitable locations for developing human settlements.

Keywords: Floods; Territorial vulnerability; Tectonics; Geomorphology; Palaeo fluvial forms

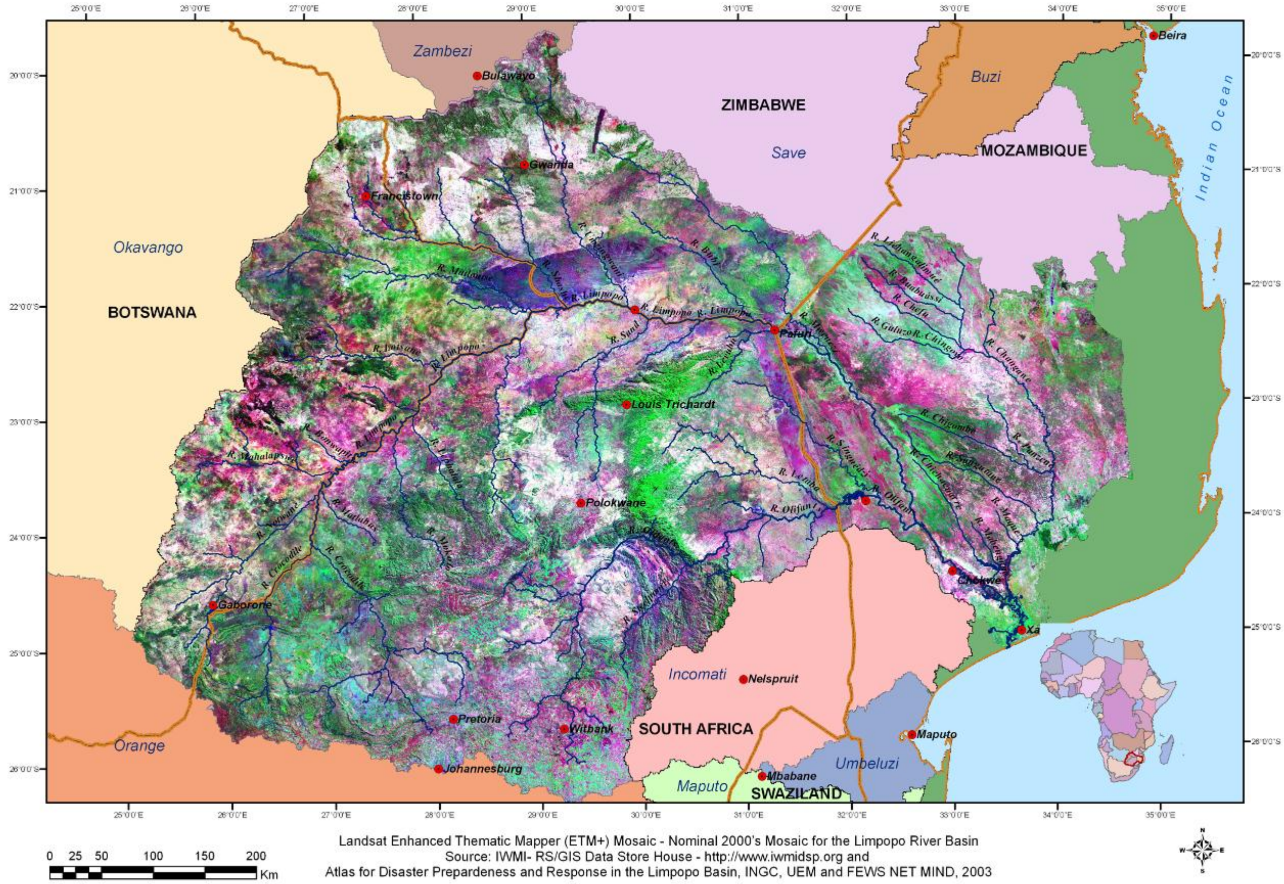
3.2. Introduction

The Limpopo River belongs to a transboundary basin located in the south-eastern Africa and has its outlet in the Indian Ocean (see Fig. 3.1). Spaliviero et al. (2011) noted that human settlements tend to concentrate closer to river streams due to the semi-arid or sub-humid conditions of the basin. The same authors indicate that a demographic increase was registered in recent decades in the Botswana and South Africa sections of the basin, in the delta area and along the main river channel in Mozambique, as well as in the upper reaches of the basin in Zimbabwe, often in areas prone to flooding. The greater human density in these areas increases the level of vulnerability. It therefore becomes important to propose scientific methodologies which can allow the identification of areas suitable for developing human settlements with a fair level of accuracy using a limited amount of hydraulic data, despite the natural complexity of the river and its flood dynamics.

Spaliviero (2003), while studying the historical evolution of the Tagliamento River in northern Italy, concluded that flood hazards tend to concentrate in the same locations where historic fluvial changes occurred, allowing the identification of areas under major risk. Similarly, the main objective of this paper is to analyse the territorial vulnerability to floods in the Limpopo River basin based on a better understanding on how it has evolved in the past and of its geomorphological characteristics. As stated by Goudie (2005), a detailed and systematic understanding of the complex African drainage system still requires further investigation. This statement particularly applies to the southern Africa sub-region.

Specifically, we will try to answer the following question: Do clear relationships exist between past fluvial changes and territorial vulnerability to floods in the Limpopo River basin?

<u>Figure 3.1</u>: Satellite image mosaic of the Limpopo River basin



(<u>Source</u>: Maló and Da Conceição, 2007)

From a methodological point of view, the past description of the river's evolution is combined with a geomorphological approach. In particular, this paper investigates the role played by tectonics (as underlined by Blum & Tornqvist, 2000) in determining major changes of the Limpopo River. First, we reconstruct the past development of the river through a literature review regarding the geological evolution of southern Africa since the late Jurassic - Early Cretaceous period. Then, we collate data from participatory land use planning exercises undertaken in the upper-middle Limpopo and geomorphological observations made in the lower Limpopo during a field visit to provide evidence that apparently abandoned palaeo drainage patterns are often re-activated by the floods at present. Finally, we analyse the geographical extent of the flood events that occurred in the years 2000 and 2013, we discuss the relevance of the approach proposed and we derive some conclusions.

3.3. The geomorphological evolution of southern Africa since the Jurassic period and its influence on the Limpopo River's development

For a better understanding of the current fluvial geomorphological settings of the Limpopo River basin, one needs to revert to the late Jurassic - Early Cretaceous period corresponding broadly to the Gondwana disruption (separation of the supercontinent and formation of the existing continents due to plate tectonics). In general, the sequence of events which have successively changed the territorial morphology of southern Africa from the Jurassic to present consisted in cycles of erosion (Maufe, 1935; King, 1963; Lister, 1987; Partridge and Maud, 1987). According to the pioneering interpretation of Du Toit (1933) which has then been substantiated by the findings of Moore (1999), Moore and Blenkinsop (2002), Cotterill (2003) and Moore et al. (2007, 2008, 2009a, 2009b), the referred erosion cycles were primarily triggered by crustal movements determining periodically new drainage patterns. The same authors infer that these crustal movements are the result of complex plate tectonic dynamics associated with rifting processes and deep-originating mantle plumes, resulting in crustal flexuring or warping.

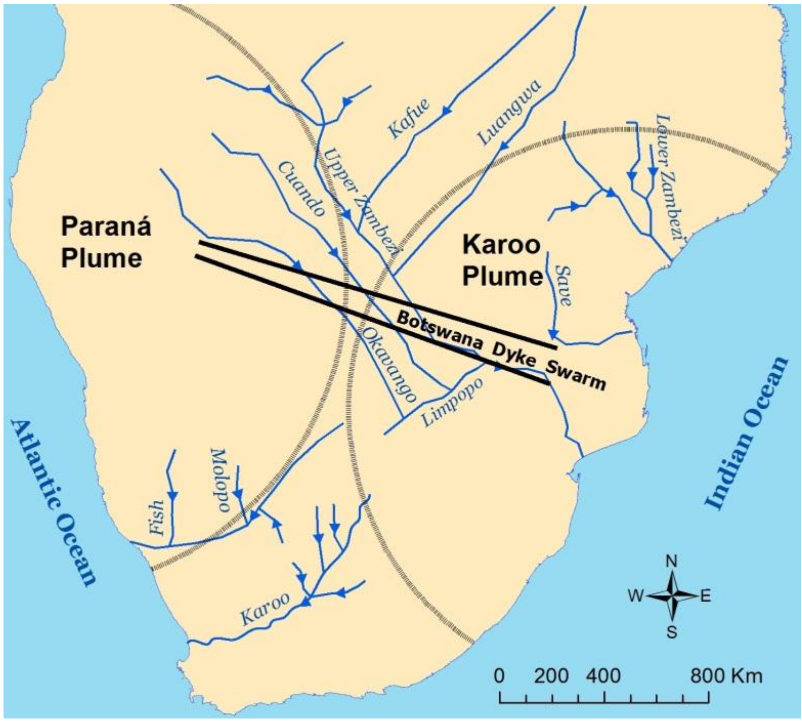
3.3.1. A much greater palaeo-Limpopo River during the Early Cretaceous

Volcanic eruptions of the Karoo, which Moore and Blenkinsop (2002) estimated to have occurred from the Permo-Carboniferous to the lower Cretaceous period in association with the Gondwana fragmentation, have provoked a major reorganisation of the drainage system in southern Africa. By that time the Karoo plume (see location in the map of Fig. 3.2, extracted from Moore and Blenkinsop, 2002), which is linked to the opening of the Indian Ocean, initially imposed a westwards flowing drainage pattern due to its doming effect. The same authors indicate that this pattern was reverted 40 to 50 million of years later (approximately during the Early Cretaceous) to a dominantly eastwards flowing system, due to the opening of the Atlantic Ocean related to the Paraná plume (see location in Fig. 3.2). While referring to White (1997), Moore and Blenkinsop (2002) explain that such change of flowing direction was also magnified by the subsidence of the Mozambique plain during the same period as a result of sediment loading. The East still represents the dominant flowing direction of the fluvial system in southern Africa today, with Mozambique, located downstream, receiving nine international rivers in its territory.

Fig. 3.2 is derived from the drainage reconstructions of Moore (1999), who based some of his deductions from early intuitions of Du Toit (1933), and which were later confirmed by De Wit (1999), Moore and Larkin (2001) and Goudie (2005). It shows clearly that the palaeo-Limpopo River during the early Cretaceous period was by far the largest river of southern Africa, as it was also including the southeast-flowing Cuando, Okavango and Upper Zambezi Rivers as main tributaries. The latter, which was most probably linked to the Limpopo through the Shashe River (Moore and Larkin, 2001), was already receiving waters from the Kafue and Luangwa Rivers originally flowing to a southwest direction (Moore and Blenkinsop, 2002).

Moore and Blenkinsop (2002) and Moore et al. (2007) explain that the palaeo-Limpopo River entered the coastal plain of Mozambique by exploiting the corridor traced by the Botswana dyke swarm oriented along a west-northwest direction (see Fig. 3.2). This important geological feature, related to the disruption of Gondwana and its associated volcanism, further confirms the rift control over important and long-lived drainage lines (Potter, 1978; Moore et al., 2007; Moore et al., 2009a). In addition, Moore et al. (2007) highlight the parallel southeast and southwest pattern of this major river system which again confirms an important geological structural influence on the drainage pattern.

Figure 3.2: Main drainage system of southern Africa during the Early Cretaceous period



(Adapted from: Moore, 1999)

The above described geomorphological conformation of the palaeo-Limpopo determines an inherent territorial vulnerability to flooding of the river basin at present. In fact, as described for the Tagliamento River by Spaliviero (2003), this paper will demonstrate that the apparently abandoned drainage conformation of the palaeo-Limpopo River constitutes today preferential flood-prone areas in case of major rainfall events.

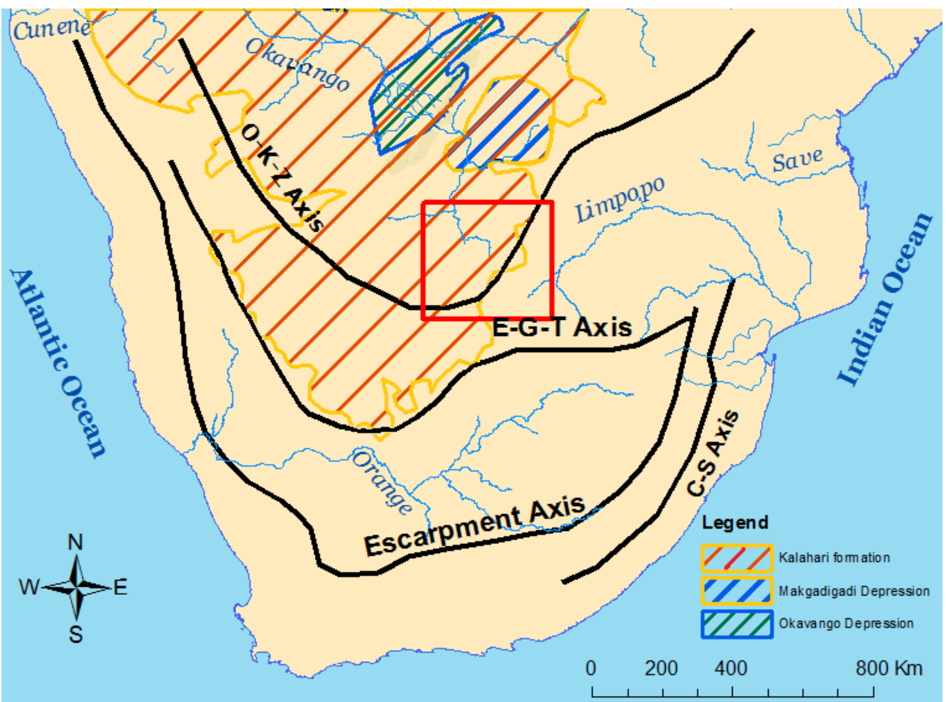
3.3.2. The evolution of the Limpopo River after the Gondwana disruption due to crustal flexuring

In his influential article, Moore (1999), based on preliminary suggestions from Du Toit (1933), has identified three main axis of crustal flexure (see Fig. 3.3, adapted from Moore, 1999) that arose due to plate tectonics in southern Africa. These axes of uplifting, which define the divides of important river watersheds today, have much influenced the drainage evolution in the sub-region by determining successive river cuts and river captures (Moore and Lankin, 2001). According to Moore (1999) and Moore et al. (2009b), they appeared in the following chronological order:

- **Late Jurassic - Early Cretaceous:** uplifting of the *Escarpment Axis* running in parallel to the coastline and linked to the rifting process which initiated the break-down of Gondwana (Partridge and Maud, 1987). The formation of this major geological feature started the above-referred erosion cycles which produced the “African Surface” (as it is often referred to in scientific literature) for the sub-region, on top of which were progressively deposited the sediments leading to the Kalahari formation.

- **Late Cretaceous:** uplifting along the *Etosha-Griqualand-Transvaal (EGT) Axis* further closing the southern margin of the Kalahari formation (which today is a desert) and triggering the above-mentioned sedimentation process in the Kalahari. The latter started to sink slowly due to subsidence and became a large basin. This Axis defines the southern limits of the Limpopo River basin by separating it from the Orange River system.
- **Late Palaeogene:** uplifting along the *Ovambo-Kalahari-Zimbabwe (OKZ) Axis* that has rejuvenated the main drainages and initiated the erosion of the coastal side of the flexure. This Axis forms the local boundary to the Kalahari formation. Importantly, Moore (1999) explains that the uplifting of OKV Axis cuts across the line of the Okavango and was therefore responsible for breaking the link with the Limpopo River by the end of the Cretaceous period (see squared area in Fig. 3.3), as originally predicted by Du Toit (1933). As a consequence, the Okavango, Upper Zambezi (which included the Kafue and the Lwangua Rivers) and Cuando Rivers, all attached to the palaeo-Limpopo River, became a huge endoreic drainage system. The latter supplied sediment to the Okavango and Makgadigadi depressions, originally identified by Du Toit (1933) as part of the Kalahari basin. Both the Upper Zambezi and the Cuando Rivers would then be captured by the Lower Zambezi during the Upper Pleistocene (Moore and Larkin 2001; Moore et al., 2007). The following section describes the consequences of the major changes of the Limpopo River due to the formation of this axis of flexure.

Figure 3.3: The main axes of crustal flexure of southern Africa defining the major water divides



(Adapted from: Moore, 1999)

Moore (1999) further indicates that the inferred ages of the above-described axes flexure correspond to three major peaks in volcanic activity in the sub-region. In addition, by making reference to King (1963) and Partridge (1998), this author notes that part of these axes have increased their height during the Plio-Pleistocene period along a northeast-southwest direction. Therefore the more recent crustal flexures are probably associated with the continuation of the Great Rift Valley, which may determine an additional break-up of the African continent in the future. Hence it is suggested that these phenomena (volcanism and recent crustal flexuring) are linked to a common underlying tectonic/geological process (Moore, 1999).

Importantly, Moore (1999) highlights that the three identified axes of flexure, namely the Escarpment Axis, the EGT Axis and the OKZ Axis, show a sequential uplifting according to a concentric pattern developing further inland. This triggered successive river rejuvenation on the coastal side of each axes of flexure, and hence activated the previously mentioned cycles of erosion (Moore et al., 2009b).

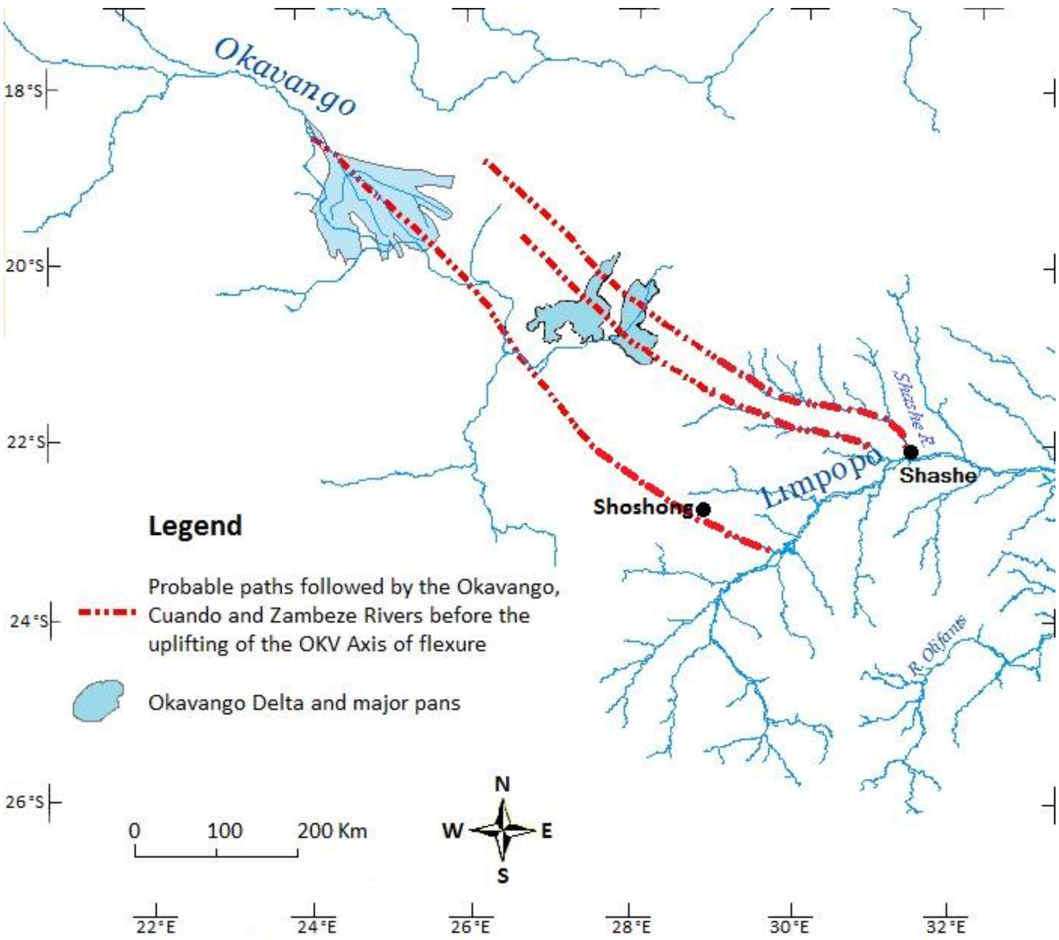
3.4. Consequences of the geomorphological evolution of the upper-middle Limpopo River in terms of territorial flood vulnerability today

Several scientific observations were provided by Moore (1999), Moore and Larkin (2001), Moore et al. (2007) regarding the disruption of the palaeo-Limpopo River due to the uplifting of the above-mentioned OKZ Axis of crustal flexure during Late Cretaceous - early Tertiary period:

- Moore (1999) demonstrated that while the isopachs of the sub-Kalahari valley show a northwest flowing direction of the now abandoned Okavango River, the distribution of the ilmenites derived from the Orapa kimberlite field located to the north implies that this river originally flowed towards the southeast direction.
- The uplifting of this axis of flexure determined several abandoned tributaries to the Limpopo, especially in Bostwana up to the border with Zimbabwe. These are often braided river channels showing a width and gravels' size which cannot be explained by an ephemeral flow, thus constituting evidence that they were part of a major drainage system (Moore and Larkin, 2001).
- Moore et al (2007) provide several scientific references showing the occurrence of common fish and plant species between the Okavango and the Limpopo Rivers, which prove that they belonged to the same drainage system in the past.

Fig. 3.4 shows the probable paths followed by the Okavango, Cuando and Upper Zambezi Rivers when they were still major tributaries of the palaeo-Limpopo River during the Cretaceous period. We will now analyse the territorial flood susceptibility of Shoshong and Shashe areas, whose location is indicated in this Figure, as direct consequence of these abandoned fluvial systems.

Figure 3.4: Probable paths followed by the Okavango, Cuando and Zambezi Rivers when they were still major tributaries of the palaeo-Limpopo River



(Adapted from: Moore and Larkin, 2001)

3.4.1. The territorial vulnerability to flooding of Shoshong area, Botswana

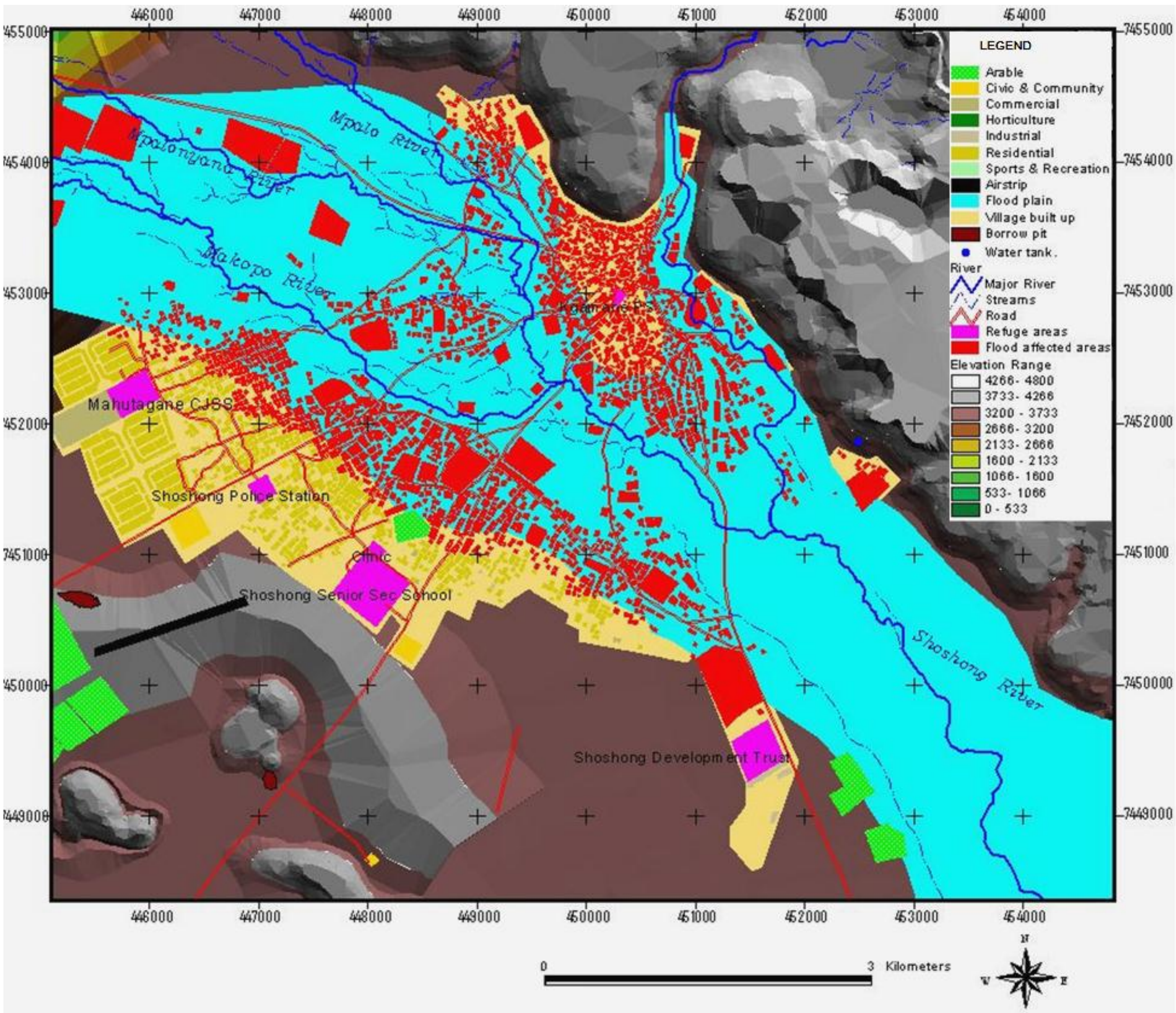
Participatory land use plans were prepared in various locations of the Limpopo River basin during a sub-regional project implemented between 2004 and 2007 by the United Nations Human Settlements Programme (UN-Habitat) in collaboration with the United Nations Environment Programme (UNEP)[1]. Each riparian country was requested to select particularly flood-prone settlements to implement this activity. The Government of Botswana indicated Shoshong village, which is crossed by a homonymous river system that reaches the Bonwapitse River, a tributary of the Limpopo River (see the location of Shoshong in Fig. 3.4).

According to the information collected by Mpho (2007), Shoshong is regularly affected by flash-floods during the rainy season. Major events occur every five years in average since the 1990's, provoking severe loss of crops, livestock, physical property and sometimes even human life. In fact, this settlement of approximately 10,000 inhabitants is located in the middle of a former wide and important fluvial braiding system belonging to the Okavango River before the raise of the OKZ Axis of crustal flexure.

[1] NB: more details about this initiative can be found in Spaliviero et al., 2011.

The map in Fig. 3.5 shows clearly the high level of vulnerability of Shoshong, with most of its built-up area lying in the flood plain (see also Fig. 3.6). The Shoshong River, despite being dried over long periods of time, can suddenly reactivate after persistent rainfall. This occurs essentially because its current geomorphological settings are the result of a much more important fluvial regime in the past, when the Okavango was a major tributary of the palaeo-Limpopo River. Therefore we can conclude that most of Shoshong settlement is located in an area prone to endemic floods.

Figure 3.5: Flood risk map of Shoshong settlement, Botswana



(Source: Maló and Da Conceição, 2007)

Figure 3.6: Abandoned houses in the Shoshong floodplain

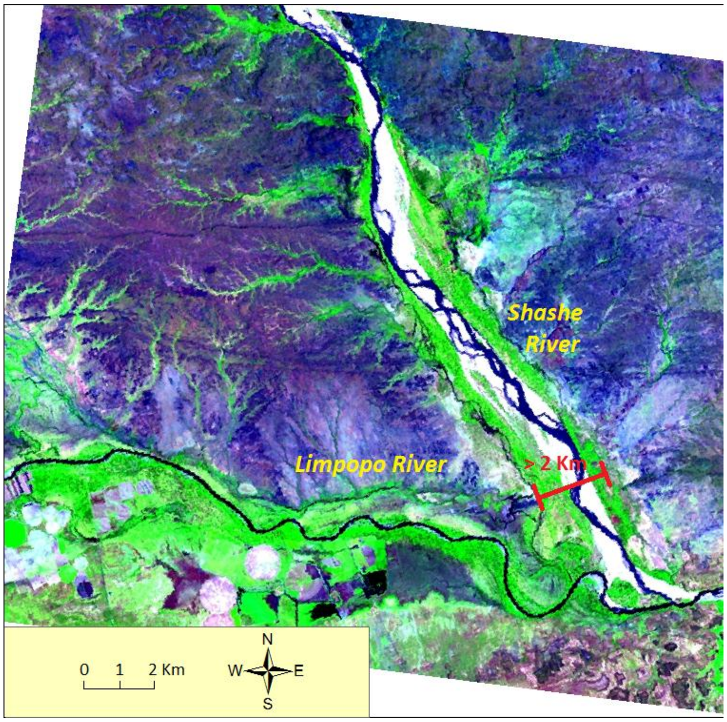
(Photographer: Mpho, 2007)

3.4.2. The territorial vulnerability to flooding of Shashe area, Zimbabwe

Moore and Larkin (2001) infer that the important width of the floodplain of the Shashe River at its confluence with the Limpopo (more than 2 km – see Fig. 3.7) can be explained by the former course of the Cuando River. It maintained a southeast course and was part of the palaeo-Limpopo River (see Fig. 3.2) before being captured by the Zambezi drainage system as consequence of the uplifting of the OKZ Axis of flexure.

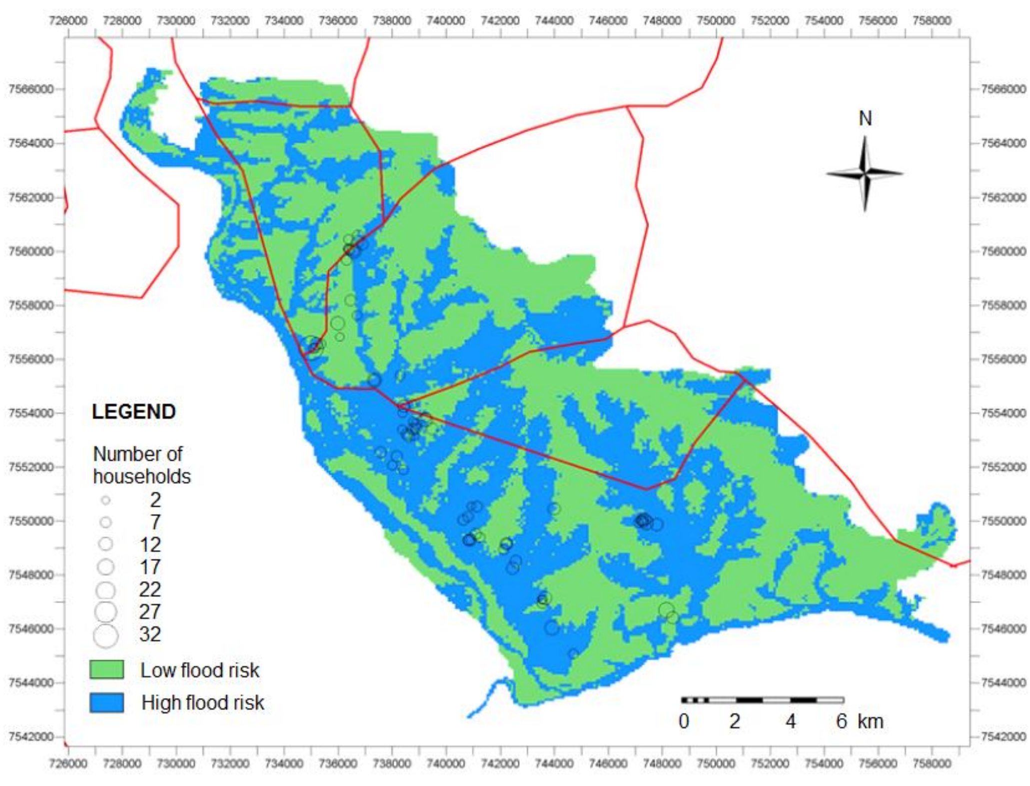
Similarly to what has been observed in Shoshong in Botswana, the confluence of the Shashe River is considered to be one of the most vulnerable locations to flooding in Zimbabwe along the Limpopo River today. This is confirmed by the participatory land use plan regarding the Shashe study area prepared by Murwira et al. (2006) within the framework of the above-mentioned UN-Habitat/UNEP Limpopo project. The local communities reported the loss of property, crops and destruction of infrastructure due to recurrent flooding. Fig. 3.8 shows clearly that approximately 65% of Shashe's population lives in areas of high flood hazard risk.

<u>Figure 3.7</u>: False colour-composite Landsat 7 image of 2000 showing the confluence between the Shashe and the Limpopo Rivers



(<u>Source of the satellite image</u>: Murwira, 2005)

<u>Figure 3.8</u>: Flood risk map of Shashe area

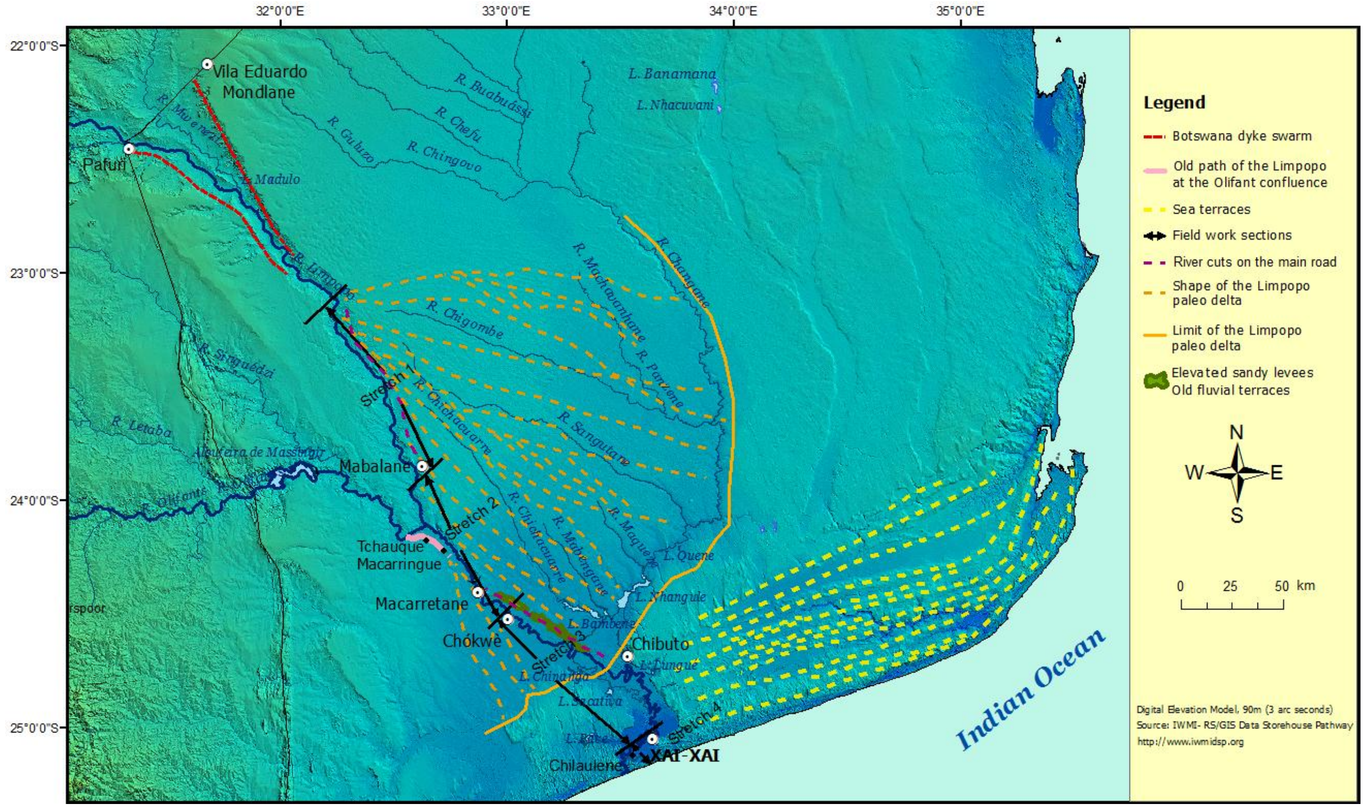


(<u>Source</u>: Murwira et al., 2006)

3.5. Geomorphological description of the Lower Limpopo River based on existing literature

This section describes some of the geomorphological settings of the lower part of the Limpopo River basin, starting from Pafuri settlement (see location in Fig. 3.9) at the Mozambican border with Zimbabwe, downstream to the outlet in the Indian Ocean.

Figure 3.9: Main geomorphological features of the lower Limpopo River



According to Du Toit (1933) a great part of the plain lying in southern Mozambique (hereafter referred as the "southern Mozambique Plain") is built of Cretaceous, Tertiary and Pleistocene sediments which have been raised above the sea level. These sediments result from river deposits which occurred during different geological periods, particularly as consequence of the successive erosion cycles induced by the crustal uplifting events described earlier in this paper. A general description of the succession of the past events which lead to the formation of the southern Mozambique Plain, where the lower Limpopo River has been flowing since the Jurassic period, is provided below:

- As mentioned earlier, the Limpopo River has entered the southern Mozambique Plain by exploiting the crustal opening made by the Botswana dyke swarm in association with the Gondwana break-up (Moore and Blenkinsop, 2002; Moore et al., 2007), as shown in Fig. 3.2. Therefore, this fluvial system has been building up the southern Mozambique Plain through successive erosion periods by flowing mainly through that same corridor (where the Pafuri settlement can be found today, see Fig. 3.9) during at least the past 130 to 150 million of years. This had important implications for the geomorphological settings of the lower Limpopo River, as it facilitated the formation of a mega fluvial delta as described below.

- Moore and Larkin (2001) refer to the presence of a prominent seaward bulge in the coastal plain of Mozambique lying between Beira and Maputo. They indicate that a sequence of sediments of 1.3 to 2 km thickness dating from the disruption of Gondwanaland (Jurassic to lower Cretaceous) can be found in the middle of the plain, parallel to the coastline. Much earlier, Dixey (1955) explained that the great thickness of Cretaceous terrestrial sediments observed in this area show that the coastline at that time was located much further east compared to its current location. This is consistent with the fact that the palaeo-Limpopo River was by far the most important fluvial system of southern Africa at that time, bringing huge loads of sediments to the eastern coast and progressively building up the southern Mozambique Plain. Accordingly, Burke and Gunnel (2008), referring to Burke (1996), indicate that this ancient river formed an important delta during the Jurassic-Cretaceous period (see Fig. 3.9). We note with interest that this palaeo-delta is proportional to the size the river had during that period. It is our opinion that there can be no other explanation for the formation of such a huge deltaic system. In addition Burke and Gunnel (2008), by referring to the thermal history data of organic material collected in deep wells in the southern Mozambique Plain, indicate that, stratigraphically, the upper part of the delta complex started to form during the early Jurassic. The same authors, by citing Wilkinson (2004), also mention the existence of a megafan in correspondence to the lower Limpopo River, together with other fourteen megafans scattered all over the African continent. They comment that these peculiar geomorphological formations have not yet been sufficiently investigated.

- As mentioned before, White (1997) explains that the coastal plain of Mozambique started to progressively sink by the early Cretaceous due to the enormous amount of sediments deposited. This is again consistent with the great size of the palaeo-Limpopo at that time, and confirmed by sedimentary thermal history data presented by Burke and Gunnel (2008).

- Moore and Larkin (2001) refer to a net reduction of sediment supply to the southern Mozambique Plain by the lower Tertiary. This probably corresponds to the beginning of the uplifting process of the OKZ Axis of crustal flexure during the late Palaeogene suggested by Moore (1999), cutting off the Okavango, Cuando and Upper Zambezi Rivers from the Limpopo River basin. This is also confirmed by Salman and Abdula (1995) who, being cited by Burke and Gunnel (2008), state that there was no active Limpopo delta during the early Cenozoic (approximately between 65 and 30 million of years ago). According to Moore et al. (2009a), the uplifting of the OKZ Axis then rejuvenated the drainage system and provoked a new cycle of erosion determining an increase of sediment supply during the Oligocene period. This triggered the displacement of the Limpopo River mouth southwards during the same period (Moore and Larkin, 2001). We suggest that any drainage modification of the lower Limpopo River, as consequence of crustal flexuring events which occurred after the existence of the palaeo-Limpopo River, could most probably not escape from the morphological conformation imposed by the huge delta or megafan of such an ancient river.

- The last major geological event which influenced the overall morphology of the southern Mozambique Plain was probably the general uplifting which occurred during the Plio-Pleistocene period (Maufe, 1935; Moore, 1999; Moore and Larkin, 2001). Citing Partridge (1998), Moore and Larkin (2001) mention the uplifting of the Ciskei-Swaziland (C-S) Axis of crustal flexure during the same period, which is located between the Great Escarpment Axis and the current eastern coastline of southern Africa (see Fig. 3.2). This must have been an abnormally swift process (Du

Toit, 1933; Moore and Larkin, 2001) of raising the Tertiary sediments, which were previously submerged and reworked by the sea, to form the present coastal plain. This uplift is also confirmed by Salman and Abdula (1995). Lister (1987), cited by Moore et al. (2009a) identified young Pliocene age sedimentary surfaces in the Mozambique Plain, most probably formed by an additional drainage rejuvenation triggered by the raising of the same C-S Axis. Interestingly, Du Toit (1933) explains the high speed of this general uplift by describing the topographical profile of the main southern African rivers crossing this Axis, This profile is slightly convex upwards, which proves that the erosional process has been slower than the uplifting. Furthermore the series of parallel sea terraces indicated in Fig. 3.9 are probably features resulting from this rapid uplifting process.

In October 2009, the authors of this paper conducted fieldwork in the lower Limpopo to examine the geomorphological settings of the area. Their findings confirmed most of the aspects mentioned above. They are presented in the next section, in which a territorial vulnerability analysis to floods is undertaken.

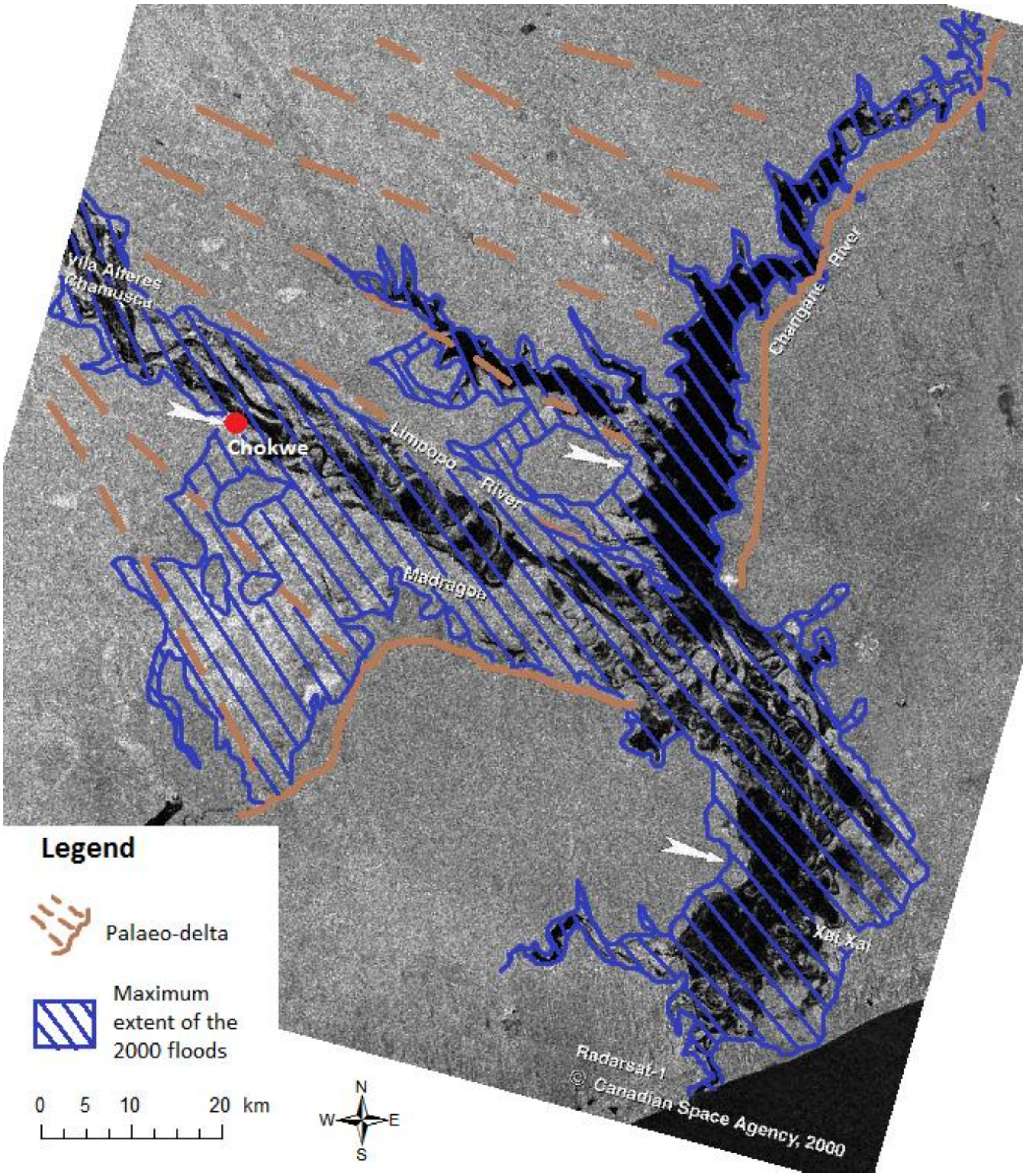
3.6. Consequences of the geomorphological evolution of the lower Limpopo River in terms of today's territorial vulnerability to flooding

A careful assessment of the geographical extent of the 2000 floods allows obtaining a better understanding of the territorial vulnerability to floods of the southern Mozambique Plain. It also helps establishing linkages with the past geomorphological evolution of the plain described in the previous section. The radar satellite image of such dramatic event in Fig. 3.10 is useful for this purpose. The flooded areas appear in dark while the maximum extent reached by the floods is indicated by the white arrows. To facilitate their identification, the maximum extent of the 2000 floods were digitised in blue in the Figure.

It is noted that in addition to the typical invasion of the larger floodplain along the lower Limpopo River itself, the topographically lower eastern part of the identified palaeo-delta has been the most affected area by the 2000 floods, especially along the Changane River, a major tributary. The map presented in Fig. 3.11 confirms this pattern, which extends southwards to the right bank of the Limpopo River. This corresponds to the area south of Chókwè appearing whitish in Fig. 3.10 (see maximum extent of the floods).

Therefore, the territory defined by the northwest-southeast oriented triangular shape of the palaeo-delta can definitely be considered vulnerable to flooding. In fact, it is the opinion of the authors that the whole drainage system which is composed by the Rivers Chigombe, Panzene, Sangutane, Maqueze, Mabengane and Chichacuarre, all ending into the lower Changane River and showing a north-south orientation before reaching the lower Limpopo River, are simply defining the shape of this very ancient deltaic complex (see Fig. 3.9). It would not be surprising if most of this drainage system is alimented by the waters of the Limpopo River via sub-surface groundwater flow.

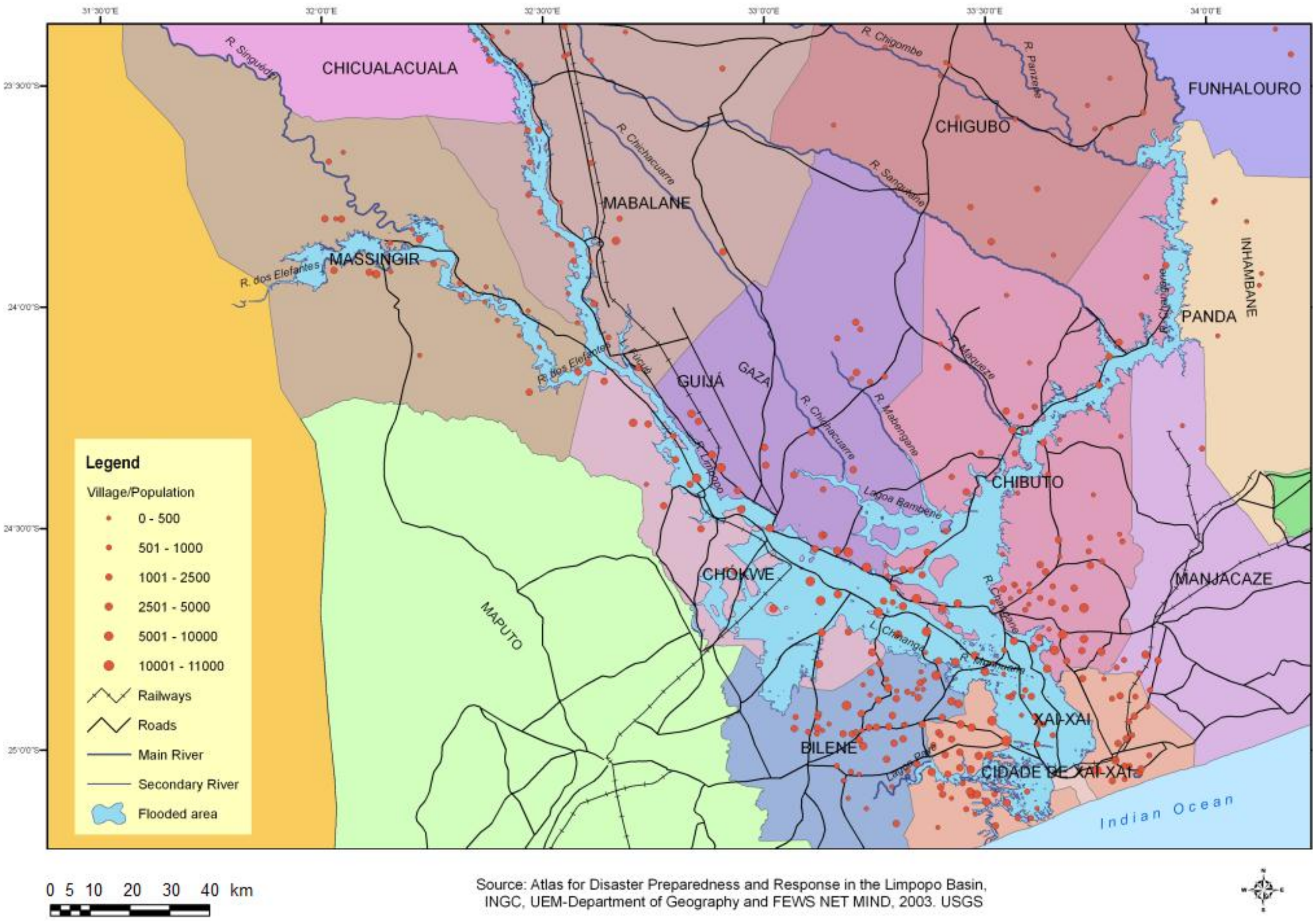
Figure 3.10: Radarsat-1 image recorded on 28 February 2000 showing the maximum extent of the 2000 floods affecting the lower Limpopo



(Source of the satellite image: Canadian Space Agency)

Importantly, Fig. 3.11 shows clearly that the identified flooded areas also correspond to the highest concentration of human settlements. This can be explained by the human dependency on agricultural activity (there are the most fertile soils) and the basic need to live close to fresh water.

Figure 3.11: Maximum extent of the 2000 floods in Mozambique



(Source: INGC et al., 2003)

A geomorphological analysis based on fieldwork activities carried out by the authors in October 2009 follows. This is done according to four main stretches starting from the apex of the megafan to the Indian Ocean, as shown in Fig. 3.9.

3.6.1. Area 1 stretching from the mega-delta apex to south of Mabalane

At the megafan apex we observed not fully consolidated conglomerates, probably dating from the Tertiary (see Fig. 3.12). The weathered, incised and terraced river gravels are possibly associated with the crustal uplifting that occurred during the Pliocene-Pleistocene period. This is much older than the terrace observed in the Macarretane area (see the location in Fig. 3.9). Several river cuts are observed along the road Macarretane – Vila Eduardo Mondlane, especially to the North and South of the Mabalane area. These cuts were determined by the floods, showing a fluvial tendency to reactivate the palaeo-deltaic system.

Figure 3.12: Weathered, incised and terraced river gravels at the apex of the megafan

(Photographer: De Dapper, 2009)

3.6.2. Area 2 stretching from the Olifants - Limpopo Rivers' confluence to Chókwè

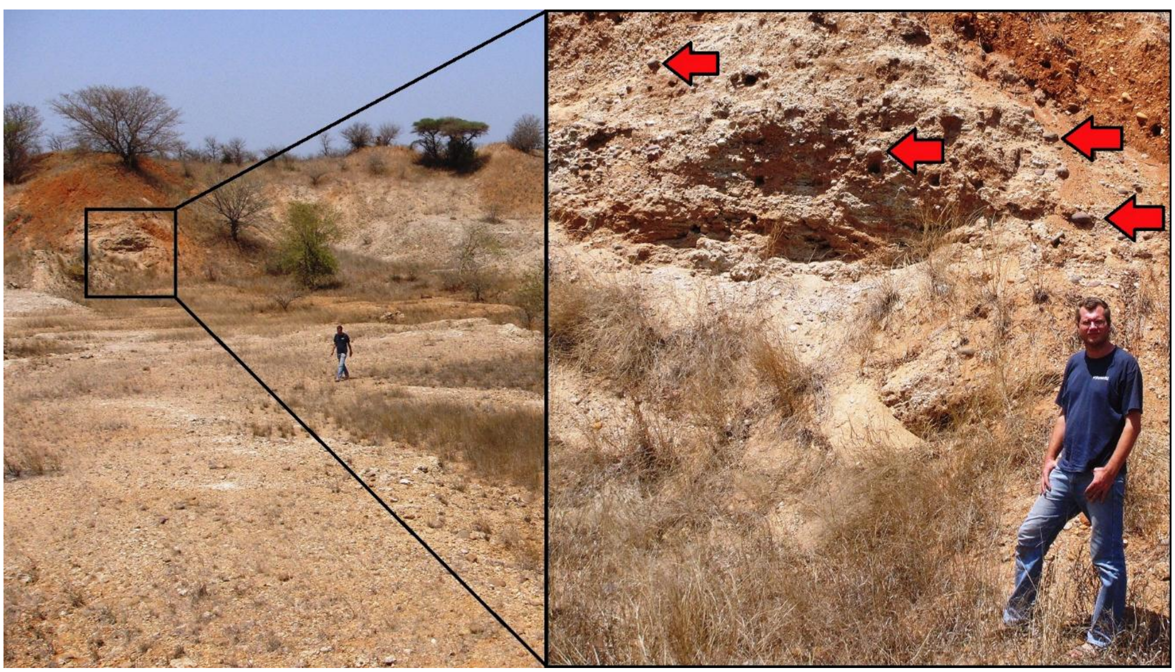
In the lower Limpopo area, the confluence with the Olifants River represents a critically vulnerable location. In fact, fieldwork confirmed that the settlements in that area, in particular Tchauque and Macaringue (see map in Fig. 3.9) were completely surrounded by water during the 2000 floods. This was confirmed by interviews with the local population.

A photo taken close to the confluence (see Fig. 3.13), where a data gauging station is located, shows the elevation reached by the high water mark. A closer interpretation of the relief of the confluence shows that most probably the riverbed followed a different path in the past, slightly to the West of its current position, as interpreted in Fig. 3.9. This old path is reactivated in case of major floods, as it occurred in February 2000. The quantity, size and depth of round boulders found deposited in the quarries close to the confluence (see Fig. 3.14) and at Macarretane confirm that the Limpopo River at this stretch was a much larger fluvial system in the past.

Figure 3.13: High water mark at the Olifants-Limpopo confluence

(Photographer: De Dapper, 2009)

Figure 3.14: Round boulders deposit at a quarry close to the Olifants River's confluence



(Photographer: De Dapper, 2009)

3.6.3. Area 3 stretching from Chókwè to Xai-Xai

In this stretch we find a complex system of elevated and old sandy levees (see Fig. 3.15). On top of these levees, which run parallel to the fluvial system, are located the first organised human settlements of the lower Limpopo in correspondence to the Bantu's migration to southern Africa, which occurred approximately 3,000 years ago. Interestingly, the levees also host the burial site of the heroic traditional leader Ngungunhane (1895). This is understandable as this geomorphological features represent elevated and secure locations away from the flood risk areas. This explains the higher concentration of human settlements there, where also the Portuguese decided to develop the railway system during the colonial times.

The settlement process was accompanied by a change in land use shifting from forest to agriculture. The deforestation provoked ravine erosion -contributing to sedimentation- which is very pronounced still today, especially in the Chibuto area, a compacted old dune system.

Figure 3.15: The Limpopo River flowing next to Chibuto; elevated sandy levees can be observed at the horizon on the right side, as indicated by the red arrows

(Photographer: De Dapper, 2009)

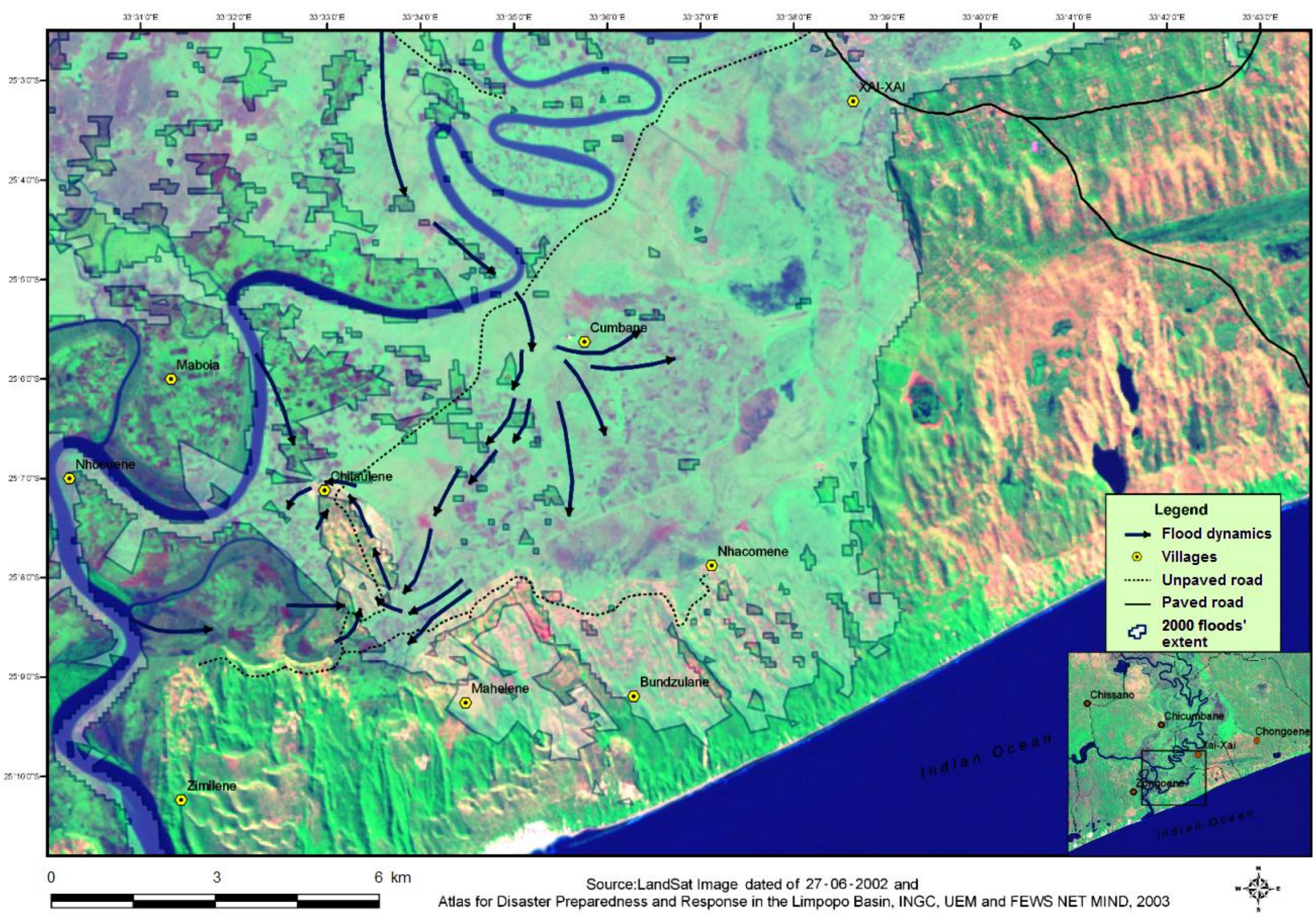
The area of confluence between the Changane and the Limpopo Rivers (see Figs. 3.9 and 3.10) is particularly complex from a topographic point of view, and highly susceptible to flooding. It is a large depressed area, probably due to the subsidence process caused by the load of sediment since it corresponds to a critical depositional area of palaeo-delta. In fact, during the 2000 floods, people observed that the water tends to flow from the Limpopo towards the Changane River and not the opposite. A multitude of large abandoned meanders can be found in this stretch, again confirming the presence of a much bigger fluvial system, part of the megafan.

3.6.4. Area 4 stretching from Xai-Xai to the Indian Ocean coast

The territorial morphology of the lowest part of the Limpopo River shows a strong marine influence. A complex and consolidated sand dune system distributed along the coastline seems to have forced the river in deviating its original course towards the south-southwest direction to reach the Indian Ocean, as shown in the map in Fig. 3.16. In fact, during the dry period the sea tide influence reaches beyond Xai-Xai, the capital of Gaza Province located some 15 km away from the coast. Therefore, some important irrigation schemes can be observed in this area, which are provided with sluice systems to protect the agricultural crops from salty water invasion. Several of these irrigation schemes were completely destroyed during the 2000 floods.

The map shown in Fig. 3.16, which is derived from fieldwork and satellite image interpretation, describes both the dynamics and the extent reached by the waters during this flood event. The dykes were broken by the spinning force of the floodwaters which formed river wheels. As a result the community living on top of the sand dune of Chilaulene, located in the middle of the floodplain, was flooded from river waters coming from different directions and completely isolated for weeks. Mapping the flood dynamics allows better planning of flood mitigation measures.

<u>Figure 3.16</u>*: Description of the 2000 floods' dynamics in the last stretch of lower Limpopo*



(<u>Source</u>: Maló and Da Conceição, 2007)

3.7. Discussion and conclusion

This paper represents one more attempt, as per what Spaliviero (2003) suggested for the Tagliamento River in northern Italy, to emphasise the need for a good understanding of the past evolution of a river system to adequately plan flood mitigation measures in a given territory. The authors demonstrate that flood hazards tend to concentrate in the same locations where major fluvial changes have occurred. Accurate and reliable flood risk information is essential for preparing a land use plan involving the development of human settlements, with the aim to reduce the vulnerability to this natural hazard.

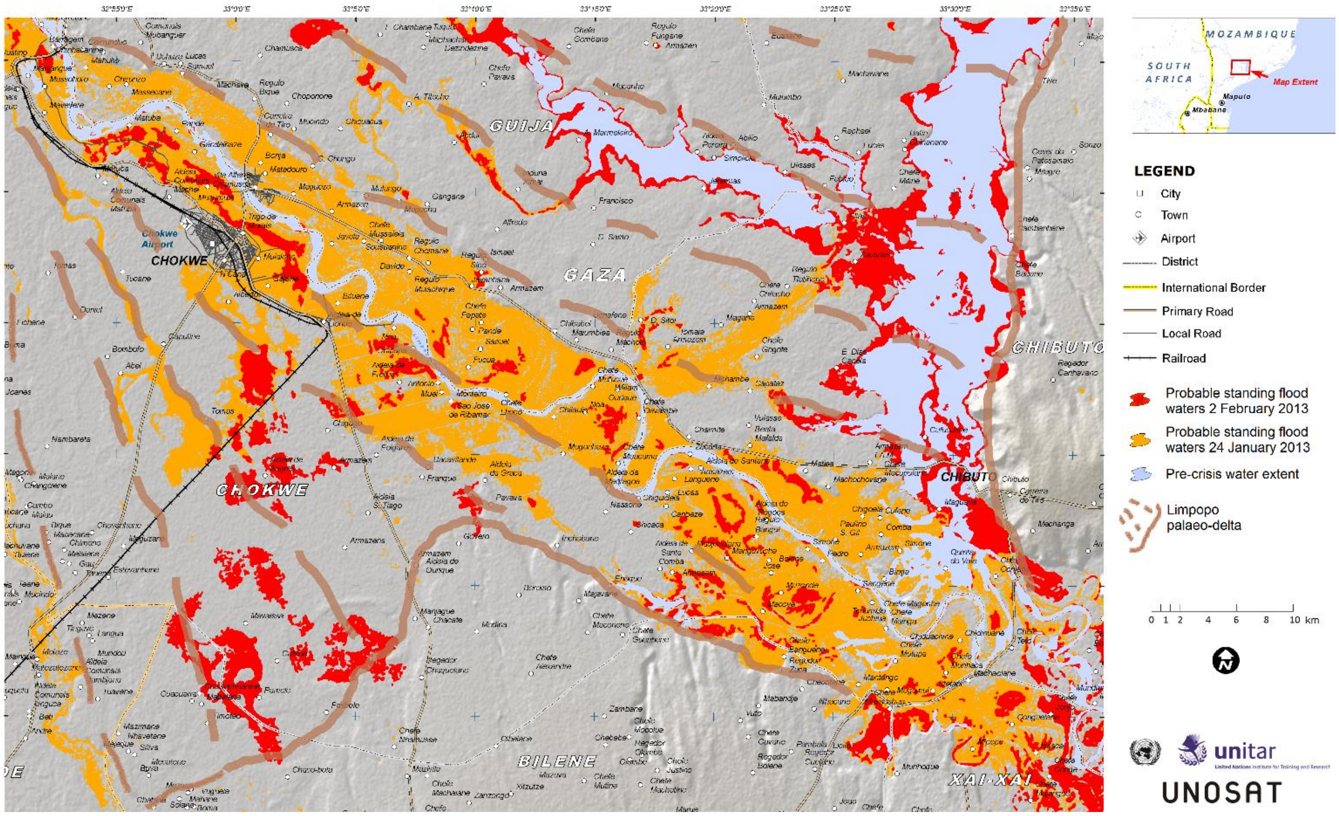
The Limpopo River is a drainage system located in south-eastern Africa which shows complex geomorphological settings resulting from a series of tectonic activities that have occurred since the late Jurassic period. This paper shows that apparently abandoned valley floors of the ancient hydrography of the river, which was a much larger fluvial system during the Early Cretaceous (in fact, by far the largest of the whole southern Africa), are today preferentially occupied by the floodwaters.

Particularly vulnerable areas are the broken links between the Limpopo River and the Okavango, Upper Zambezi and Cuando Rivers such as Shoshong in Botswana and Shashe in Zimbabwe. Another very flood-prone territory is most of the area corresponding to the huge palaeo-delta identified in the Mozambican floodplain, which has imposed a peculiar drainage pattern shown by the Shangane River and its tributaries before joining the lower Limpopo. The influence of this important morphologic feature on the flood dynamics was clearly revealed by the geographical extent reached by the most devastating event of the last 50 years which occurred in 2000.

To highlight the relevance and test the accuracy of this method, we now analyse the floods that occurred in January and February 2013 in the lower Limpopo River. This disastrous event determined approximately 50 deaths and displaced around 150,000 people (OCHA ROSA, 2013). Interestingly, these floods followed the same dynamics of the 2000 event. Once again floodwaters have concentrated along the lower area delimited by the mega palaeo-delta described above (see Fig. 3.17), which was built up millions of years ago when the Limpopo River basin was three to four times its current size.

Therefore, in reply to the research question of this paper, the authors conclude that there are definitely clear relationships between the past fluvial changes and the territorial vulnerability to floods in the Limpopo River basin. The description of the past river's evolution combined with a geomorphological approach has proven to be relevant in analysing the territorial vulnerability to floods in this region.

Figure 3.17: Analysis of the 2013 flood extent in the lower Limpopo River through satellite image interpretation



(Adapted from: http://www.unitar.org/unosat/maps/MOZ, accessed on 02/02/2013)

The Limpopo River basin can be defined as relatively scarce in data, especially when referring to hydraulic and topographic data, which are commonly used to run dynamic flood simulations through spatial models in a Geographic Information System environment. The method proposed allows, when considering the natural complexity of the flood dynamics of a transboundary river such as the Limpopo, identifying unsuitable areas for developing human settlements, which are exposed to high flood risk connected to the past morphology of the river.

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4. *Participatory approach for integrated basin planning with focus on disaster risk reduction: the case of the Limpopo River*

Mathias Spaliviero, Morgan De Dapper, Chris Mannaerts and Antonio Yachan (2011); published in WATER, vol. 3, open access: www.mdpi.com/journal/water

4.1. Abstract

This paper defends the idea that a participatory approach is a suitable method for basin planning integrating both water and land aspects. Assertions made are based on scientific literature review and corroborated by field experience and research carried out in the Limpopo River basin, a transboundary river located in southern Africa which is affected by periodical floods. The paper explains how a basin strategic plan can be drafted and disaster risk reduction strategies derived by combining different types of activities using a bottom-up approach, despite an institutional context which operates through traditional top-down mechanisms. In particular, the *"Living with Floods"* experience in the lower Limpopo River, in Mozambique, is described as a concrete example of a disaster adaptation measure resulting from a participatory planning exercise. In conclusion, the adopted method and obtained results are discussed and recommendations are formulated for potential replication in similar contexts of the developing world.

Keywords: Participatory approach; Integrated basin planning; Living with Floods; Limpopo River

4.2. Introduction and objectives

The identification of suitable strategies for river basin planning is the object of continuous scientific, political and institutional discussions and research (White, 1998). Since river basins are biogeophysical units with high degree of functional integrity, they can serve as widely applicable, non-ephemeral, operational landscape units for planning and management (Barrow, 1998). An integrated river basin management approach is essential for land and water use planning due to the complexity of land and water interactions (Tysona, 1995). However, integrated basin development is complex (Koppel, 1987) and implies the application of a holistic and multi-disciplinary approach (Barrow, 1998; Rowntree, 1990; Newson, 1997). Ideally, the latter should aim at maximising a combination of economic, social and environmental benefits (Ziyun, 1985). For this purpose, solid technical, institutional, political, and economic capacity is needed at the different decision-making levels (Van der Zaag and Savenije, 1999; Farinan, 1980).

The experience suggests there is continuing urgent need for expanding the range of management measures considered as part of the planning process, which require formidable institutional and analytical efforts (White, 1998). Such requirements are rarely found, especially in developing countries. This is mainly due to rigid institutional structures unable to interact effectively with other sectors and to engage in a real dialogue with local communities, lack of technical capacity, weak economic conditions, and poor political will. Dealing with transboundary rivers is even more difficult (Wolf, 1997; Biswas, 1999). Frequently, countries located at the upstream reaches of international basins take river management decisions (e.g., dam construction) that seriously affect countries downstream (Vaz and Pereira, 2000), eventually worsening the impacts from drought or floods.

In addition, there is a difficult equilibrium to be reached between the river's inherent dynamism and the stability requirements for socio-economic development (Ureña and Ollero, 2001), especially in the river's lower stretches. During flood events, dramatic fluvial changes in pattern and location take place, due to continuous erosion, transport and sedimentation processes (Twidale, 2004; Osborn and du Toit, 1990; Spaliviero, 2003). Although there is still no relevant documented scientific literature, the Limpopo River is no exception to such natural dynamic behaviour over time. Changes in land use and land cover determined mainly by anthropogenic interventions (such as deforestation, for example) have much influence on runoff response after a rainfall event, and exacerbate flooding and erosion processes. Slocombe (1993), after decades of investigations, affirms that there is still a need to provide a transdisciplinary framework that links biophysical and socio-economic research and practice in a region or ecosystem through holistic, ecological and participatory methodology.

This paper analyses the implementation of participatory methods for basin planning in developing countries where, in general, data is scarce and capacity is weak at both institutional and community levels. Analysis and results obtained through the project *"Sustainable Land Use Planning for Integrated Land and Water Management for Disaster Preparedness and Vulnerability Reduction in the Limpopo River Basin"* are presented and discussed. This initiative, which was funded by the Global Environment Facility with approximately one million US dollars, was implemented between 2004 and 2007, and counted on the participation of all four riparian countries, namely Botswana, Mozambique, South Africa, and Zimbabwe. It was managed by the United Nations Human Settlements Programme (UN-Habitat) in collaboration with the United Nations Environment Programme (UNEP). Its objective was to develop and implement participatory land use tools and plans for sustainable land management in the basin to reduce the impact of floods on land, ecosystems and human settlements. Two main results were expected, mainstreaming bottom-up approach: (i) an integrated land use management plan of the basin prepared, and (ii) capacity and tools for participatory land use planning and disaster preparedness enhanced.

In terms of the paper's structure, after presenting the methodology and defining the research question, the main characteristics of the Limpopo River basin are described, leading to a comprehensive definition of the problem under research. The applied participatory method during project implementation is then presented in detail, starting from the local level up to the basin dimension, putting emphasis on how interactions can take place between these two scales of intervention. This process resulted in drafting the Limpopo Basin Strategic Plan which focuses on reducing vulnerability to floods and drought. As a concrete experience derived from this basin planning tool, participatory approach and collaborative work with the Mozambican government authorities, the *"Living with Floods"* initiative is presented, which is still being implemented today. It represents a flood adaptation measure which, when applied in combination with a sound resettlement strategy, can effectively reduce the vulnerability of the communities living in the lower parts of the river basin. Finally, a discussion is developed regarding the application of the participatory method for basin planning and conclusions are drawn.

4.3. Methodology and research question

This paper is based on a critical reflection of more than three years of work (between 2004 and 2007) in four riparian countries, which was undertaken by a multidisciplinary team of professionals, and subsequent activities implemented especially in the lower stretches of the Limpopo River (between 2008 and today). Studies, workshops, consultations, trainings, fieldwork, and implementation of physical works, among other activities, were carried out at the local, national and basin levels in the context of the above-referred project. This allowed inquiring and making linkages from the local to the basin scale and vice-versa.

A qualitative research approach is adopted in this paper, which is an inquiry process of understanding based on different methodological traditions of research that explore social or human-related issues. Assertions are based on scientific literature review complemented with information collected throughout the work developed in the Limpopo basin, which are then put in perspective based on the knowledge and experience of the authors of the paper. The main focus is on participatory approach for a more integrated basin planning at the local, national and sub-regional scales. At the local level the stakeholders were the target population of selected rural settlements, central and local authorities, the academic or technical sector, the civil society and the private sector, while at the national and sub-regional levels the approach involved mainly inter-sectoral and inter-country coordination respectively, as well as legal and policy framework analysis. Lessons learned and best practices are derived, which contribute to knowledge on alternative basin planning methodologies with special focus on sustainable development and vulnerability reduction to natural disasters.

At present, dynamic models working through complex algorithms are commonly applied to simulate hydrological processes and sometimes even anthropogenic interventions at the basin scale. However, there are limiting aspects to be considered when applying modelling in developing countries, in particular: (i) data uncertainty and poor data input availability, making it difficult to generate spatially distributed scenarios (Fohrer, 2003); and (ii) high costs involved in determining large numbers of specific indicators (Kauffman, 2002). Data collection and monitoring is particularly challenging in these countries in which, not only resources are limited, but also historical information (which is very important to make consolidated projections) is often not available.

"Where data is a problem, approaches should be flexible and adaptive" (Holling, 1978). The authors believe that applying participatory planning represents a concrete answer to data scarcity, complex environmental conditions and weak institutional capacity. Several examples of successful initiatives from around the world which applied participatory approach at the community level towards a more integrated management of water resources are reported in scientific literature (Williams, 1995; Jorge, 1997; Liedberg Jönsson, 2004; Dungumaro and Madulu, 2004). This approach derives from the Participatory Rural Appraisal (PRA) which, according to Absalom et al. (1995), is meant "to enable rural people to share, enhance and analyse their knowledge of life and conditions, to plan and to act". Brace (1995) broadens the definition of PRA as a holistic approach focusing on the complex people-environment relationship. Interestingly, Chambers (1998) indicates that the PRA has evolved fast, and continues to evolve so differently that no final definition is adequate. In the same paper, Chambers explains that participation devolves power to the poor and encourages professionals to make changes to their personal, professional and institutional values and practices.

Why adopt a participatory approach? First of all, it is generally accepted that public participation ensures sustainability (WCED, 1987; Warburton, 1998; Corbett and Keller, 2006). Some authors even consider it as essential for obtaining successful project results (Kalbermatten and Gunnerson, 1978; Binns, 1997). According to Freire (1970; 1974), one of the pioneers of the participatory approach, the poor and exploited people can and should be able to conduct their own analysis of their reality, and take action to change it. From this perspective, developing countries offer particularly fertile conditions for applying this method (World Resources Institute and UNDP, 1992), as it also promotes a more democratic decision-making process.

From the above, the main research question arises: how can participatory approach lead to more integrated (land and water) basin planning in the case of a transboundary watercourse, and which disaster risk reduction strategies can be derived?

4.4. Main characteristics of the Limpopo River basin and problem definition

Physical settings: The Limpopo River basin is located in the South-Eastern region of the African continent and is shared among four countries. From upstream to downstream, the river first follows the boundary between Botswana and South Africa, then between Zimbabwe and South Africa and finally it reaches the Indian Ocean by crossing southern Mozambique (see Fig. 4.1). These particular geo-political settings complicate the inter-country management of the river. Since it follows the boundaries between three countries, different management options are applied in both sides of the same river stretch. Furthermore, as stated earlier, any basin management decision taken by the three upstream countries will affect Mozambique, which is located downstream. In general, dry land cover conditions are predominant in the basin, while irrigated and wetland ecosystems occupy 0.9% and 2.8% respectively of its area. Over the last 60 years most of the original forest cover was lost due to deforestation activities, reducing from over 50% to less than 1% of the basin area; this process was accompanied by a regular expansion of agricultural land use to more than half of the basin area (CGIAR, 2003; FAO, 2004). Such observations have profound land degradation implications due to increased runoff, erosion and sedimentation processes, eventually worsening flood and drought impacts. The relief characteristics of the basin are shown in Fig. 4.2.

Figure 4.1: Geographical settings of the Limpopo River basin

(Adapted from: INGC et al., 2003)

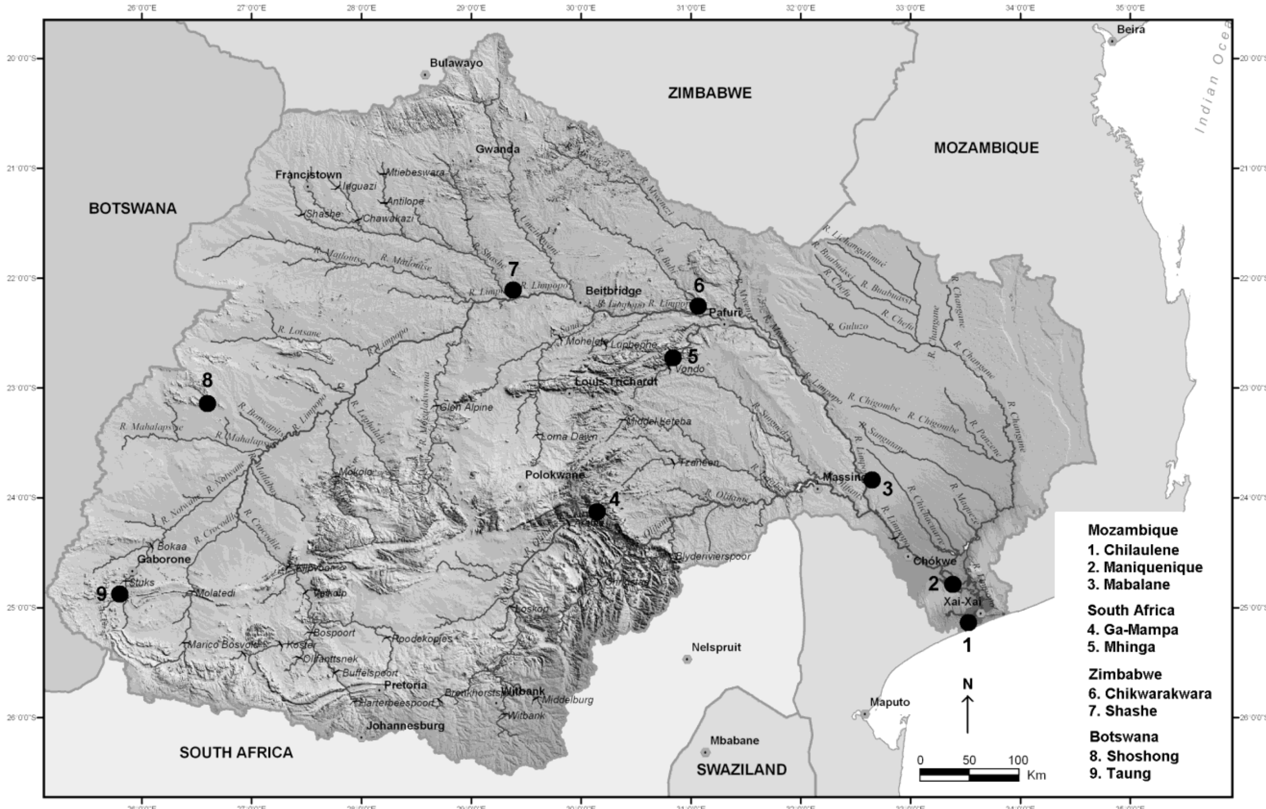
Table 4.1: Limpopo River population data

Country	Total area of riparian country (km^2)	Country area within basin (km^2)	% of the total basin area	Country population in 2005 (million)	Country population in the basin* (million)	% of the country population
Botswana	581,730	80,118	19	1.8	1.1	60
Mozambique	801,590	84,981	21	20.5	1.6	8
South Africa	1,221,040	185,298	45	48.1	11	23
Zimbabwe	390,760	62,541	15	12.5	1.1	9
Total		412,938	100	71.6	14.8	100

(Sources: CGIAR, 2003; Murwira and Yachan, 2007)

* NB: Projections made by the authors based on the updated country population in 2005.

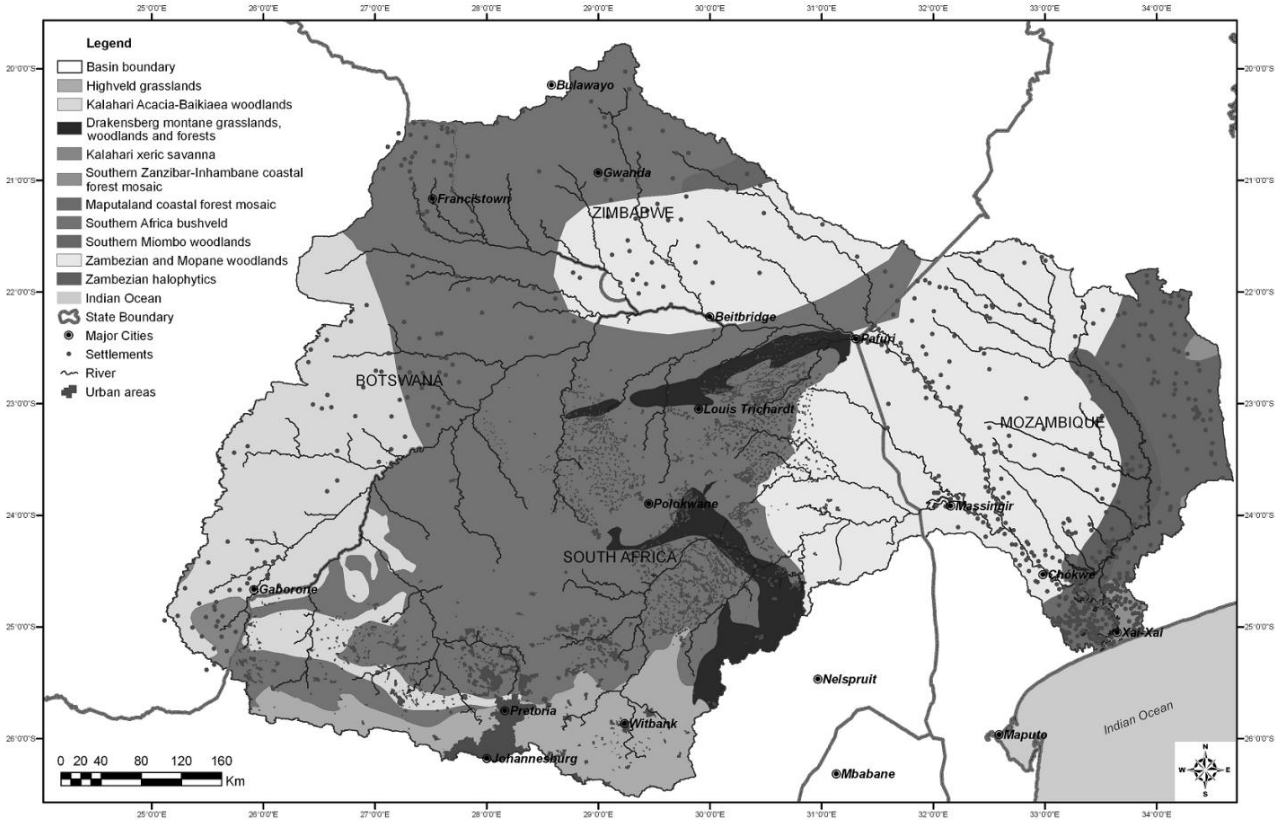
Figure 4.2: Relief characteristics of the Limpopo River basin and location of the nine project study areas



(Adapted from: Maló and Da Conceição, 2007)

Human settlements: The basin has an estimated population of 14.8 million inhabitants distributed in approximately 5,200 human settlements. It is the second most populated in Southern Africa after the Orange River basin (Murwira and Yachan, 2007), and includes approximately 60 per cent of Botswana's total population (see Table 4.1). Generally, human settlements tend to concentrate close to the stream banks due to the overall arid conditions of the basin, and they are much denser in Mozambique and South Africa as compared to Botswana and Zimbabwe (see Fig. 4.3). During the last three decades, a demographic densification process occurred in the Botswana and South Africa sections of the basin, in the delta area and along the main river channel in Mozambique, as well as in the upper reaches of the basin in Zimbabwe (Murwira and Yachan, 2007). Such a trend can be explained by considering the natural growth of the population coupled with the rural migration to the main urban centres within the basin. However a significant decline in population until 2050 is forecast due to the impacts of HIV/AIDS (CGIAR, 2003).

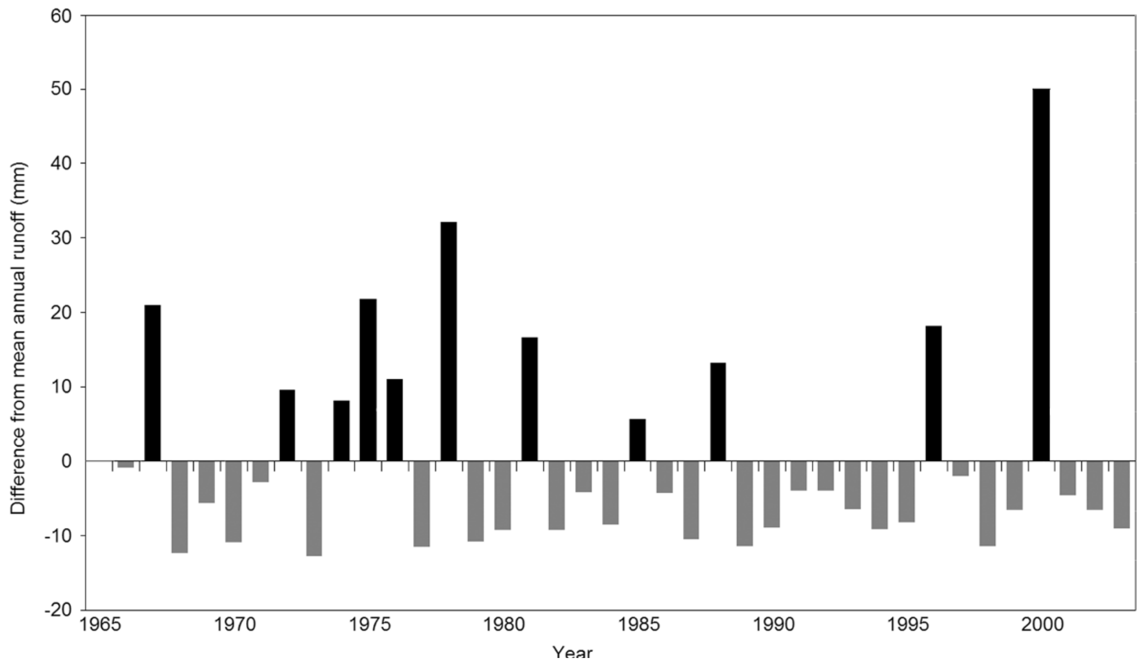
Figure 4.3: Human settlements and ecosystems in the Limpopo basin



(Adapted from: Maló and Da Conceição, 2007)

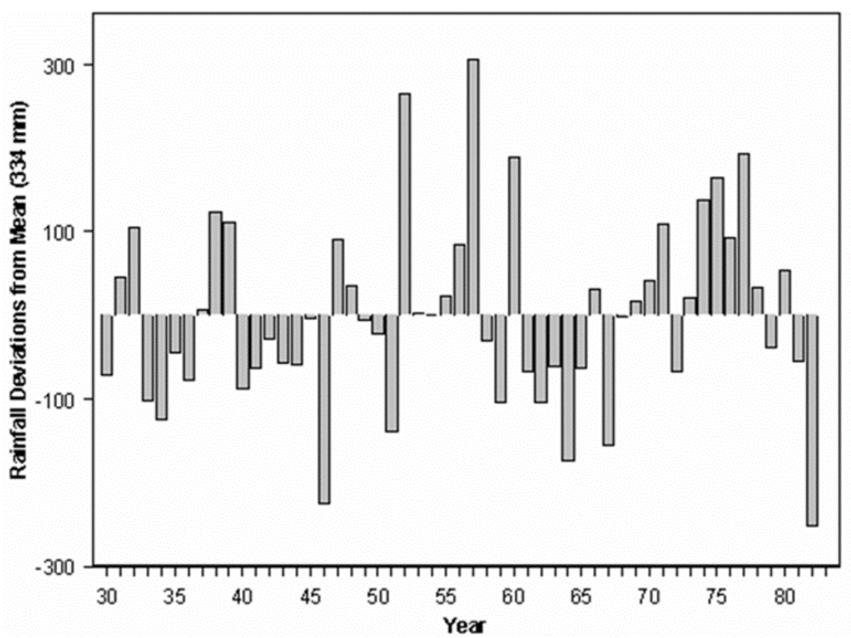
Hydrology, floods and drought: In the last 40 years the Limpopo River has shown a highly variable hydrological regime, especially in its lower course, with drought periods of two to seven years that are abruptly interrupted by flood years (see Fig. 4.4). A considerable spatial and temporal variation in the rainfall regime in the basin is observed, as much of the rainfall occurs in a limited number of rain events (Murwira and Yachan, 2007). An example of the temporal variability of rainfall is illustrated in Fig. 4.5. During the last decade, drought effects in the lower river stretches have been exacerbated by increased water withdrawals from a large number of reservoirs located upstream. On the other hand, greater floods occur when peak flows of the Limpopo River and its main affluent, the Olifants River, coincide downstream from their confluence, as happened in 2000 (CGIAR, 2003). On that occasion, more than 700 deaths were registered, including two million people affected and massive destruction of property and infrastructure (Kundzewicz et al., 2002). While studying the hydrological response of the Sabie River catchment—a Limpopo sub-basin located in South Africa—Smithers et al. (2001) estimated that the return period of such flood events ranged from 50 years to more than 200 years. Generally the main cause of floods in this sub-region relates to the occurrence of cyclones, which is more likely during the months January to March, provoking excessive rainfall. This was the case for the 2000 flood event triggered by Cyclone Eline. The flooding problem is exacerbated by the increased runoff as a consequence of the above-mentioned land cover and land use changes.

Figure 4.4: Difference from the mean annual runoff recorded at Combomune, Gaza Province, Mozambique, from 1966 to 2003, showing the irregular hydrological regime of the lower Limpopo River



(Source: DNA, 2005)

Figure 4.5: Difference from the mean annual rainfall recorded at Beitbridge, Matabeleland South Province, Zimbabwe, located on the Limpopo River at the border with South Africa, from 1931 to 1984



(Source: Murwira, A.; Yachan, 2007)

Economic characteristics: The basin countries exhibit considerable macro-economic differences, with Botswana and South Africa possessing stronger economies than Zimbabwe and Mozambique (CGIAR, 2003). With the exception of Zimbabwe, which entered a well-known crisis in the late 1990s, all countries have registered a positive economic growth in the last 10 years: the average annual Gross Development Product (GDP) growth has been 4 per cent for Botswana and South Africa, 6 per cent for Mozambique and -6.5 per cent for Zimbabwe[2]. When compared to Mozambique, the agricultural value added per worker (a measure of productivity) is twice in Zimbabwe, four times in Botswana, and 27 times in South Africa (CGIAR, 2003). However, while approximately three quarters of the total employed workforce is engaged in the agriculture sector in Mozambique, the other three riparian countries tend to concentrate more on industry and services.

To contribute to a better problem definition, the following aspects were analysed thanks to the information extracted from different baseline studies carried out during project implementation (Kgaodi, 2007; Muianga, 2007; Perrin, 2007; Merka, 2007; Timmermans, 2007; Kaseke et al., 2007; Murwira, 2006):

Land use planning: In all four countries decisional processes are top-down and centralised, particularly when large infrastructure development projects are concerned. Overall, governments' capacity to engage in broad participatory planning and decision-making processes is limited. Community participation is sought only within the context of small-scale actions involving Civil Society Organisations (CSOs). However, there are on-going political efforts for reinforcing local capacities. The decentralisation process is slow, especially in Mozambique, but early results are encouraging. This country is experiencing an important municipalisation process since 1997, as well as a recent establishment of provincial assemblies. Communities generally do not have access to formal planning data and tools.

Land use management: In general, there is a weak enforcement of laws and policies due to the inherent complexity of land issues. This complexity is due to a combination of historical reasons, such as the colonisation and recent decolonisation process, land conflicts between the formal and customary systems with consequent difficulty in securing tenure, and high speculation mechanisms due to private investments' interest in land for mining, agricultural or industrial purposes. Institutional frameworks for land management vary for each riparian country at the central level (different ministries are mandated to regulate the land sector) while the land allocation and registration responsibility is commonly delegated to local authorities. The latter face serious difficulties in applying the land policies and regulations (which were approved rather recently due to a late independence and democratisation process), especially when interacting with traditional powers which are still following customary procedures, as it occurs in rural areas. In general, communities' poverty, lack of awareness and unsuitable land conservation practices lead to increased vulnerability to natural disasters such as floods and drought. These practices, which provoke land degradation and deforestation, are related with subsistence agriculture practiced with poor means, traditional techniques for housing construction (e.g., making of mud and fired bricks), production of charcoal, lack of proper drainage systems in settlement areas, obsolete irrigation schemes, among other aspects.

[2] Percentages estimated by averaging the countries' GDP data of 2000, 2005, 2007 and 2008, reported in website: http://web.worldbank.org visited on December 2009; NB: for Zimbabwe, no data are available for 2007 and 2008.

Disaster management: Relevant legislation is still missing in Mozambique and Botswana, is difficult to enforce in Zimbabwe due to its formulation, and is more advanced in South Africa. Despite the awareness in this sub-region of the high vulnerability to natural calamities, disaster risk reduction aspects are not yet sufficiently integrated into sectoral policies or legal tools. Efforts to improve this situation are being made in recent years, especially in policy and strategy development. Local disaster management committees are established but not sufficiently empowered nor equipped. The flow of early warning information to vulnerable communities still needs improvement.

Legal, policy and institutional settings at basin level: The Limpopo River Basin Permanent Technical Committee (LBPTC) was established by the four riparian countries in 1986 for providing technical advice to the respective governments concerning basin management issues. The LBPTC is comprised of four representatives of each country (typically from the water sector) with a rotational chairmanship. Due to political tensions among neighbouring countries until 1994 (official end of the apartheid regime in South Africa), the LBPTC became effective only in 1995. After the ratification of the Southern Africa Development Community (SADC) Revised Protocol on Shared Watercourses, a slow process started to establish the Limpopo Watercourse Commission (LIMCOM), with more regulatory powers and a secretariat in Mozambique, which is currently being concluded. Despite the strong water management focus of both LBPTC and LIMCOM, there is growing interest for integrating disaster management and land-related aspects. In fact, the recently approved Regional Water Policy (SADC, 2006) advocates for integrated regional disaster management, appropriate land use planning, settlement policies, and climate change strategies. However, up to now, no major pilot initiatives tried to implement this policy. Finally, while the establishment of sub-regional institutions demonstrates the riparian states' commitment to transboundary river management, deliberations at basin level are still considered of secondary importance to national governments. Apart from South Africa, riparian states lack financial and technical means for setting up effective basin management mechanisms.

Inter-country cooperation: A network of gauging stations for sharing real-time information on water flows was established at basin level thanks to the SADC Hydrological Cycle Observing System (HYCOS) project. Unfortunately, this equipment could not be properly maintained, probably because local communities were not sufficiently involved in the planning and management process, which resulted in many stations being vandalised. In general, coordination between the different basin countries is weak; for instance, up-to-date technology and knowledge of South Africa is not yet benefiting the other countries, and flood forecasting and early warning at basin level suffers from the absence of standardised procedures.

From the above, there is a clear need for improving planning and management capacities at the basin, national and local levels. For this purpose, policies and tools have to be put in place and capacities reinforced.

At the sub-regional level, policies and institutional mechanisms for basin management exist but present several gaps. Despite the recognition of the importance of enlarging the current water management focus to integrate land and disaster issues, effective mechanisms for that purpose have not been found yet. In particular, inter-country coordination is weak. Therefore it is urgent to develop sub-regional initiatives looking at the basin as a single natural system, despite administrative boundaries, promote an exchange of experiences and increase technical cooperation among riparian countries.

4.5. Application of the participatory approach: starting at the local level

The main methodology adopted during the Limpopo project was a participatory bottom-up approach bringing together different stakeholders in the planning process to: (i) reduce the "distance" between decision-makers and the local population; (ii) maximise the use of local knowledge and resources, hence empowering local communities; and (iii) positively influence decision-making at higher (national and even sub-regional) levels.

Fig. 4.6 shows a typical participatory planning consultation conducted in Mozambique, in which all stakeholders (target community, central government officials, local authorities, technical experts, CSOs, and private sector) are present at the same time and in the same location. The participation rate to these events has been typically between 40 and 60 people. The decision making process implies transparent negotiations until consensus is reached and mutual commitments are made among the participants publicly. In this way, the decisions taken are easier to be monitored by the local population and the different stakeholders, and are most of the times enforced.

Figure 4.6: Participatory meeting in Chilaulene, Gaza Province, Mozambique

(Photographer: Trindade, 2005)

Table 4.2 summarises the methodological steps of the participatory planning approach that were applied in nine rural settlements located within the Limpopo basin (see Fig. 4.2), in close collaboration with the national authorities. Such exercises resulted in the preparation of nine local participatory plans at the village level (Murwira et al., 2006; Mpho, 2007; Trindade, 2006; Perrin and Mhlongo, 2006). Three main phases can be identified:

Mapping and characterisation of the study area (Steps 1 and 2): Different aspects characterising the study areas are mapped, such as flood risk, human settlements (especially basic and social infrastructure and services), land use as well as relevant topographic, geomorphological and environmental features. *Mapping is a key component of the whole participatory planning method* since, as emphasised by Rambaldi et al. (2006), it is "a fundamental way of displaying spatial human cognition and for communicating on issues related to territory". Different mapping techniques can be used: features drawn directly on top of aerial photographs or pre-prepared maps, satellite images or community hand-drawn maps (see Fig. 4.7). Importantly, maps are printed in a large format to allow all participants recognising familiar features of the areas and actively participating in the planning process. This is especially important for availing illiterate people with a concrete tool for providing their inputs. Thanks to this technique, the use of local knowledge is maximised and the planning process accelerated, as fieldwork is carried out only to confirm the information collected during the stakeholders' consultations and complement it as needed.

Table 4.2: Different steps of the participatory planning methodology applied in the Limpopo basin

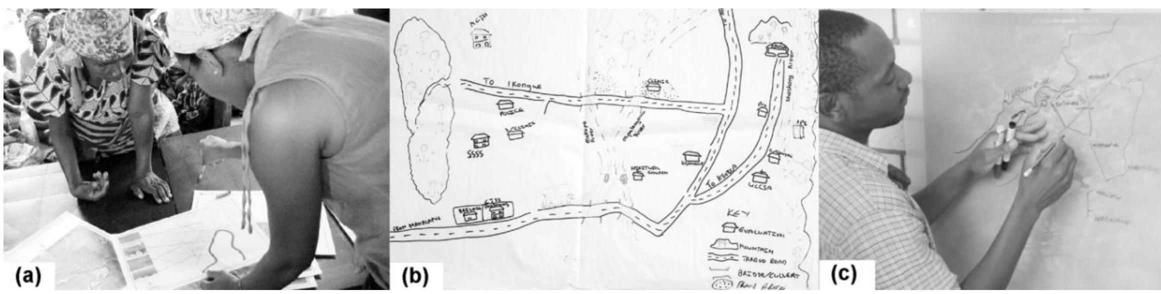
Participatory Planning Stages	Specific Activities
Step 1 **Characterising the study area**	▪ The technical team presents a map, aerial photographs and/or satellite image of the study area to the target community, local authorities, government officials, NGOs and private sector; ▪ In collaboration with the community, determine the geographic location of the main features of the area.
Step 2 **Mapping the existing situation**	▪ Based on the information provided by the resident population, draw a land use map of the area; ▪ Determine the location of the main infrastructure and basic services; ▪ Complement by fieldwork activities as needed.
Step 3 **Defining the main problems**	▪ According to the inputs of the participants, draft a list of the existing problems in the area; ▪ Try as much as possible to locate the problems in the map; ▪ Discuss the problems openly and prioritise them.
Step 4 **Identifying possible solutions**	▪ The community, assisted by the local authorities and the technical team, proposes its own solutions to the listed problems; ▪ These solutions are discussed in relation to their feasibility and according to the available resources; ▪ Consequently, priority interventions are agreed in consensus; ▪ Develop the implementation strategy in consultation with all participants, and determine the community's contribution.
Step 5 **Elaborating the action plan**	▪ The technical team organises the collected information in the form of a proposed action plan; ▪ The proposal is presented to the community and local authorities for a joint assessment, formulation of suggestions and corrections, and final approval; ▪ The whole planning process is supervised by government officials, to ensure its consistency with national and local plans, strategies and/or policies; ▪ The approved plan is adequately integrated in the local, district and provincial development plans by the competent authorities.

Table 4.2 (cont.)

Participatory Planning Stages	Specific Activities
Step 6 **Implementing priority interventions**	▪ Define the responsibilities of each stakeholder for the implementation phase; ▪ Jointly, assess the training and capacity building needs at the local level; ▪ Prepare all required technical drawings and detailed projects for undertaking the selected interventions; ▪ Establish partnerships at the institutional level to ensure proper coordination, including with the private sector; ▪ Involve the community in the whole implementation process and as subsidised manpower.

(Source: Feuerhake and Spaliviero, 2006)

Figure 4.7: Different mapping techniques: (a) Mozambique; (b) Botswana; (c) South Africa

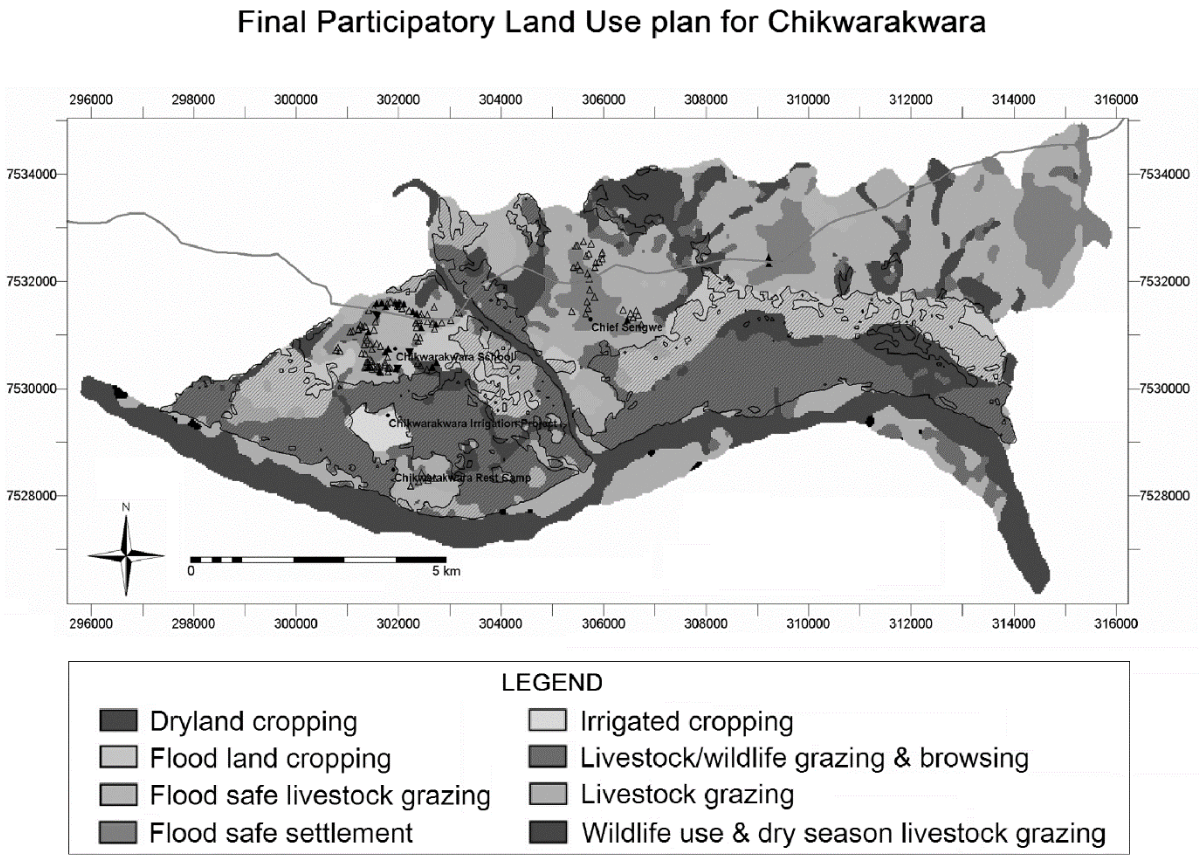


(Photographers: (a) Ferreiro, 2005; (b) Mpho, 2007, (c) Timmermans, 2005)

Problem discussion and identification of solutions (Steps 3 and 4): Maps are used as basis for discussion, negotiation and conflict management and resolution (see also Chapin, 2006). In particular, problems affecting the areas are discussed in plenary, classified according to a decreasing order of importance and systematically located in the maps. Hence, the cartographic output serves as support during the whole exercise, and information in it is constantly updated by interacting with the participants. For example, questions are asked to the participants regarding the areas that are flooded when it rains and the main drainage lines. It is generally the same population living in the study area (selected rural village or urban neighbourhood), and who has learned to recognise the features in the map, who can indicate with great precision how such phenomenon occurs spatially and which are the affected locations. The map is then updated accordingly on the spot by the technical team mediating the process. In Zimbabwe, problems were also identified through individual interviews at the household level, giving slightly different results than the plenary sessions with community leaders. This shows that, ideally, the same issues should be analysed from different angles in order to obtain more accurate planning information. Once problems are classified, the resident population is requested to come up with alternative solutions. In coordination with authorities, the technical experts help to assess the feasibility of each solution in plenary according to available financial, human and material resources, in a transparent manner. Discussions are then moderated around project identification and modalities of implementation. As recommended by Chambers (1998) in the first PRA pillar: “outsiders should facilitate and not dominate”.

Drafting local plans and implementation of priority interventions (Steps 5 and 6): The presence of authorities from provincial or central levels contributes to frame working the plan within a larger scale, thus avoiding that locally-biased decisions are taken without due consideration of the micro-region settings and dynamics in which the study area is inserted. This allows also fulfilling the requirements defined in provincial or national plans, strategies and/or policies (see also Mc Call, 1993). Final maps are prepared in a Geographic Information System (GIS) environment to be included in the drafted local plans, which are then submitted to the consideration of the participants for validation (see an example of final maps in Fig. 4.8). The validation exercise occurs once the technical team has worked out a draft of the local action plan based on the data collected in the first planning session. For such purpose, a second participatory planning session is organised, preferably with the same participants, to get confirmation that what was discussed in the previous session has been properly reflected in the drafted plan, and to identify necessary amendments or corrections to be made. In particular, Corbett et al. (2006) assert that Participatory GIS (PGIS) can: (i) enhance capacity in generating, managing and communicating spatial information; (ii) stimulate innovation; (iii) encourage positive social change. PGIS is geared towards community empowerment; it is a flexible practice which adapts to different socio-cultural and biophysical environments, by combining “expert” skills with local knowledge (Rambaldi et al., 2005). Importantly, based on the negotiated solutions during the previous phase, priority interventions are defined, which will constitute the immediate and direct consequence of the planning process. The organisation that goes into carrying out these interventions works as a catalyst, as it encourages participants to contribute actively to decision-making, hence reinforcing the sense of ownership of the process as well as their commitment to achieve what was planned. Implementing tangible activities also reduces the risk of raising the communities’ frustration, as it generally occurs when the whole process is perceived as a mere data collection exercise ending up only with a printed document. For implementing the plan a local committee is elected, in a gender-balanced manner, which should enjoy the trust of the population. The committee is generally constituted by community leaders and serves as intermediary body between the resident population and the local authorities. An agreement is signed between these two entities for defining the roles and responsibilities of the different stakeholders in carrying out the plan’s implementation. Ideally a community centre is established where regular meetings are held for organising and monitoring the execution of the planned activities. During implementation, all relevant (including budgetary) information is shared publicly and issues are discussed in a step by step fashion until a consensus is reached on the way forward. Experience shows that such community involvement approach is effective for solving conflicts deriving from individual interests which clash with community and/or public interests (e.g., an individual house abusively built along a natural drainage line is demolished for the benefit of the whole community, and rebuilt in a proper location with the support of the neighbours).

Figure 4.8: Local Participatory Plan for Chikwarakwara area, Matabeleland South, Zimbabwe



(Source: Murwira et al., 2006)

Interestingly, even though the same methodological steps were followed, different types of local plans were produced in each riparian country. This means that *the proposed participatory approach is flexible* and can easily be adapted to local conditions and expertise of the team of facilitators. Additionally, *strengthening local capacities is key for carrying out participatory planning successfully*. For this purpose, it is necessary to develop tools and guidelines that are easily understandable by target communities and local authorities. At the same time, experience shows that *more decentralised decision-making mechanisms can be established* by ensuring the participation of representatives from central government in the local planning process.

4.6. Scaling up to the basin dimension

According to Lundqvist et al. (1985), the water divide constitutes a natural physical boundary for examining the interdependence between land and water; meanwhile these issues are generally treated separately. The same authors observe that, commonly, river basin organisations (such as LIMCOM) are only water-oriented. This situation leads to a "reductionist" idea of the complexity of water management issues at basin level, as pointed out by Falkenmark (1996). Integration of water and land involves changes in attitude and institutional building (Lundqvist et al., 1985). To overcome this situation in the Limpopo basin, efforts were made for establishing *inter-sectoral committees at the* *national level*. Dialogue was promoted between the different sectors by planning concrete activities to be carried out at the local level.

Locally implemented activities were brought up for discussion at the sub-regional level through a series of workshops in which all four countries participated (Merka and Timmermans, 2007). Language barriers between the riparian countries[3] were overcome by organising simultaneous translation, and also thanks to Mozambican participants making efforts to speak in English. During these meetings, riparian governments learned about the benefits of the adopted participatory approach. Different key ministries were present during these sub-regional events, representing the following sectors: water, land and environment, meteorology, and disaster management. This allowed reducing the distance between the local reality and decision-making at basin level as well as establishing a crucial inter-sectoral confrontation based on concrete actions carried out at ground level. The discussions were then used to draft a Limpopo Basin Strategic Plan (LBSP) focusing on vulnerability reduction to floods and drought, which are two interrelated types of natural disasters most commonly affecting the basin (see outline of the LBSP in Table 4.3). The plan also integrated the information derived from the different studies, reports, activities and products obtained during the project's implementation. In this manner the planning-decisional cycle was completed: information and planning decisions collected from the local and national levels were brought up to the sub-regional level, where they were analysed and strategic decisions were consequently taken in terms of basin management.

In general, additional time would have been needed to reach more elaborated and endorsed results in the context of the Limpopo project and, in particular, to obtain more effective inter-sectoral and inter-country coordination mechanisms for better basin planning and management. Getting the four riparian countries and all concerned stakeholders at the different levels fully on board has required considerable efforts. Once a strong interest was shown to the initiative by the respective governments after three years of implementation (2004-2007) the project was finished and all available (and limited) funds completely spent. Unfortunately no adequate follow-up could be ensured at the basin level as pledged funds for continuing the initiative were finally not confirmed by the Global Environment Facility, despite the support of the countries. Hence the drafted LBSP could not be adequately discussed nor implemented, although its proposed activities are still valid today.

[3] Out of the four riparian countries, Mozambique is the only one speaking Portuguese while the official language in the other three is English.

<u>Table 4.3</u>: Proposed activities of the Limpopo Basin Strategic Plan for the first four years of implementation

Themes	a. At the basin level	b. At the national level	c. At the local level
<u>Theme A</u> **Legal and policy framework**	A.a.1. Establishment of formal coordination mechanisms for flood and drought forecasting and early warning. A.a.2. Elaboration of a SADC policy on natural disaster management which promotes inter-sectoral approach and integrated land and water management.	A.b.1. For those countries where it is still needed, complete the formulation and/or approve legal instruments on disaster management. A.b.2. Design and implement a national dissemination program of disaster management policies.	A.c.1. Encourage local discussions on existing regulations for a more efficient involvement of local authorities and communities in disaster management operations. A.c.2. Deliver local capacity building to enable effective implementation of disaster management policies.
<u>Theme B</u> **Institutional set-up**	B.a.1. Strengthen LBPTC and LIMCOM to include expertise and procedures for disaster management and land use planning. B.a.2. Streamline institutions dealing with disaster management among the different riparian countries for improving inter-country coordination and flow of information.	B.b.1. Reinforce national institutions responsible for disaster management. B.b.2. Clarify roles and responsibilities of line ministries by promoting inter-sectoral dialogue. B.b.3. Identify institutional strategies for increasing and simplifying access to funds for disaster management.	B.c.1. Build local capacities to implement disaster management operations at ground level. B.c.2. Improve flow of disaster management information at the different local levels by clarifying roles and responsibilities.
<u>Theme C</u> **Disaster Preparedness**	C.a.1. Set-up inter-country early warning mechanisms for floods and droughts. C.a.2. Run inter-country simulations, evaluate the local response and prepare a sub-regional training consequently.	C.b.1. Set-up mechanisms for sending SMS warning messages directly to community leaders. C.b.2. Deliver training on flood and drought forecasting, monitoring, and early warning at the central level.	C.c.1. Improve/upgrade network stations and establish community-based management mechanisms. C.c.2. Create floods and droughts preparedness capacity at community level.
<u>Theme D</u> **Sustainable ecosystem utilisation**	D.a.1. Reinforce the implementation of current transfrontier park initiatives, in particular by promoting community participation and sustainable use of natural resources.	D.b.1. Prepare an integrated land and water management plan for disaster preparedness and vulnerability reduction, including: risk zoning, suitable areas for irrigation and dam management schemes, rural-urban linkages to be developed, practices for reducing land degradation, etc.	D.c.1. Carry out participatory planning at community level to prepare Activity D.b.1 and design local coping solutions to floods and droughts. D.c.2. Promote community-based wildlife management initiatives to improve the livelihood of vulnerable population.
<u>Theme E</u> **Flood and/or drought safe infrastructure development**		E.b.1. Based on Activity D.b.1, identify suitable areas for developing safe havens or elevated platforms provided with basic water and sanitation facilities, to be used both during floods or droughts. E.b.2. Design and deliver capacity building to promote adequate building techniques and solutions for increasing resistance to floods, including rainwater harvesting systems. E.b.3. Promote investments for constructing or rehabilitating small irrigation and dam management schemes, as per plan drafted in Activity D.b.1.	E.c.1. Based on local solutions designed under Activity D.c.1 and on the locations identified in Activity E.b.1, construct elevated platforms (e.g. markets) and social services (schools, health posts, warehouses for storing food and basic goods, *etc*.) equipped with flood-proof water and sanitation facilities, and including rainwater harvesting systems; these solutions will work as safe havens during floods and as important social/basic facilities during droughts.

(Adapted from Murwira and Yachan, 2007)

4.7. Living with Floods in Mozambique

Despite these difficulties, activities could have more continuity in Mozambique, which is also the country located downstream in the most vulnerable position to flood disaster. Some provisions made by the drafted LBSP could be implemented there since 2008, as consequence of the participatory planning approach applied in few locations and an intense work with the national authorities. With a much larger floodplain, the Limpopo River is more dynamic in Mozambique and, hence, more complex to manage compared to upstream countries, especially in terms of human-fluvial spatial requirements and relationships.

It is worth highlighting that after the 2000 floods, the Mozambican government carried out major resettlement operations of people living in low areas to higher grounds, following a policy which has been enforced since independence in 1975. Unfortunately, experience shows that if no initial investment is made in the short term for providing basic and social services, and no social integration and sustainable livelihood mechanisms are in place, the resettlement areas will soon become unsustainable locations to live in (Yachan, 2002; Calengo and Moreno, 2002). As a result a high percentage of the displaced population returns to the areas at risk, perpetuating a vicious cycle of vulnerability. The main reason for such behaviour is related with the extreme poverty of the population and its dependency on subsistence agricultural schemes applied in the floodplains, which are very fertile (Cosgrave et al., 2007). This aspect was also confirmed by a recent study carried out in the lower Zambezi River after the 2007 and 2008 floods which shows that the resettled population, although accepting to live in houses (subsidised by the Government) located in higher grounds, is returning to the low areas on a daily, weekly or seasonal basis depending on the distance from their crops (UEM, 2009).

Therefore, for people living in large floodplain areas characterised by a flat topography and whose relocation would mean to be moved too far away from their crops, resettlement is not a viable solution. In these cases, adaptive solutions need to be explored, such as *"Living with Floods".* This is particularly feasible for low-lying areas prone to moderate flooding, having reached a maximum height of one meter during historic exceptional floods. Such approach has been promoted by UN-Habitat in Mozambique since 2003, in close partnership with the Government (Spaliviero, 2006). A similar strategy was adopted long ago in Bangladesh where the destructive impact of flooding is reduced by the adjustments that peasants inhabiting the floodplain regions have historically made, adapting their agricultural practices, cropping patterns and settlements to the annual deluge (Zaman, 1993). In fact, building expensive flood-control structures is often an unaffordable option for poor countries which are highly vulnerable to this kind of natural disaster, especially when large and dynamic rivers are concerned. According to William (1994), the goal of flood management is to reduce the hazard to lives and properties by the most cost-effective measures, recognising that not all flood-risks can be eliminated. The same author further explains that this can be accomplished through proper land use planning, flood proofing, flood warning, and financial incentives, and that elevated structures are a valid alternative to flood control.

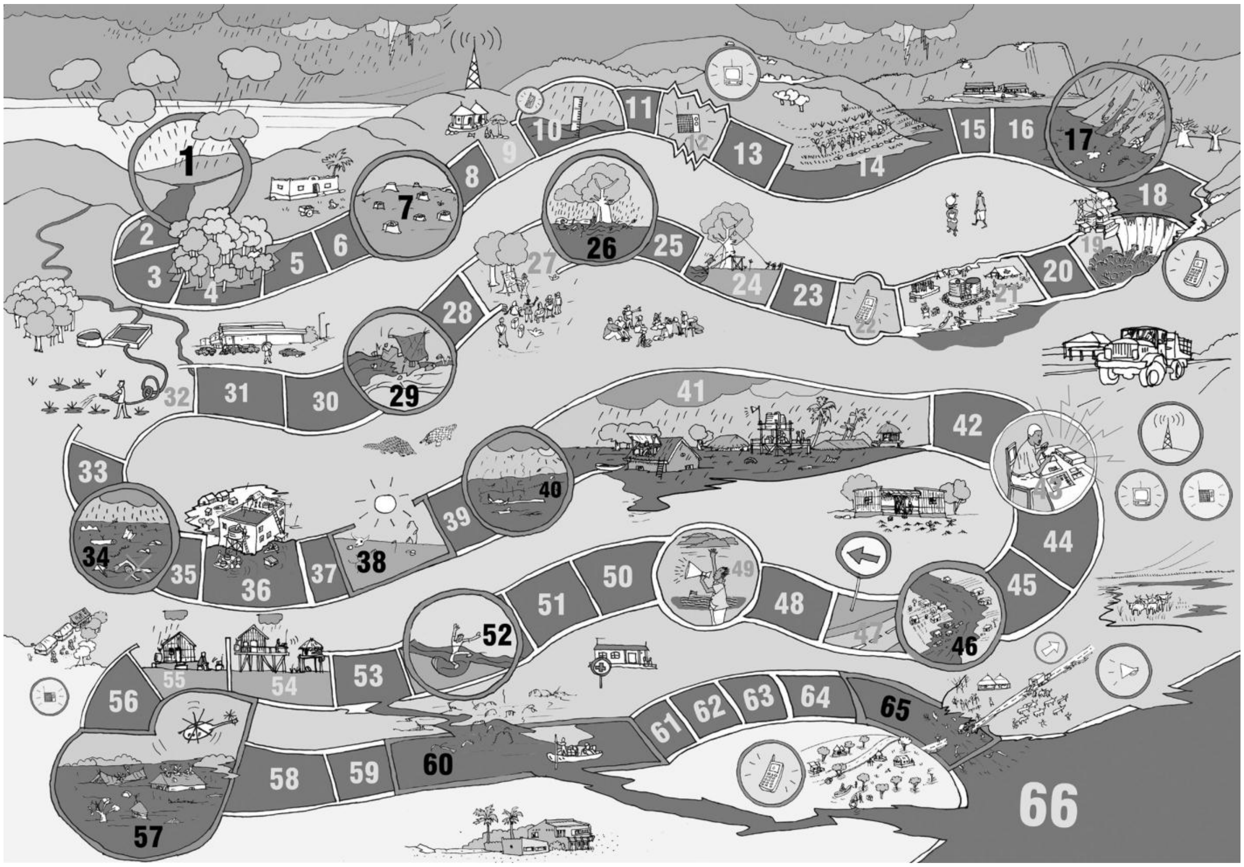
Along this line of thought, the selected priority interventions during the preparation of the local participatory plan for Maniquenique village, Gaza Province (see area 2 in the map of Fig. 4.2), was the construction of an elevated school. Such structure was designed to function as a safe-haven in case of floods (see Fig. 4.9), with a wooden floor built half a meter higher than the level reached by the floodwaters in 2000 (Ferreiro et al., 2007). The one-slope roof is reinforced so that it can be used as higher refuge-platform in case of a dramatic event. Moreover, it works as a rainwater harvesting system linked to a water tank with a capacity of 30 m^3, allowing the community to access safe drinking water at all times, especially during a flood. The building design is adapted to the local reality and to climatic features of the area, being resistant also to cyclones. Man-power was recruited locally and trained on-the-job during the construction phase. Such demonstration activity, which is currently being replicated in the lower Zambezi River at a bigger scale, is meant to influence the building codes of public facilities such as schools and health centres of settlements located in areas potentially vulnerable to moderate flooding. The elevated school of Maniquenique was used in November 2010 by the national authorities as part of the flood simulation exercise.

Figure 4.9: Elevated school of Maniquenique, Gaza Province, Mozambique

(Photographer: Ferreiro, 2008)

Complementing such pilot intervention, awareness raising activities for vulnerability reduction to floods, drought and cyclones are also being carried out. One of most important didactic tools to reach the communities and increase their adaptive capacity is the River Game, which provides an overview of the most important recommendations regarding flood preparedness, contingency, early warning, land use management, drought mitigation, among other aspects. It includes a board game depicting the winding course of the Limpopo River from the mountains to the sea, which is divided into segments which contain simple instructions corresponding to the throw of a dice (see Fig. 4.10). This learning by playing concept is currently having a great impact at community level and among partners across borders.

<u>Figure 4.10</u>: The River Game



(<u>Source</u>: Feuerhake, 2006)

Based on these activities a strategy for vulnerability reduction and sustainable development targeting areas prone to moderate flooding was designed and is currently being discussed and analysed by different government institutions in Mozambique. The strategy combines both the resettlement and the *“Living with Floods”* approaches according to the following three main lines of intervention, trying to maximise sustainability:

- Establishment of serviced resettlement areas in higher/safe grounds not too far from the productive/low areas. These areas will serve as centres for attracting resources, investments and people, setting up vocational training facilities, running commercial activities and providing services to the surrounding population within a radius of 10 to 20 km, which should include the productive/low areas and attract/serve approximately 40,000-50,000 people.

- Installation of elevated support platforms in the fertile lowlands susceptible to moderate flooding, which can serve as social facilities or resource centres in normal times and as safe-havens or evacuation centres during flood times. These platforms need to be well-connected to the resettlement areas, within a logical, interlinked and functional spatial planning framework.

- Set up a permanent institutional capacity development process at the different local (district and village) levels concerning governance, local management and service delivery for disaster risk reduction and for increasing agricultural productivity.

To start implementing this strategy and ensure the feasibility of investments, a comprehensive territorial assessment needs to be undertaken in the first place, looking into the flood vulnerability characteristics at district level, so that resettlement areas and elevated platforms can be properly planned and located. Regional planning concepts will be applied, in particular looking to the inter-connectivity with the main settlements.

4.8. Discussion and conclusion

Based on the findings presented above, the major bottlenecks for obtaining a more integrated planning and effective management of the Limpopo River basin (which are typical in the context of the developing world) can be summarised as follows: (i) weak inter-sectoral and inter-country coordination; (ii) top-down decision-making mechanisms and lack of community empowerment; (iii) overall lack of capacity, especially at the local level, leading to a weak policy enforcement; (iv) high vulnerability of riparian communities to natural disasters which are provoked by climate change and variability; and (v) excessive pressure on natural resources leading to deforestation and land degradation, worsening the impact of floods and drought.

In this paper, participatory approach was presented as a potential method to overcome some of the above challenges. The authors argued that planning decisions need to be made after a careful analysis of the situation on the ground, by mainstreaming community involvement. However, such approach presented the following shortcomings during the implementation of the Limpopo project:

- It took time and effort to convince decision-makers at central level that participatory planning could work as an effective tool for better defining regulatory policy instruments at the basin level. In fact such methods refer to a given geographical area (in the case of the project: nine rural villages) in a given period of time. To be representative of the complex and changing reality of the basin, more locations would need to be selected.
- Overall, it was also time-consuming to identify pilot sites and mobilise expert teams to run the participatory planning sessions at the local level (in average three months and two sessions per site, mostly located in remote areas, were needed).
- An additional challenge was represented by the particular skills needed by these teams for conducting the sessions, such as the language to be adopted for enabling proper understanding of all participants, delicate situations to mediate which can result in tensions and conflicts between the local stakeholders, among other aspects.
- Finally, the financial means for carrying out pilot activities based on the adopted decisions were generally limited (an average of 15,000 US dollars per study area).

Despite these difficulties, the results obtained from the participatory planning activities produced reliable “snapshots” of the situation on-the-ground which were useful for understanding on-going processes as well as potential developments of the areas under study. The authors believe that if replicated according to a pre-defined sampling scheme, this approach allows “capturing” the complexity of a river basin. Hence, local plans resulting from a bottom-up decisional process can positively influence policy-makers at national and basin levels, as they represent a sort of “ground truth”.

An added-value of the participatory planning method applied in the Limpopo project was its mapping dimension, which allowed maximising the use of local knowledge. Thanks to the detailed spatial information contained in the aerial photos or satellite images (in which even single houses can be detected), even illiterate participants from the targeted community are able to provide valuable contributions, based on their experience and deep knowledge of the study area. This increases time and cost-effectiveness in data collection about the study area (Spaliviero, 2006).

The local participatory plans in particular facilitated the identification of gaps to be filled in and linkages to be strengthened between the different sectors of intervention. Examples in scientific literature provide evidence that, through use of a participatory approach, plans integrating land, water and disaster management aspects can be produced locally (Williams, 1995; Jorge, 1997; Liedberg Jönsson, 2004; Dungumaro and Madulu, 2004). During the Limpopo project, the presentation of these local plans in sub-regional fora in which the different sectors concerned were represented has stimulated the discussions and highlighted the need for a more integrated approach, not only limited to land and water management aspects, but also including economic development and disaster management in the planning process. It is worth mentioning that after this initiative in the Limpopo, the LBPTC requested a Joint Limpopo River Basin Study of the four riparian countries, whom scoping phase was completed in 2010 (MOPH, 2010). Once again, the latter mainly focuses on water management aspects, ignoring the needed inter-sectoral approach needed for dealing with basin planning and management appropriately, as highlighted in this paper. There is still a long way to go before such coordinated approach is foreseen and applied, and resources are made available for such purpose.

Once strategic guidelines are determined at the basin level (such as the attempt made during the Limpopo project to draft a basin strategic plan), they need to be tested locally and then assessed for further replication. In this way the assessment, planning and decision-making cycle is completed, linking the different levels in a self-regulatory manner. This can be done through continuous needs assessments, local planning, testing of policy decisions in each cycle, hence determining the consequent adjustments to be made for the next cycle. A concrete example of such multi-level adaptive management is the *"Living with Floods"* experience in Mozambique. Following the provisions and recommendations of the LBSP, a flood adaptation pilot activity was identified at the local level through participatory approach and complemented with awareness raising activities. This activity has then stimulated the formulation of a vulnerability reduction strategy for areas prone to moderate flooding, which now needs to be approved at the central level and tested locally in other locations, so that it can be validated and upgraded to a policy and legislation.

According to the authors, considering its complexity, a basin plan should be constituted by broad strategic orientations based on a synthetic analysis for a sample of local situations, and positively influence the formulation of improved national and regional strategies and policies. If it contains too much detail, the basin plan would be impossible to implement. Therefore, basin planning and management ideally resembles policy-making, providing strategic development guidelines and allowing some flexibility and adaptive management while applied at the local level.

It is clear that an initiative in the Limpopo River basin such as the one described in this paper, in which different countries are involved and who are struggling for controlling the same water resources, would need more time than just three years as well as more resources to significantly contribute in achieving improved basin planning and management. The implementation of the *"Living with Floods"* strategy in Mozambique since 2006 to today is the demonstration that adequate time and resources are needed to induce effective institutional and political changes for up scaling such an approach which initially did not fit the main policy advocated by the government: resettlement of the population at risk to higher grounds.

Through this paper, the potential use of the participatory approach for more integrated basin planning becomes clearer. As stated by Buller (1992) and Newson (1997): "popular action is progressing the concepts of integrated river basin management". This approach is seen by the authors as particularly valuable in developing countries where data are scarce, as it can be carried out with minimum resources. Importantly, it avoids falling into a top-down logic and allows acknowledging local population's opinions in decisions made at the national and sub-regional levels. It also strengthens the local capacities and facilitates inter-sectoral integration and coordination.

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5. Integrating Slum Upgrading and Vulnerability Reduction in Mozambique

Mathias Spaliviero (2006); published in OPEN HOUSE INTERNATIONAL, Special Issue: "Managing Urban Disaster", vol. 31, n.1, pp.106-115

5.1. Abstract

Due to its location, Mozambique suffers from cyclical flooding associated with heavy rains and cyclones. In recent years, extreme flood events affected millions of people, disrupting the economic recovery process that followed the peace agreement in 1992. Despite this natural threat, most of the population continues to live in flood prone areas both in rural environment, due to the dependency on agricultural activities, and in urban environment, since unsafe zones are often the only affordable option for new settlers.

This paper presents a brief analytical review on different issues related with urban informal settlements, or slums, based on different project activities developed by the United Nations Human Settlements Programme (UN-Habitat) in Mozambique. The aim is to identify applicable strategies to reduce vulnerability in urban slums, where approximately 70 per cent of the urban population live. The implemented project activities target different organisational levels in an integrated manner, seeking for active involvement of the Government, local authorities and communities at each implementation stage, from decision-making to practical implementation. They consist of three main components: 1) supporting policy-making in order to ensure sustainable urban development, 2) delivering a comprehensive training and capacity building based on the mainstreaming concept of *"Learning How to Live with Floods"* as valid alternative to resettlement, and 3) facilitating participatory land use planning coupled with physical upgrading interventions at the local level.

In the long-term, the intention of UN-Habitat is to progressively focus on community-based slum upgrading and vulnerability reduction activities, coordinated by local authorities and actively monitored by central institutions, in improving and managing basic services and infrastructures (i.e. water supply, drainage, sanitation, waste management, road network, etc.). This type of bottom-up experiences should then represent a basis for setting up a slum upgrading intervention strategy to be applied at the national level.

Keywords: Mozambique, Slum upgrading; Vulnerability reduction; Floods; Participatory approach.

5.2. Introduction

Mozambique, one of the poorest nations in the world, is highly susceptible to floods. The country is located downstream of important international river basins, such as the Zambezi, Limpopo, Save, Rovuma, among others, with 60 per cent of its surface constituted by floodplains. In the year 2000, an extreme flood event occurred with catastrophic consequences in terms of human lives (more than 700 fatalities, two million people affected, 400,000 people resettled), basic services and infrastructures (drainage, water, sanitation and road systems heavily damaged) and socio-economic settings (entire staple crops destroyed, 80 per cent of cattle lost, etc.) (Kundzewicz et al., 2002). Other floods were recorded in 2001, inducing a break in the economic recovery process started after the signature of the peace agreement in October 1992, which ended 16 years of civil war.

In rural areas, as main long-term response to floods, the Government organised a massive resettlement programme of the affected population to higher grounds. Unfortunately, the living conditions in the new areas are often not sustainable, offering little possibilities to develop agriculture[4]. Hence, most of the resettled families would like to return to their fertile lands located in the floodplains, which might be already occupied by other people (Calengo and Moreno, 2002). On the other hand, the land rights of the families who want to remain in the resettlement areas are often not yet legally recognised. Therefore, resettlement operations cause more land tenure insecurity in an already complex legal and institutional framework. In fact, according to the new Land Law approved in 1997, the State retains ownership of all land (urban and rural), and rights of use are acquired through long-term leaseholds. The law allows good-faith occupiers on unclaimed land to request for permanent use title. However, due to the poor technical conditions, lack of reliable knowledge about concessions and unclear roles of the different concerned institutions[5], an impressive number of unresolved land title requests remain in the "pipeline". This situation is leading to conflicts between smallholder occupation and large-scale agribusiness interests, since the new economy policy seeks to attract foreign investors through a partnership scheme with the tenants of customary rights (Yachan, 2003).

In the urban areas, the Portuguese at colonial times preferred to develop cities along the coastline and close to a river estuary or delta, such as Maputo, Beira and Quelimane, so that they could have easier access by foreign and inland navigation. While twenty years ago Mozambique's urbanisation process was still relatively slow compared to most of the African countries (Spaliviero, 1986), it has tremendously accelerated since then. Such phenomenon started as a consequence of the civil war and was then consolidated by the migration of poor rural population to the cities, seeking for better services and economic opportunities. Consequently, during the last two decades, a proliferation of unplanned human settlements was observed around the urban centres, gradually expanding in topographically depressed and marshy areas with high flood risk by rains or river overflows.

The effect of flooding in the suburbs is worsened by poor living conditions of the inhabitants, the reduced financial and technical capacity of the local governments and, in particular, the general deficiency in basic infrastructures and services for water and sanitation (see Fig. 5.1). This results in the spreading of diseases such as cholera and malaria. Recent studies by Forjaz et al. (2005) estimate that informal settlements, or slums[6], constitute more than 70 per cent of the total urban population today.

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[4] Approximately 80 per cent of the Mozambicans depend on agriculture.

[5] For more details see section 2: *Support to policy-making*

[6] A slum is defined as a group of houses, lacking one or more of the following conditions: (i) Access to improved water; (ii) Access to improved sanitation facilities; (iii) Sufficient living area, not overcrowded; (iv) Structural quality/durability; and (v) Security of tenure (UN-Habitat, 2003).

Figure 5.1: Slum area in Maputo City, Mafafala Neihbourhood

(Photographer: Mazzolini, 2005)

In the light of these findings, it seems essential to integrate vulnerability reduction activities with slum upgrading. The latter is an issue still not adequately considered in the current National Poverty Reduction Strategy Papers (PRSP, locally called PARPA), for obtaining a sustainable urbanisation process in Mozambique. From this perspective, the United Nations Human Settlements Programme (UN-Habitat) is developing several projects aiming at strengthening the relationships between the different organisational levels (i.e. central Government, local authorities and resident communities), which consist of three main components: 1) support to policy-making, 2) training and capacity building, and 3) participatory land use planning and consequent implementation of physical interventions at the local level. These components are presented in the next sections, which provide an overview of the results obtained from different project activities implemented since 2002, such as consultancy studies, fieldworks, local consultations, trainings, key demonstrative activities, etc.

5.3. Support to policy-making

UN-Habitat's support to Mozambican development policies is essentially following the outcomes of the Second United Nations Conference on Human Settlements held in Istanbul in June 1996 which identified *good local governance* and *security of land tenure* as the two pillars ensuring sustainable urban development (UN- Habitat, 1996). Concerning urban governance, an important step was made since all 23 existing cities in Mozambique as well as 10 towns have acquired a new autonomous status after the first municipal elections held in 1998, within the framework of a new Autarchic Law. Although 58 towns are still uncovered, the appliance of this Law translates a positive decentralisation effort made by the Government. This is just the beginning of a complex administrative reform, which has gradually to be translated into adequate practice of local governance and democratic processes.

According to the above-mentioned pillars, an essential complementary action to this should be the establishment of a solid legislation granting security of land tenure. Unfortunately, despite the approval of the above-referred new Land Law, an Urban Land Regulation is still missing[7]. Secure land tenure is necessary for stimulating slum dwellers to invest in improving their housing conditions as well as the surrounding physical environment (drainage, road accessibility, etc.) (UN-Habitat, 2003). In fact, being registered within a simplified cadastral system, as proposed by the Ministry of State Administration (MAE) (2005), would allow to regularly connect the house to sewer, water and electric supply systems. It would represent an important basis for the community while undertaking any decision, action or discussion related with urban planning and slum upgrading. A recent study by Negrao et al. (2004) highlights that, at present, the first investment made by a householder is to clearly delimitate his/her plot by planting trees or building a fence, a behaviour being generally explained by the lack of secure tenure.

Added to the absence of regulatory instruments, there is a problem of general uncoordinated institutional frameworks related to urban planning issues, namely:

- The MAE, through its National Directorate for Autarchic Development (DNDA), is responsible for empowering the Municipalities according to the directives of the Autarchic Law, and is currently proposing the introduction of a simplified cadastral system to be developed by the respective City Councils.
- The Ministry for Coordination of Environmental Affairs (MICOA), through its National Directorate of Territorial Planning (DINAPOT), deals directly with urban planning and has recently presented a Territorial Policy and related project of Law to the Ministry Council.
- The Ministry of Public Works and Housing (MOPH), through its National Directorate of Housing and Urban Development (DNHU), has several overlapping functions with DINAPOT-MICOA and is responsible for developing a not yet existing Housing Policy.
- The Ministry of Agriculture, through its National Directorate of Geography and Cadastre (DINAGECA), is responsible for releasing land use titles in accordance to the Land Law in the rural areas and in those Municipalities with no cadastre system.
- The City Councils themselves, according to the Autarchic Law, are responsible to approve municipal development and master plans, urbanisation and construction rules, among other issues.

Finally, as already mentioned, upgrading informal urban areas is not a priority included in the PARPA, which has five years validity, whilst it has been addressed by the “Agenda 2025” that should theoretically represent the long-term development strategy of the Government.

As a concrete support, UN-Habitat has co-funded, together with the Food and Agriculture Organization of the United Nations (FAO), the preparation of the Territorial Policy and an associated law project,

[7] The Urban Land Regulation (finally approved in 2006) defines the criteria and mechanisms to be applied for obtaining land use titles in urban areas. This issue is particularly critical for slum dwellers.

which is supposed to set the legal framework of reference regulating all physical planning activities in Mozambique and coordinating existing laws. As an important innovation, this Territorial Law project advocates for the active participation of the community in the planning process. UN-Habitat also sponsored the continuation of the Housing Policy preparation process that was stopped in the 90's. Unfortunately, despite many efforts, an open debate on such fundamental legislation involving all concerned sectors could not yet be obtained.

UN-Habitat is now promoting the Cities Without Slums initiative (UN, 2000)[8]. During the preparatory phase, two components were included: 1) the preparation of a city situation analysis describing the present status of the urban slums in Mozambique, and ii) the proposal of a Slum Upgrading Intervention Strategy through discussions with all Municipalities and local authorities in several seminars. The central idea of such strategy is strengthening the urban management technical capacity at the local level by placing skilled national professionals in the Municipalities. In the meantime, a highly qualified and mobile team stationed at the central or regional level should function as a backstop and be ready to intervene when needed. To be successful, such "technical knowledge decentralisation" system needs to apply participatory planning, in particular by actively involving the resident population. With the start of the implementation phase, the objective of this initiative is progressively building a comprehensive slum-upgrading programme with interventions realised at the local level and coherent policy-making and correlated investments at the governmental level.

5.4. Training and capacity building

The flood disasters occurred in 2000 and 2001 highlighted the convergence of vulnerable human settlements and unstoppable natural hazards, creating thousands of homeless and displaced persons. Up to now, the responses have been almost exclusively reactive. National and international funded emergency relief are still the predominant reaction to the flood problematic, which is addressing the symptoms and ignoring the causes (Moreno, 2001).

As mentioned earlier, the long-term option taken by the Government was to resettle the endangered population, creating unsustainable living conditions in the new areas. In collaboration with MICOA, UN-Habitat conceived an alternative strategy: why not considering the possibility to live in flood-prone areas and learning how to cope with the risk, as it occurs in other poor countries with similar characteristics[9]? The 2000 floods were an exceptional event with an estimated return period of 200 years. Hence, preparedness and mitigation techniques could minimise the negative impacts of moderate flooding on human settlements, avoiding resettlement.

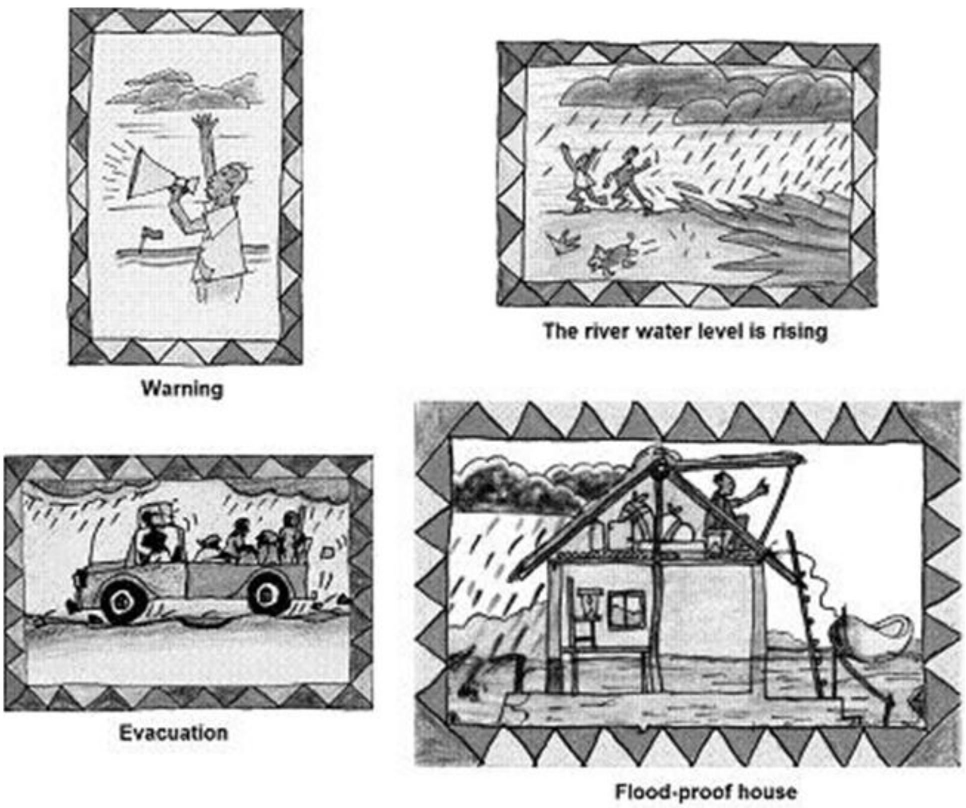
Consequently, a training programme under the mainstreaming idea *"Learning how to live with floods"* was launched in 2003, based on a colourful manual associated with a card game (see Fig. 5.2) (Feuerhake, 2004a). Such material presents key information for reducing vulnerability to floods, with

[8] It corresponds to the Millennium Declaration Goal 7, Target 11: "By 2020, to achieve a significant improvement in the lives of at least 100 millions slum dwellers".

[9] The best example is Bangladesh, which territory is delimited by the Ganges river delta and is flooded twice a year.

special focus on slum areas, and uses a simple language and attractive illustrations. Each chapter of the manual is associated with 4 cards (these are 52 in total), which present basic concepts such as: factors causing the floods, type of flood risks, different preparedness and mitigation techniques, contingency planning, community self-organisation, response actions, etc. While playing with these cards, immediate associations between these concepts are made, stimulating creativity, enthusiasm and participation. The solutions proposed in the manual are based on experiences found in Mozambique, thus can be effectively implemented by the local population. Of course, one of the main purposes of this didactic material is to promote different slum upgrading activities (like improving the drainage and road conditions, facilitating access to drinking water, maintaining proper sanitation, efficient waste management, etc.) as concrete solutions for reducing the vulnerability to floods.

Figure 5.2: *Example of cards associated with the Manual "Learning How to Live with Floods"*



(Source: Feuerhake, 2004a)

The training product was tested through different workshops, at both national and local levels, in different Mozambican Provinces. The programme targeted the following target groups: City Council leaders, technical local staff, community leaders and primary school teachers. The latter is a crucial link to reach the children, who represent the country's future. The final objective is to fully integrate the manual within the official educational programme in order to ensure its maximum diffusion. In the meantime, training activities organised by MICOA and UN-Habitat had a catalyser effect and are gradually expanding in national awareness campaigns involving NGOs and Provincial Governments. It also helped in creating partnerships, resulting in the production of valuable complementary materials, such as some posters (see Fig. 5.3).

<u>Figure 5.3</u>: Elevated platform, extracted from the poster series "Learning How to Live with Floods"

(<u>Source</u>: Feuerhake, 2004b)

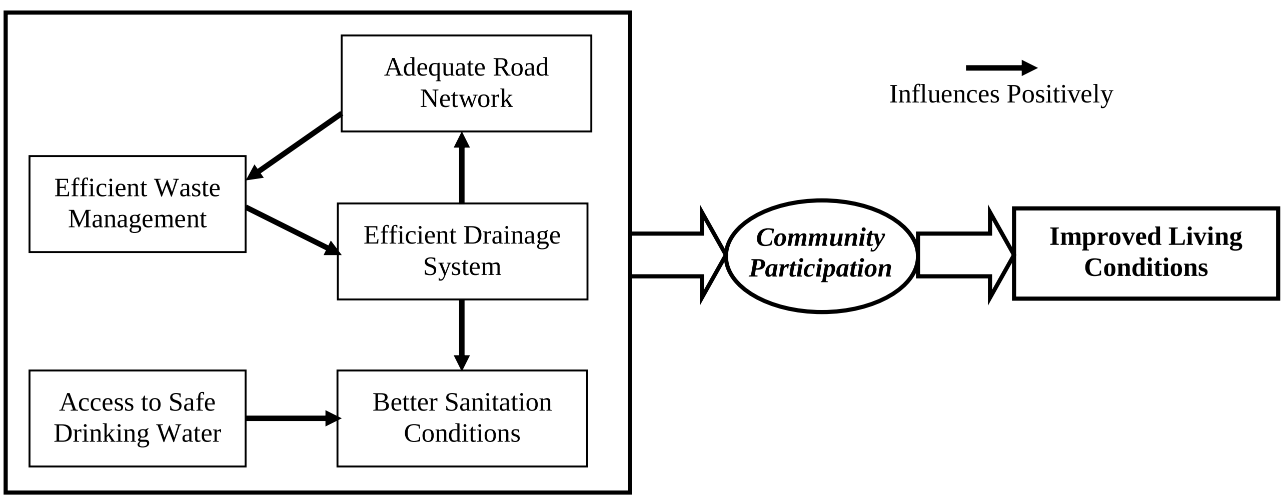
5.5. Participatory land use planning

Project experiences and consultations concerning slum areas confirmed that the following issues are top priorities in the agenda of most Mozambican Municipalities (the order of importance can change from place to place):

- *Poor drainage efficiency*
- *Difficult access to safe drinking water*
- *Lack of sanitation facilities*
- *Inadequate road network*
- *Inefficient waste management*

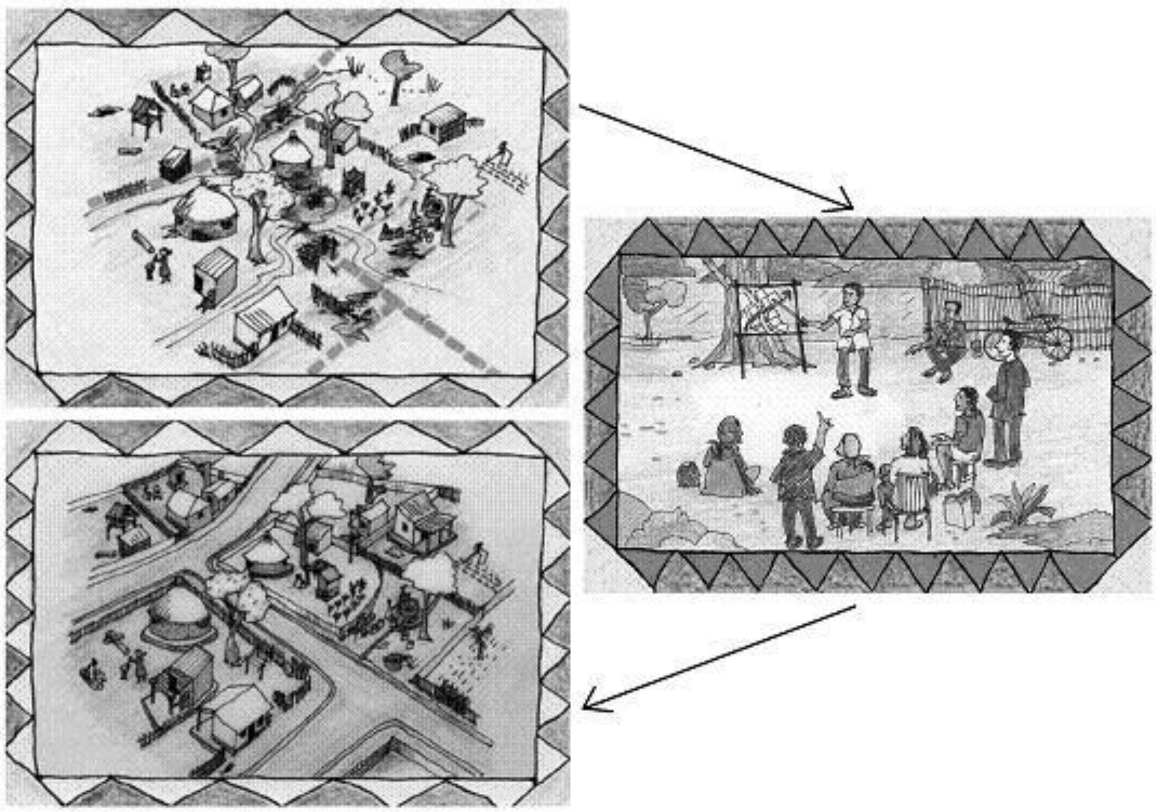
As depicted in Fig. 5.4, these are interlinked key factors that need to be addressed in an integrated manner in order to reduce vulnerability and obtain sustainable improvement of the living conditions in informal neighbourhoods. In fact, ensuring a good drainage is a pre-condition for reducing the flood impact in urban areas and establishing a solid road network, avoiding erosion problems. It would also allow efficient evacuation of stagnating or spilling sewage waters. In the meantime, adequate waste collection helps in reducing the accumulation of domestic garbage in the drainage channels, which would prevent water flow and engender sanitation risks. A road network allowing the transit of a truck or tractor would facilitate all waste management operations, as well as vehicle access for evacuation in case of emergency. Accessing safe drinking water helps in improving the population's health status and reducing risks related to poor sanitation, such as disease transmission through improper water consumption. Of course, vulnerability reduction is much more effective if improved basic sanitation services are provided to the targeted population, such as latrines and public lavatories.

Figure 5.4: Interlinked factors for improving the living conditions in urban informal settlements



One indispensable condition is missing in this explanation: the role of the resident community. In Fig. 5.4 "Community Participation" is placed as "filtering object" before reaching the final result: "Improved Living Conditions". In fact, dwellers themselves make the described slum upgrading and vulnerability reduction process as much sustainable as possible. They need to be actively involved in all planned activities, i.e. from decision-making (as illustrated in Fig. 5.5) up to self-organisation and labour-intensive collaboration. As stressed by Hamdi and Goethert (1997), community is the powerful agent in achieving beneficial change within cities to ensure social equity and sound environmental principles.

Figure 5.5: Slum upgrading through community participatory planning



(Source: Feuerhake, 2004a)

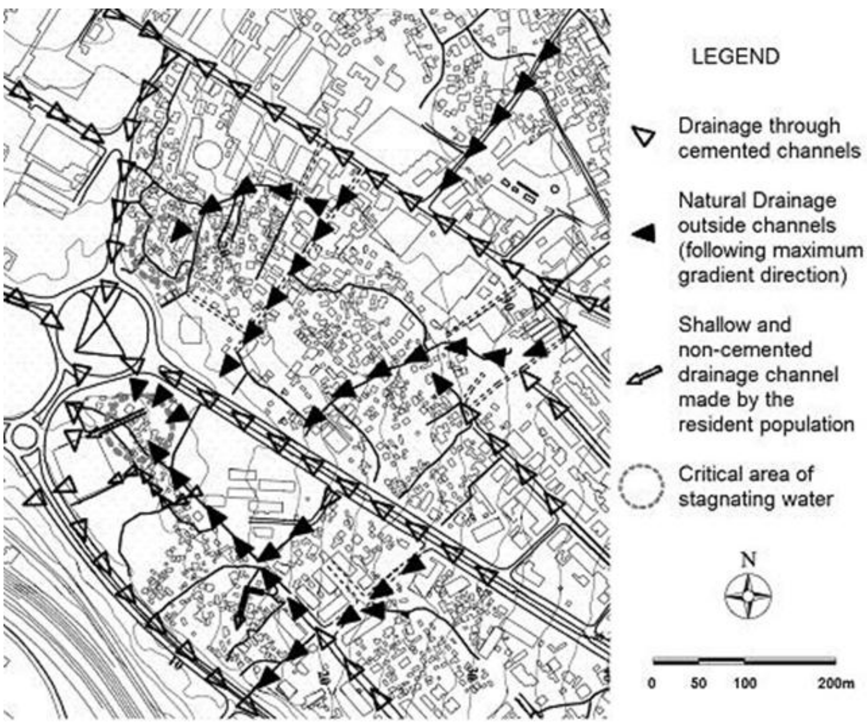
UN-Habitat, in close collaboration with MICOA, recently concluded land use participatory planning activities in informal settlement areas of four cities, namely: Maputo, Chókwè, Tete and Quelimane. This exercise was carried out following the methodology described below:

1. Each City Council indicated a critical neighbourhood where upgrading interventions were urgently needed.
2. A team of national consultants was hired, composed of two urban planners and one disaster management specialist, collecting secondary data for each study area (maps, aerial photographs, high resolution satellite images, existing reports, etc.).
3. A first round of local consultations was held with the concerned communities of the four selected neighbourhoods, including officials from the central Government and the City Council. Aerial photos or, when available, satellite images of the study area were amplified and served as basis for discussions with the slum dwellers; identified problems were systematically located in the image. Information collected during the local workshops was complemented by specific field visits.
4. After compiling all collected information, first drafts of environmental land use plans and disaster management plans were prepared by the hired team, strategically linking slum upgrading intervention strategies with vulnerability reduction techniques.
5. A second round of four local consultations was organised for discussing the drafted plans, as well as adequately preparing the implementation of one priority intervention selected by the dwellers.

6. Implementation of slum upgrading interventions, involving as much as possible the resident community.

As final outputs, four environmental land use plans and associated disaster management plans were produced, and used while executing the priority intervention. These plans represent a reference document when scheduling future upgrading activities. They contain different types of information, such as: general physical conditions of the neighbourhood, land use, location of water points, social service, road network, drainage system efficiency (see Fig. 5.6), etc. They also include methodological instructions to be applied within the framework of municipal slum upgrading strategies.

Figure 5.6: Analysing the drainage network of Malanga Neighbourhood, Maputo City



(Source: Trindade et al., 2004)

The application of the above-described participatory planning exercise in the selected neighbourhoods (steps 1 to 6) includes several advantages:

a. Involving the three administrative levels in the planning phase, namely: central Government, local authorities and local communities. This allows strengthening the relationship between the Municipal Council and the resident community by creating a climate of trustfulness and mutual commitment. It also serves as concrete capacity building activity for central government institutions, which are usually not familiar with such type of approaches.

b. Establishing a transparent decision-making process among key community stakeholders. This generally facilitates the effective resolution of any conflict or difficulty that may rise during the implementation phase (e.g. reducing the individual courtyard space in order to increase the road access width, which is of public use).

c. Maximising the use of local knowledge. Thanks to the detailed spatial information contained in the aerial photos or satellite images (in which single houses can be detected), even illiterate slum dwellers could provide valuable contributions, based on their experience and deep knowledge of the study area.

d. Motivation of the community to contribute to the planning activity, since they could effectively take the initiative and influence the decisions taken. To this end, having the possibility of immediately funding a concrete intervention as direct consequence of the planning phase represents an important incentive.

e. Increased time effectiveness compared to the standard land use planning procedures. In fact, the advantage mentioned under bullet b allows a smooth execution of the planned intervention. Furthermore, maximising the use of local knowledge (reported under bullet c) reduces the time needed by the contracted technical team for carrying out fieldwork activities.

f. These last remarks (bullet e) make the method also more cost-effective. Furthermore, high-resolution satellite images can be purchased at relatively low prices nowadays.

5.6. Community-based slum upgrading and vulnerability reduction

As direct consequence of the above-mentioned participatory planning activities, excellent results were obtained in the neighbourhood of Quelimane City. During the planning process, it was decided that the community would be involved as manpower in the selected labour-intensive interventions. Hence, under the supervision of municipal technical staff and the coordination of a local committee, almost 400 dwellers were contracted on a rotational basis during a period of two months. With a relatively small investment of 20,000 US Dollars, the following interventions were executed[10]:

- A cumulative drainage channel length of ten kilometres was cleaned and regularised, connecting a secondary system to the primary drainage channel;
- The neighbourhood's main access road, which was flooded after each rain event and obstructed by courtyards and trees, was generally improved for an approximate length of three kilometres.

Such considerable extent of physical interventions could be implemented with a reduced budget because the added value of community self-organisation capacity was taken into account. In fact, the latter represents the crucial factor for obtaining successful outputs in a cost-effective manner. As consequence of the realised works, water drained correctly into the improved channels during an intensive rain event which occurred following the intervention. Secondly, the main road is now accessible to regular vehicle transit, avoiding traffic being diverted through a road that passes by a primary school. Hence, such activity is currently representing the starting point for a project proposal formulation with much greater dimension[11].

[10] Neighbourhood's estimated population: 20,000 inhabitants; hence, the investment for realising the intervention corresponded to one US dollar per habitant.

[11] The main expected output of this new project is paving one kilometre of primary drainage channel through labour intensive activities. This will be complemented by interventions regarding water, sanitation, waste

This positive experience has reinforced the community's will to contribute to improving the living conditions of their own neighbourhood. Similarly to other community-based experiences described by Hamdi (2004), dwellers were enthusiastic about the results obtained, especially because they selected the priority intervention themselves and then executed it. This served to develop a powerful awareness campaign in the neighbourhood for maintaining proper conditions of the drainage system and access road. The activity also provided temporary income to the contracted inhabitants, which are amongst the poorest population in Quelimane City. Finally, within the framework of a bigger intervention, a fair taxation system should be introduced for guaranteeing long-term maintenance and improvement of basic services and infrastructures. Consequent benefits could then be shared between a responsible community-based organisation and the Municipality.

5.7. Conclusions

In the light of this kind of experiences[12], while still supporting policy making at the central level and developing capacity building activities, UN-Habitat's intention in Mozambique is to progressively focus on integrated and participatory slum upgrading activities at the local level. In fact, the latter represents an adequate solution for reducing vulnerability and obtaining sustainable urban development. While the legislative and institutional frameworks dealing with informal urban settlements issues are still not clearly defined, the slum problem at the ground level is aggravating every day. Therefore, it is important to sustain a more interventionist approach implemented by the community and its correlated administrative level, the municipal authorities, in line with the strategy proposed within the Cities Without Slums initiative. The Government should be involved as permanent monitoring agent, and gradually transforming in the main promoter of such community-based approach. This linkage could positively influence the policies and regulations currently under preparation.

management and road improvement, as well as delivering capacity building, as per integrated slum upgrading process described in Fig. 5.4.

[12] The Quelimane experience is not an isolated case. For example, very similar results were obtained in Manica municipality, within the framework of a community-based slum upgrading project implemented by the Faculty of Architecture and Physical Planning (University Eduardo Mondlane, Maputo) in collaboration with the German Agency for International Cooperation (GIZ) and the Italian Cooperation (Trindade et al., 2003).

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6. Conclusion

This research has focussed on rivers and human settlements, on how the flooding phenomenon relates these two dimensions and which spatial dynamics it can engender. The analysis looked particularly at the *territory*, which etymologically comes from the Latin word *"territorium"*, indicating a place or land around or within the jurisdiction of a town, domain or district[13]. The definition of this word has been evolving over time, and it was used in this thesis to referr to land which is occupied and managed by Man, who has interest in defending it against the river or flooding in general.

As underlined in Chapter 1 (Introduction), river floodplains constitute preferential areas for establishing human settlements because of their soil fertility, the proximity to fresh surface water and its inherent resources, like fishing, the importance of navigation, etc. Meanwhile the river can also widen its own "pertinent territory" by several times in case of floods, repeating dynamics which have occurred in the past. Therefore, the essence of this study is the "natural interest" of both Man and River for the same territory, and on how best a "consensual" equilibrium can be established between these two forces. This implies the definition of proper flood risk management mechanisms and strategies, and the adoption of a multi-disciplinary analytical approach.

This work is relevant when considering the high incidence of flood hazard at the global level, with an increasing frequency linked to the effects of climate change[14] and the growing urbanisation. Importantly, it also looks at developing countries, whose needs in terms of vulnerability reduction are greater. In fact, there is still a huge disproportion between rich and poor countries when assessing the losses provoked by natural hazards of the same severity affecting a comparable population size. The combination of poverty and weak governance certainly increases the level of risk, and subsequently of vulnerability (UNISDR, 2011). For instance, Peduzzi et al. (2012) estimate that, for similar tropical cyclones, the risk of mortality can be as much as 225 times greater in low-income countries compared to developed countries. Earthquakes of similar intensity which in early 2010 hit Haiti and Chile is another good example, killing more than 220,000 people in the first case and less than 500 in the latter case (UNISDR, 2011).

Fig. 6.1 shows the type of economic impact of natural hazards around the world in the year 2011. It appears clearly that floods affect more the global South. Obviously, in this map, the estimated loss calculated for a poor country such as Mozambique, for example, has a much greater impact on the national economy than for a rich country.

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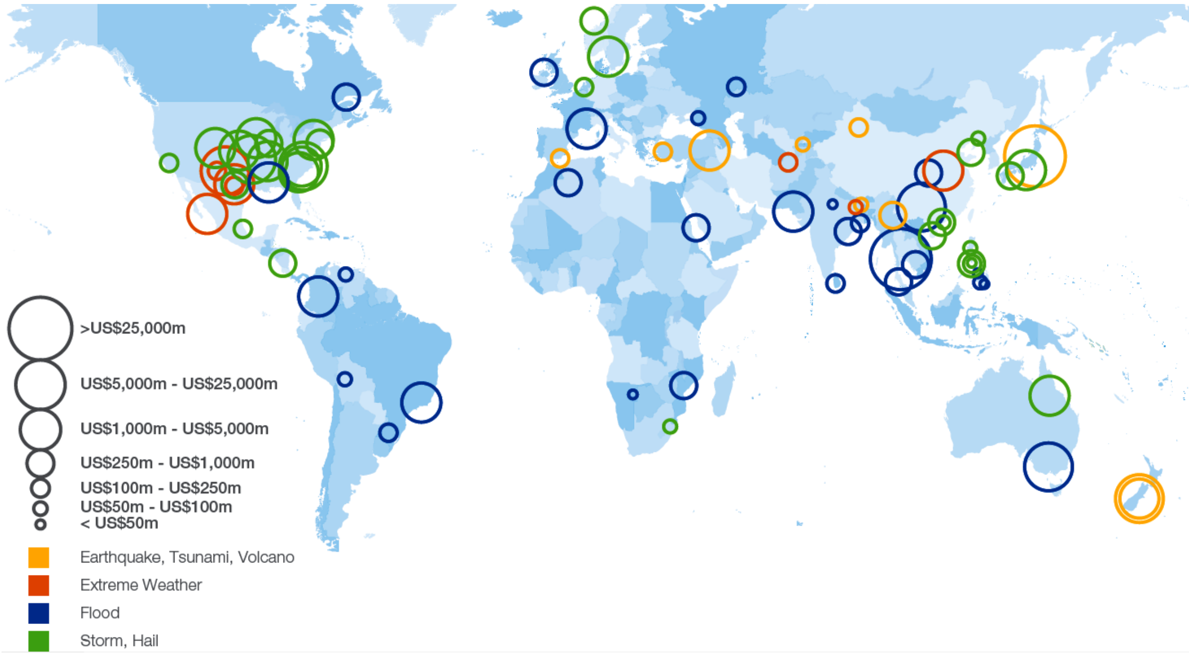
[13] Definition from Douglas Harper, Historian, retrieved from the *Online Etymology Dictionary* at the website http://dictionary.reference.com/browse/territory (accessed: 10 February 2013).

[14] NB: the study of the linkages between climate change effects and flooding, despite being relevant, goes beyond the scope of this thesis.

Figure 6.1: 2011 economic losses in relation to selected types of natural hazards (in millions of USD)



(Source: World Economic Forum, 2013)

For instance, the recent floods that occurred in early 2013 in the lower Limpopo River partly highlight the purpose of Chapters 3 and 4, which deal with this important transboundary river located in southern Africa. Firstly, from a geomorphological perspective (Chapter 3), by looking into its past evolution and the subsequent vulnerability of its surrounding territory to the floods. Secondly, from a social and institutional angle (Chapter 4), trying to identify suitable planning solutions to reduce the flood risk in human settlements located in the basin, by adopting a participatory approach and promoting inter-sectorial coordination. The images of the recent floods (Figs 6.2 to 6.4) speak by themselves regarding the relevance of the findings in these two chapters.

Figure 6.2: Main road infrastructure disrupted near Xai-Xai, lower Limpopo River

(Photographer: Ferreiro, 2013)

Figure 6.3: Extent of the 2013 floods in the lower Limpopo floodplain

(Photographer: Capizzi, 2013)

Figure 6.4: Families trapped by the flood waters in Chókwè

(Photographer: Ferreiro, 2013)

As explained in Chapter 3 this flood event replicated similar dynamics as in the year 2000, reactivating the ancient hydrography of the river. Similarly, the recommendations derived in Chapter 4, regarding the need for greater capacity for disaster preparedness and adaptation, hence following the logic of *Living with Floods*, remain valid today.

The main objective of this research is to contribute to more holistic and improved flood risk management. For this purpose, an attempt is made to combine natural sciences and social sciences so that the complex and dynamic Man-River relationship can be studied from different angles. In particular, the author has privileged the use of geomorphology and participatory planning as the two key disciplines for assessing, managing and adapting to flood risk.

A similar approach is used for river basins rich in data (the typical case of developed countries, like the Tagliamento River in Italy) and poor in data (the typical case of developing countries, like the lower Limpopo River in Mozambique). It consists in retracing the river's past evolution through geomorphological analysis and literature review, and relating it to the development of human settlements in its surrounding territory to assess the flood risk. In a complementary manner, this research highlights the advantages of adopting a participatory approach for managing and adapting to flood risk in a more sustainable manner. This is done by involving the concerned communities and authorities in the land use planning exercise, inter-relating the different scales (local, national and regional) and working across the various sectors (land, water, environment, infrastructure development, disaster management, etc.). Accurate and reliable flood risk information is essential for preparing a land use plan meant for the development of human settlements, with aim to reduce the vulnerability to this type of natural hazard.

The Main Research Question of this thesis is: ***can people improve flood risk management based on geomorphological knowledge and participatory land use planning?*** To answer to it thoroughly, we will first address the 4 research sub-questions corresponding to Chapters 2, 3, 4 and 5 and establish linkages between them.

First Research Sub-Question: *How has anthropogenic intervention determined fluvial changes and influenced the flood dynamics of the Tagliamento River, a typical fluvial system of the developed world?*

Chapter 2 provides evidence that: (i) the aggrading of the middle course of the Tagliamento riverbed, (ii) the shifting downstream of the braiding-meandering transition of the river, and (iii) the consistent reduction of the river space over the last two centuries, were directly provoked by the anthropogenic pressure on the river's pertinent territory. The construction and constant raising of dikes and the subsequent transformation of its natural corridors into agriculture, urban or industrial land have definitely determined important fluvial changes and increased flood risk. The dikes in the middle and lower Tagliamento River provide a false sense of security from floods to the urban riparian population. This situation is typical of a developed country with a high population density, such as Italy or the Netherlands. In the case of the Tagliamento River, the human pressure over the ecosystem is enormous and modifies completely the natural conditions. As a result there is no sufficient space for the river, and in case of floods, the damage can be huge.

As mitigation measure, the author has defined fluvial corridors meant to regulate land use and infrastructure development. This solution can only be implemented if local authorities have proper control capacity, a situation which is more likely to occur in a developed country.

Interestingly, by reconstructing the past evolution of the Tagliamento River, it was observed that floodwaters tend to overflow in the same locations, following a cyclical behaviour dictated by the overall geomorphological settings of the floodplain. The floodplain was built by huge alluvial fans just after the glaciations period. This provides valuable information for organising a proper flood risk management strategy, and links directly with the findings of Chapter 3, in which a similar approach was adopted and conclusions reached.

Second Research Sub-Question: *Do clear relationships exist between past fluvial changes, identified through geomorphologic analysis, and territorial vulnerability to floods in the Limpopo River basin, a typical transboundary basin of the developing world?*

Chapter 3, through an exhaustive literature review combined with fieldwork activities, describes the Limpopo River's evolution since the time of the Gondwana continental break-up. Successive tectonic events have completely modified its hydrology. Meanwhile, it is demonstrated that the geomorphological settings of the palaeo-Limpopo River, i.e. before its basin was reduced to a third or even fourth of its original size due to the raising of crustal flexure axis, have determined a fossil hydrology which is reactivated in case of floods at present. Therefore, similarly to what was found for the Tagliamento River in Chapter 2, there is a direct and clear relationship between past fluvial changes and the inherent vulnerability to floods of the Limpopo River basin today.

As for Chapter 2, the description of the past river's evolution and the adoption of a geomorphological approach are relevant for analysing the territorial vulnerability to floods in the Limpopo River basin, even if less data could be found in comparison to the Tagliamento River. When considering the complexity of the flood dynamics in large rivers, compounded by the scarcity of data in the case of the Limpopo, the method proposed seems to be adequate for identifying unsuitable areas for developing human settlements, which are exposed to endemic flood risk because of the ancient river's morphology.

Differently from what occurs in the Tagliamento River, the Limpopo River tends to dominate against Man, as it is typically the case for large rivers. This fluvial system has completely shaped the surrounding territory, and re-occupies it regularly in case of floods. It is the opinion of the author, based on the analysis made, that structural solutions for flood defence -despite being object of an intense debate nowadays and being very expensive- will only mitigate the problem but not solve it completely. In this case, as suggested in Chapters 4 and 5, Man needs to adapt to the River and learn to live with floods. There is a constant linkage to be made between the natural system, the River, and the social, economic and institutional measures that Man needs to apply for ensuring adequate flood risk management.

Third Research Sub-Question: *How can participatory approach lead to a more integrated (land and water) planning of the Limpopo River basin, and which flood risk reduction strategies can be derived?*

Managing a transboundary river basin involves several challenges. In addition to inter-sectorial coordination at country level, since river basin management should not be reduced to merely water-focussed activities, there is a need for setting up an adequate decision-making system among the riparian countries. This implies a strong institutional capacity, which is still difficult to find in most developing countries. Furthermore, the population living within the river basin, considering that the latter occupies a large surface, are usually not consulted concerning key management decisions to be made, such as building a dam, raising dikes or installing large-scale irrigation schemes. On the other hand, the pressure on the basin natural ecosystem, in terms of deforestation and land degradation, can be significant.

In the case of the Limpopo River, the author was managing a basin initiative aiming to reduce the vulnerability to floods and drought, which are recurrent natural hazards affecting the basin, and had the opportunity to apply a participatory method at different levels (sub-regional, national and local). The adopted bottom-up approach allowed bringing up community-based decisions, in which local authorities had participated, to the inter-country committee dealing with the overall management of the basin. This process proved to effectively reflect at the highest decisional level the complexity and the several influential factors found in the ground concerning land and water management. A strategic basin plan could be obtained through the preparation of local participatory plans in just nine locations of the basin, according to a pre-defined sampling scheme, which were successively discussed at the national and sub-regional levels.

Therefore, this constitutes an easily applicable methodology for preparing a river basin strategy, which uses relatively limited data. The latter is a relevant aspect to be considered in the context of developing countries. Concerns expressed by vulnerable communities concerning adaptation and mitigation needs to natural hazards can be successfully mainstreamed into river basin management instruments. The practical experience undertaken in the Limpopo basin demonstrated that, indeed, participatory approach can lead to more integrated river basin planning.

In the case of Mozambique, based on the recommendation of the Limpopo basin plan, the author proposed the *"Living with Floods"* as strategy to reduce flood risk, consisting of soft-engineering adaptation measures complemented with awareness raising activities. As mention before, in the case of large rivers and considering the high natural vulnerability of a country like Mozambique, hard structural solutions are difficult to be applied with satisfactory results. This approach could be replicated in other developing countries showing similar economic, social and environmental characteristics, to reach more sustainable results. Participatory planning and *"Living with Floods"* were also mainstreamed in poor urban areas for reducing vulnerability to flood risk, as described in Chapter 5.

<u>Fourth Research Sub-Question</u>: *How participatory slum upgrading can be used in Mozambique to reduce the vulnerability of poor urban dwellers to flooding?*

The urban poor tend to concentrate in unsafe areas since it is often the only land they can access to build their dwellings. In the case of Mozambican cities, these are often flood-prone areas where slums develop rapidly. Between 2002 and 2005 vulnerable informal neighbourhoods were selected in four cities and towns of Mozambique where the United Nations Human Settlements Programme (UN-Habitat) supported the identification of suitable strategies for flood risk reduction.

Once again, participatory planning was used as effective mechanism to obtain the right level of involvement of the slum dwellers as well as to ensure the commitment of local authorities. The use of high resolution satellite images or of existing aerial photos facilitated the participation of the slum dwellers to the planning exercise, enabling them to contribute with their local knowledge of the neighbourhood. Using tools that allow communities to recognise their territory represents a fundamental component to the design of sustainable risk reduction solutions. Consequently, priority interventions can be quickly identified, validated and action plans agreed for implementation. In the case of Mozambique, the latter consistently followed the adaptation approach of *"Living with Floods"* through pilot demonstration activities.

This initiative allowed UN-Habitat to influencing policy-making at government level. To obtain the expected effect at community level, it is important to complement the above-described process with awareness raising activities which can stimulate pro-active involvement in the identified risk reduction strategies. The participatory approach in slum areas proved to be successful for reducing the vulnerability of poor urban dwellers to flooding.

The replies to the four research sub-questions, when considered together and linkages are established among them, prove that ***people can, indeed, improve flood risk management based on geomorphological knowledge and participatory land use planning***. The combination of physical sciences and social sciences disciplines allows obtaining a more holistic approach to flood risk management, which is much needed as flood hazard intensifies around the world. The innovative manner used to address the dynamic Man-River territorial relationship, expressed through the need to first understand the past evolution of the river for assessing the future flood impact and undertake adequate basin management decisions, has proven to be relevant for both developed (data-rich areas) and developing (data-scarce areas) countries.

How to combine the river's natural spatial requirements with the need of reducing the vulnerability of the riparian populations to flooding? As stated by Hogan and Marandola Jr. (2007), from a different angle but within the same people-environment research context, there is still much to explore regarding the relationship between population dynamics and the vulnerability of people and places.

The method proposed in this thesis can only represent a partial contribution to help addressing this multi-faceted issue. The geomorphological approach used for determining the territorial vulnerability to floods in Chapters 2 and 3 needs to be combined with other methods, according to the availability of data, such as hydrological modelling, thorough field assessments including households' interviews, among others. The morphology of river basins is so variable and complex that only by cross-checking different assessment methodologies a satisfactory level of accuracy can be reached. This involves time, financial means and qualified expertise. Once assessments are carried out and strategic action plans are elaborated, there is need for strong political will to enable the implementation of the recommended measures.

This research has tried has much as possible to draw scientific lessons from practical activities carried out within the framework of different projects that the author had the chance to manage during the past decade, especially in Mozambique and in the Limpopo River basin. However, time was often limited for carrying out a more thorough investigation regarding the different topics which are presented in this thesis. In addition the reduced financial means available only allowed to look into some of the key aspects. Therefore, the results which were discussed here should be considered with due understanding that a more comprehensive scientific analysis still needs to be conducted.

Despite promoting active community and stakeholders' involvement in decision-making, as discussed in Chapters 4 and 5, participatory planning approach also shows some weaknesses. The process is still far from being institutionalised, which is a necessary condition for enabling its more systematic use. In addition to participatory sessions, complementary field assessments are needed, as well as door to door households' surveys, to collect the required information for proper action planning. Skilled and unbiased mediation represents one of the critical aspects to achieve meaningful participatory planning. Fair and gender-balanced representation of the key stakeholders is unfortunately not always guaranteed.

It has been this research's clear intention to concentrate on the Third World region and contribute to sustainable development knowledge. This work has identified, through consultative and participatory mechanisms, and thanks to practical experience, some of the strategies that can be adopted to manage flood risk. In general, non-structural solutions have been preferred. These are found to be more affordable in the long run, such as innovative adaptation measures and solutions, combined with awareness raising and institutional capacity development. However, more solutions can be proposed, especially in the sphere of infrastructural engineering. For instance, the Mozambican authorities are currently exploring the feasibility of building more dams and dykes to better control the floods in the lower Limpopo River. This type of interventions goes hand in hand with the economic development of the country, which in recent years has been rather consistent.

On the light of this research, new areas of study can be identified, especially for what concerns flood risk management in urban areas. With the constant expansion and appearance of cities, an increasing number of slum dwellers remain very vulnerable to this type of natural hazard. There is urgent need to design handy and easily applicable approach and solutions to build urban resilience, which is a rather complex and multi-dimensional topic. Especially in the developing world, municipal authorities are often ill-prepared to face the consequences of the increased incidence of natural hazards, exacerbated by the effects of climate change. The world is urbanising rapidly, and the required expertise and financial means to face these threats are still limited.

This research represents a modest contribution to the international research concerning flood risk management. It has the merit of trying to be innovative and to provoke out-of-the-box thinking. There is still much to be done in this field. The author of this thesis is determined to continue working on it and to provide more knowledge and experience regarding this topic in the years to come.

6.1. Bibliographic references

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