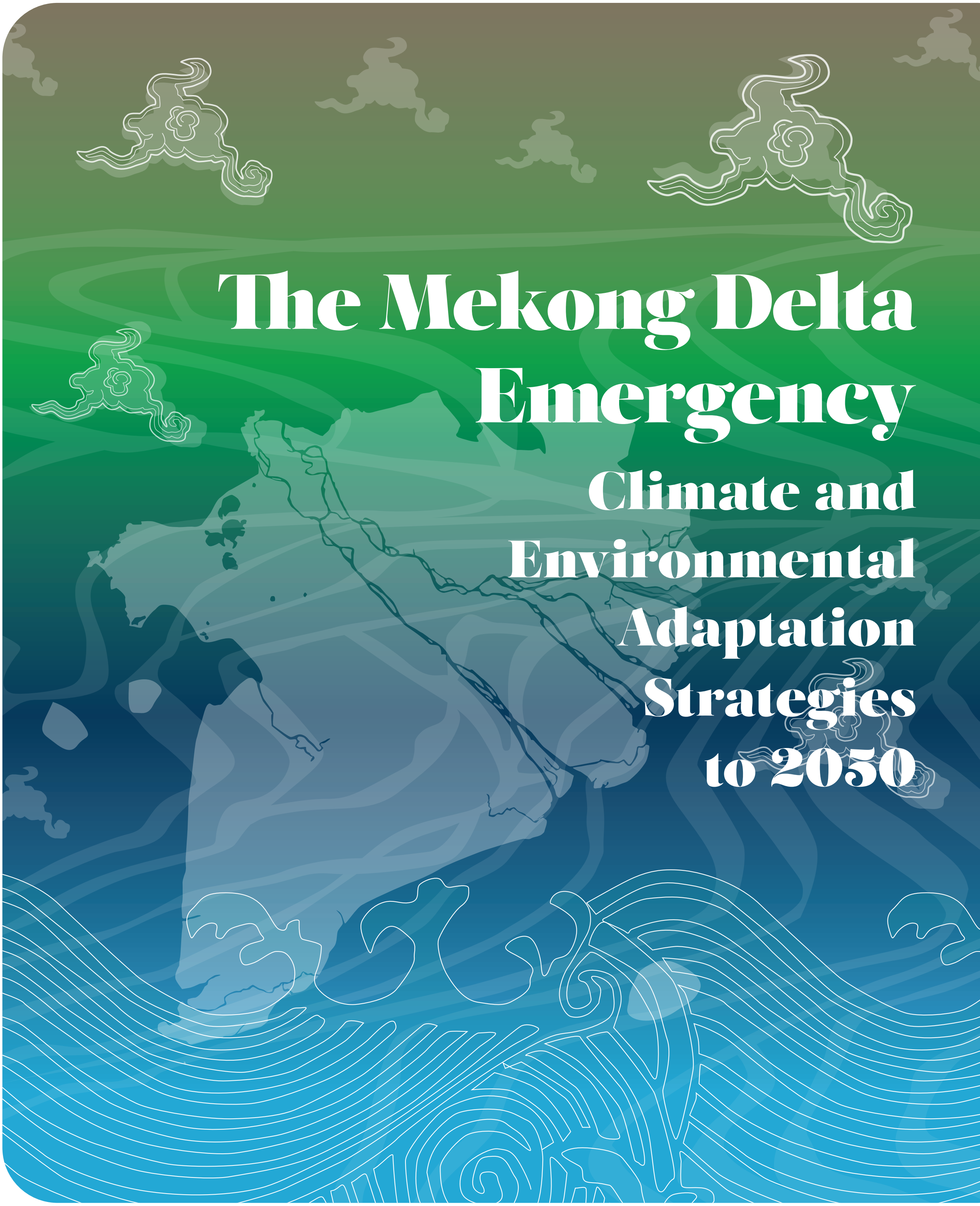
DCC Department of Climate Change
IRD Institut de Recherche pour le Développement FRANCE
2050 FACILITY
AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT



The Mekong Delta Emergency

Climate and Environmental Adaptation Strategies to 2050

The Mekong Delta Emergency

Climate and Environmental Adaptation Strategies to 2050

FINAL REPORT
GEMMES Viet Nam project

PREFACE

With 19% of the national population living in the region, and a high contribution to national agricultural production, with 50% of rice production, 65% of aquaculture production and 70% of fruit production, the Mekong Delta is well positioned for trade with ASEAN countries and the Mekong sub-region. Nevertheless, the Delta currently faces severe climate change impacts.

Within the framework of the study on the socio-economic impacts of climate change in Viet Nam and strategies for adaptation (GEMMES Viet Nam), the team of French, European and Vietnamese researchers and experts have produced the Mekong Delta emergency report. It provides a scientific assessment of the environmental and social impacts in the Mekong Delta. It also provides potential adaptation solutions to be further discussed and developed in international forums such as COP27 in Sharm El Sheikh, as well as within the framework of the ongoing national planning exercise.

Bringing together scientists from Viet Nam, France and Europe, national- and local-level policy makers as well as inhabitants of the Mekong Delta, the final report of the GEMMES Viet Nam project presents the combination of environmental pressures – climate change, upstream hydropower development, sea-level rise, subsidence, saline water intrusions, sediment starvation, coastal erosion – and some corresponding adaptation solutions. The research results offer recommendations for researchers and policy makers, at local and national levels, to support the sustainable development of the Mekong Delta, based on in-depth knowledge on the bio-physical dynamics and their socio-economic implications.

AFD has actively worked in collaboration with the Department of Climate Change in the implementation of the GEMMES Viet Nam project. Beyond this project, both parties wish to continue deepening their fruitful collaboration in order to contribute to the commitments of the international community to respond to climate change, with net-zero emission targets by 2050.

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LỜI NÓI ĐẦU

Đồng bằng sông Cửu Long chiếm 19% dân số của cả nước, đóng góp tới 50% sản lượng lúa, 65% sản lượng nuôi trồng thuỷ sản và 70% các loại trái cây của cả nước; có vị trí thuận tiện trong giao thương với các nước ASEAN và tiểu vùng sông Mê Công nhưng đang chịu sự tác động nặng nề của biến đổi khí hậu.

Trong khuôn khổ hợp tác chương trình nghiên cứu tác động kinh tế - xã hội của biến đổi khí hậu ở Việt Nam và chiến lược thích ứng với biến đổi khí hậu (GEMMES Việt Nam), các nhà khoa học Việt Nam, Pháp và châu Âu đã xây dựng Báo cáo tình trạng cấp bách của đồng bằng sông Cửu Long trong bối cảnh biến đổi khí hậu. Báo cáo đưa ra những đánh giá khoa học về tác động của sự thay đổi về khí hậu, môi trường và xã hội ở đồng bằng sông Cửu Long. Báo cáo cũng đề ra các giải pháp thích ứng dài hạn để thảo luận và nghiên cứu sâu hơn tại các diễn đàn quốc tế như Hội nghị COP27 năm nay tại Sharm El Sheikh năm 2022, đồng thời cung cấp những thảo luận về xây dựng, thực hiện các kế hoạch quốc gia có liên quan.

Với sự tham gia của nhiều nhà khoa học từ Việt Nam, Pháp và châu Âu, các nhà hoạch định chính sách cấp quốc gia, địa phương và cả những người dân đang sinh sống tại khu vực đồng bằng sông Cửu Long, Báo cáo đã mô tả những tác động và sức ép của biến đổi khí hậu, môi trường, các hoạt động ở thượng nguồn và tình trạng nước biển dâng, sụt lún, xâm nhập mặn, cạn kiệt phù sa, xói lở ven biển; đề ra những giải pháp thích ứng cho vùng. Kết quả nghiên cứu nhằm đưa ra các khuyến nghị cho việc hoạch định chính sách của các nhà quản lý, và cho các nhà nghiên cứu, ở cấp trung ương và địa phương, nhằm giúp đồng bằng sông Cửu Long phát triển bền vững và thịnh vượng, trên cơ sở hiểu rõ và sâu sắc về những động lực vật lý - sinh học và các tác động kinh tế, xã hội của các động lực này.

AFD đã tích cực phối hợp với Cục Biến đổi khí hậu trong suốt quá trình triển khai thực hiện chương trình GEMMES Việt Nam. Ngoài các hoạt động trong khuôn khổ chương trình GEMMES, hai bên sẽ tiếp tục phát triển các hoạt động hợp tác mới và đi vào chiều sâu nhằm triển khai các cam kết cùng cộng đồng quốc tế ứng phó với biến đổi khí hậu, hướng đến phát thải ròng bằng «0» vào năm 2050.

Tiến sỹ Tăng Thế Cường
Cục trưởng
Cục Biến đổi Khí hậu
Bộ Tài nguyên và Môi trường Việt Nam

Hervé Conan
Giám đốc Quốc Gia
AFD Việt Nam

PRÉFACE

Région habitée par 19% de la population nationale, qui contribue fortement à la production agricole nationale avec 50% de la production de riz, 65% de la production aquacole et 70% de la production fruitière, le Delta du Mékong occupe une position favorable pour les échanges commerciaux avec les pays de l'ASEAN et de la sous-région du Mékong. Néanmoins, le Delta est actuellement soumis aux graves impacts du changement climatique.

Dans le cadre de l'étude sur les impacts socio-économiques du changement climatique et les stratégies d'adaptation au Viet Nam (GEMMES Viet Nam), l'équipe de chercheurs et d'experts français, européens et vietnamiens ont réalisé le Rapport d'Urgence sur le Delta du Mékong. Ce rapport propose une évaluation scientifique des impacts environnementaux et sociaux dans le Delta du Mékong vietnamien. Il propose également une série de potentielles solutions d'adaptation à discuter et à développer au sein de forums internationaux tels que la COP27 à Charm El Cheikh, ainsi que dans le cadre de l'exercice de planification nationale en cours.

Rassemblant des scientifiques du Viet Nam, de France et d'Europe, des décideurs politiques aux niveaux national et régional et des habitants du Delta, ce rapport final du projet GEMMES Viet Nam présente la combinaison de pressions environnementales – changement climatique, exploitation hydroélectrique en amont, élévation du niveau de la mer, subsidence, intrusions salines, diminution des sédiments, érosion côtière – et de solutions d'adaptation correspondantes. Les résultats de ces recherches visent à proposer des recommandations à l'usage des chercheurs et des décideurs politiques, au niveau national et local, pour l'accompagnement du développement durable du Delta du Mékong, sur la base de connaissances approfondies sur les dynamiques bio-physiques et leurs implications socio-économiques.

L'AFD a activement travaillé en collaboration avec le Département du Changement climatique dans la mise en œuvre du projet GEMMES Viet Nam. Au-delà de ce projet, les deux institutions sont désireuses de continuer à approfondir leur fructueuse collaboration afin de contribuer aux engagements de la communauté internationale pour répondre au changement climatique avec l'objectif du net-zéro émission en 2050.

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PREFACE

The Vietnamese Mekong Delta (VMD) is the third largest delta on Earth, and currently home to some 18 million inhabitants, whose livelihoods depend mainly on agricultural and aquacultural production. It is subject to a combination of environmental changes: those with local anthropogenic drivers – especially sand mining and groundwater extractions – pose the greatest threats in the first half of the century, while global climate change will probably dominate in the second half of the century. At COP26 in Glasgow, a special assessment report of the GEMMES Viet Nam project extensively developed the analysis of these combinations of bio-physical constraints. COP27 in Egypt marks the year when the ambitions of COP26 should be transformed into actual adaptation policies within consolidated net zero plans. In this context, we present a detailed analysis of possible adaptation policy options in this Mekong Delta Emergency Report. The work presented here is the result of an exceptional scientific cooperation, involving a large team of Vietnamese, French and international researchers and experts.

Most current and future environmental issues in the Delta have several drivers at scales varying from local to global, necessitating integrated solutions in the Delta system and at the river basin level, rather than at a single administrative level. However, at the level of the VMD, a review of some existing adaptation plans highlights that current policies tend to ignore some key aspects of the recent scientific evidence on the local anthropogenic sources of subsidence or salinization dynamics. It appears that major environmental constraints, particularly the existential threat of relative sea-level rise – whose main driver currently is groundwater extraction – are still insufficiently taken into consideration in existing development or adaptation plans.

In this report, we notably propose a series of Focuses on different possible adaptation options to tackle the corresponding environmental pressures, and that could be incorporated into updated adaptation strategies. Their integration into a socio-economic model finally shows how the intermediary levels of governance can help drive the bio-physical dynamics of the Mekong in a sustainable direction.

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LỜI NÓI ĐẦU

Đồng bằng sông Cửu Long tại Việt Nam là đồng bằng lớn thứ ba trên Trái đất và hiện là nơi sinh sống của khoảng 18 triệu dân, sinh kế chủ yếu phụ thuộc vào sản xuất nông nghiệp và nuôi trồng thủy sản. Đồng bằng Sông Cửu Long lệ thuộc vào sự kết hợp của những thay đổi môi trường: những thay đổi do con người gây ra – đặc biệt là khai thác cát và khai thác nước ngầm – gây ra những mối đe dọa lớn nhất trong nửa đầu thế kỷ 21, trong khi biến đổi khí hậu toàn cầu có thể sẽ chiếm ưu thế trong nửa sau của thế kỷ này. Được trình bày tại hội nghị COP26 ở Glasgow, báo cáo đánh giá đặc biệt của dự án GEMMES Việt Nam tập trung phân tích sự kết hợp của các hạn chế từ các yếu tố lý-sinh. Hội nghị COP27 sắp tới ở Ai Cập đánh dấu một năm mà tham vọng của hội nghị COP26 sẽ được chuyển thành các chính sách thích ứng thực tế trong các kế hoạch phát thải ròng bằng không. Trong bối cảnh đó, Báo Cáo Khẩn cấp Đồng bằng Sông Cửu Long này trình bày những phân tích chi tiết về các lựa chọn chính sách thích ứng phù hợp nhất cho khu vực. Công trình nghiên cứu này là kết quả của sự hợp tác khoa học đặc biệt, với sự tham gia của một đội ngũ đông đảo các nhà nghiên cứu và chuyên gia Việt Nam, Pháp và quốc tế.

Hầu hết các vấn đề môi trường hiện tại và tương lai ở Đồng bằng đều có nhiều nguyên nhân ở các quy mô khác nhau từ địa phương đến toàn cầu, đòi hỏi các giải pháp tích hợp trong hệ thống Đồng bằng và ở cấp lưu vực sông, thay vì chỉ ở một cấp hành chính duy nhất. Tuy nhiên, ở cấp độ Đồng bằng Sông Cửu Long, kết quả đánh giá một số kế hoạch thích ứng hiện có đã cho thấy các chính sách hiện hành có xu hướng bỏ qua một số bằng chứng khoa học gần đây về các nguyên nhân gây sụt lún hoặc nhiễm mặn do tác nhân con người tại địa phương. Dường như những hạn chế lớn về khía cạnh môi trường, đặc biệt là mối đe dọa hiện hữu của nước biển dâng – mà nguyên nhân chính hiện nay là khai thác nước ngầm – vẫn chưa được xem xét đầy đủ trong các kế hoạch phát triển hoặc thích ứng hiện có.

Trong báo cáo này, chúng tôi đặc biệt đề xuất một loạt các Trọng tâm về các phương án thích ứng có thể để giải quyết các áp lực môi trường, và những đề xuất này có thể được đưa vào các chiến lược thích ứng cập nhật. Việc tích hợp những kết quả nghiên cứu này vào một mô hình kinh tế-xã hội cho thấy các cấp quản trị trung gian có thể giúp thúc đẩy các động lực lý-sinh của sông Mekong theo hướng bền vững như thế nào.

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PRÉFACE

Le delta du Mékong vietnamien (DMV) est le troisième plus grand delta de la planète. Il abrite actuellement environ 18 millions d'habitants, dont les moyens de subsistance dépendent principalement de la production agricole et aquacole. Il est soumis à une combinaison de changements environnementaux : ceux dont les facteurs sont anthropogéniques et locaux – en particulier l'exploitation du sable et l'extraction des eaux souterraines – constituent les principales menaces dans la première moitié du siècle, tandis que le changement climatique global sera probablement dominant dans la seconde moitié du siècle. Lors de la COP26 à Glasgow, un rapport d'évaluation spécial du projet GEMMES Viet Nam a largement développé l'analyse de ces combinaisons de contraintes biophysiques. La COP27 en Égypte marque l'année où les ambitions de la COP26 doivent être transformées en politiques d'adaptation réelles dans le cadre de plans nets zéro consolidés. Dans ce contexte, nous présentons dans ce rapport d'urgence sur le delta du Mékong une analyse détaillée de possibles options politiques d'adaptation. Le travail présenté ici est le résultat d'une coopération scientifique exceptionnelle, impliquant une large équipe de chercheurs et d'experts vietnamiens, français et internationaux.

La plupart des problèmes environnementaux actuels et futurs dans le delta ont plusieurs moteurs à des échelles allant du local au global, ce qui appelle des solutions intégrées dans le système du delta et au niveau du bassin versant du Mékong, plutôt qu'à un seul niveau administratif. Cependant, au niveau du DMV, l'examen de certains plans d'adaptation existants met en évidence le fait que les politiques actuelles tendent à ignorer certains aspects clés des connaissances scientifiques récentes sur les causes anthropiques locales de la dynamique de subsidence ou de salinisation. Il apparaît que certaines contraintes environnementales majeures, notamment la menace existentielle de l'élévation relative du niveau marin – dont le principal moteur est actuellement l'extraction des eaux souterraines – sont encore insuffisamment prises en compte dans les plans de développement ou d'adaptation existants.

Dans ce rapport, nous proposons notamment une série de focus sur différentes options d'adaptation possibles pour faire face aux pressions environnementales correspondantes, et qui pourraient être intégrées dans des stratégies d'adaptation actualisées. Leur intégration dans un modèle socio-économique montre enfin comment les niveaux intermédiaires de gouvernance peuvent contribuer à orienter la dynamique bio-physique du Mékong dans une direction durable.

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CONTENT

ANNEXES

Part 1

Adaptation strategies in the Delta: are they consistent with current and future changes?

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Abstract

Over the past decades, the Vietnamese Mekong Delta (VMD) has been subject to significant climatic and environmental changes. These changes are driven by global climate change and/or human activities in the Delta or in the Mekong River Basin and are expected to further increase in the future, challenging the sustainability of the Delta. Therefore, the consistency between the Delta's adaptation strategies or development plans and current scientific knowledge on climatic and environmental changes appears as a major question. In order to strengthen the coherence between scientific knowledge and policy recommendations or strategies, we present a systematic review of 27 existing development or adaptation plans for the VMD published from 2012 to 2022. This review at the Delta's scale is completed by an overview of the projects in five provinces identified as hotspots for relative sea-level rise or saline water intrusions. Results show that while climate change is clearly acknowledged in the documents, it is often unclear which dimension of its physical effects are actually tackled. Most attention is put on issues related to water salinization, floods, and inundations while the existential threat of relative sea-level rise is much less addressed and does not appear to receive as much attention as it should. The issue of sediment starvation (especially sand mining), though being the major driver of increasing saline water intrusions, is nearly absent. Hence, it appears that climatic/environmental pressures receiving the most attention are the ones already having obvious and large impacts on people and livelihoods in the Delta, whereas relatively slowly increasing risks are much less considered. Whether at the Delta level or at the provincial level it also appears that adaptation plans tackle the impacts of climatic/environmental changes but not their root causes when they are actually local and anthropogenic. Based on these findings, we provide several recommendations for Vietnamese policymakers, authorities, and scientists in three domains: science and policy interface, adaptation measure strengthening, and scale-up of communication and information practices.

Tóm tắt

Trong những thập kỷ qua, Đồng bằng sông Cửu Long (ĐBSCL), Việt Nam, đã và đang phải đối mặt với những thay đổi đáng kể về khí hậu và môi trường. Những thay đổi này xuất phát từ biến đổi khí hậu toàn cầu và / hoặc các hoạt động của con người đang sinh sống tại chính ĐBSCL hoặc ở cấp độ lưu vực sông Mekong, và dự kiến sẽ còn tiếp tục gia tăng trong tương lai, tất cả những điều đó thách thức tính bền vững của Đồng bằng. Do đó, sự nhất quán giữa các chiến lược, kế hoạch phát triển thích ứng cho vùng ĐBSCL và kiến thức khoa học hiện hữu về các chủ đề như biến đổi khí hậu và môi trường trở nên vô cùng cấp thiết. Để tăng cường sự liên kết giữa kiến thức khoa học và các khuyến nghị chính sách hoặc chiến lược phát triển, nhóm tác giả thực hiện một đánh giá có hệ thống về các kế hoạch phát triển hoặc thích ứng hiện có cho vùng ĐBSCL. Việc đánh giá ở quy mô vùng ĐBSCL này được hoàn thành bằng cách nghiên cứu tổng quan các dự án được phê duyệt/lên kế hoạch cho năm tỉnh, nơi mà được xác định có các điểm nóng về các vấn đề của nước biển dâng hoặc xâm nhập mặn tương đối. Kết quả cho thấy mặc dù vấn đề biến đổi khí hậu đã được thừa nhận rõ ràng trong các tài liệu được đánh giá, nhưng đa phần các tài liệu này chưa nêu lên được chi tiết về việc các dự án, chính sách sẽ giải quyết khía cạnh nào của các tác động vật lý từ biến đổi khí hậu. Được quan tâm nhiều nhất là các vấn đề liên quan đến nhiễm mặn, lũ lụt và ngập úng trong khi các mối đe dọa của mực nước biển dâng tương đối lại ít được giải quyết và dường như chưa nhận được sự quan tâm cần thiết. Vấn đề "khát" trầm tích (đặc biệt là do khai thác cát), mặc dù là nguyên nhân chính làm gia tăng sự xâm nhập của nước mặn, nhưng hiện chưa nhận được sự quan tâm nào thể hiện trong những tài liệu được đánh giá. Do đó, có thể nhận thấy sự quan tâm hiện giờ cho ĐBSCL tập trung vào những vấn đề môi trường hoặc khí hậu với những tác động đến con người và sinh kế một cách rõ ràng và đáng kể, trong khi những rủi ro đang dần thể hiện rõ nét nhưng một cách chậm rãi và tương đối ít nhận được sự quan tâm hơn. Dù là ở cấp đồng bằng hay cấp tỉnh, các kế hoạch thích ứng hiện tại đang và sẽ giải quyết được các vấn đề liên quan đến tác động của biến đổi khí hậu và môi trường nhưng chưa hẳn tìm được giải pháp cho các vấn đề gốc rễ của chúng, đặc biệt khi liên quan đến các vấn đề ở cấp độ địa phương và do con người gây ra. Dựa trên những kết quả của đánh giá này, nhóm tác giả đưa ra một số khuyến nghị cho các nhà hoạch định chính sách, cơ quan chức năng và các nhà khoa học của Việt Nam và quốc tế về ba lĩnh vực: giao diện giữa khoa học và chính sách, tăng cường biện pháp thích ứng và mở rộng quy mô của các hoạt động truyền thông và thông tin.

Résumé

Au cours des dernières décennies, le delta du Mékong vietnamien (DMV) a subi d'importants changements climatiques et environnementaux. Ces changements, causés par le réchauffement climatique global et/ou par les activités humaines dans le delta ou le bassin du Mékong, devraient s'accentuer à l'avenir, mettant en péril la durabilité du delta. Aussi, la cohérence entre stratégies d'adaptation ou plans de développement du delta et connaissances scientifiques actuelles sur ces changements climatiques/environnementaux apparaît comme un enjeu majeur. Afin de renforcer cette cohérence, nous présentons une revue systématique de 27 plans de développement ou d'adaptation pour le DMV publiés entre 2012 et 2022. Cette revue à l'échelle du Delta est complétée par un aperçu des projets dans cinq provinces identifiées comme des points chauds face à la hausse relative du niveau marin ou aux intrusions salines. Nous montrons que, si le changement climatique est clairement mentionné dans les documents, il est souvent difficile de savoir quelle dimension de ses impacts physiques est effectivement considérée. L'attention est focalisée sur les problèmes liées à la salinisation des eaux, aux inondations et aux crues. La menace exis-

tentielle de la hausse relative du niveau marin est en revanche nettement moins abordée et ne semble pas recevoir autant d'attention qu'elle le devrait. Le problème de l'appauvrissement en sédiments (en particulier l'extraction de sable) n'est quasiment pas abordé, alors qu'il s'agit du principal facteur d'augmentation des intrusions salines. Il semble donc que les pressions climatiques/environnementales qui reçoivent le plus d'attention sont celles qui ont déjà des impacts évidents et importants sur les personnes et les moyens de subsistance dans le delta, tandis que les risques augmentant relativement lentement sont nettement moins pris en compte. Que ce soit à l'échelle du delta ou à l'échelle provinciale, il semble également que les plans d'adaptation s'attaquent aux impacts des changements climatiques/environnementaux mais pas à leurs causes profondes lorsque celles-ci sont en réalité locales et anthropiques. Sur la base de ces résultats, nous fournissons aux décideurs politiques, autorités et scientifiques vietnamiens plusieurs recommandations dans 3 domaines : l'interface entre science et politique, le renforcement des mesures d'adaptation et le développement des pratiques de communication et d'information.

1. Introduction

The Vietnamese Mekong Delta (VMD), home to about 18 million inhabitants [GSO, 2021] and the 'rice bowl' of the country, faces various changes in its climatic and environmental conditions, in particular warmer temperatures, precipitation changes, increasing saline water intrusions, sea-level rise, and coastal erosion. Some of these changes arise from global climate change but others are actually driven by human activities within the Delta or upstream.

The Delta has a long historical experience of dealing with water and climate-related factors. However, the magnitude of changes expected in future decades challenges the sustainability of the different adaptation measures implemented so far, as was previously investigated in the GEMMES-Viet Nam COP26 report [Espagne *et al.*, 2021]. Hence, the consistency between adaptation strategies or development plans for the Delta and current scientific knowledge on climatic and environmental changes appears to be a major question to address.

1.1 Context: climatic and environmental pressures on the Delta[1]

Within the framework of this study, we distinguish between 'climatic' pressures, which hereafter will refer to those driven by global climate change, and 'anthropogenic' pressures, which will refer only to those arising from human activities in the Delta itself or at the scale of the Mekong River Basin.

1. This section summarizes the main conclusions of the GEMMES COP26 report on current and future climatic/environmental pressures in the Mekong Delta. Full references are to be found in this previous work [Espagne *et al.*, 2021].

Climate change: rising temperatures and rainfall changes

Weather stations in the Delta have recorded a clear increase in mean annual temperatures over the past 40 years, with an average warming of 0.2°C/decade. Rainfall patterns are changing, although these changes are more spatially contrasted and not always statistically significant over the period considered. According to the projections from numerical climate models, the warming trend will continue in future decades, at a rate and magnitude that will depend on the level of global warming.

Warmer conditions will negatively impact freshwater resources, due to the increase in evaporation, especially during the dry season. Extreme heat events will also become more intense and frequent, with potential impacts on human health and work capacity [*e.g.* Mora *et al.*, 2017]. However, only a few studies have investigated the health impacts of heatwaves in tropical and developing countries. Viet Nam is no exception to this [*e.g.* Phung *et al.*, 2017; Dang *et al.*, 2019], and to the best of the author's knowledge, no study has investigated potential future damages caused by extreme heat in Viet Nam.

Changes in mean annual rainfall are also projected, but the sign and magnitude of change are not always consistent between different methodological approaches. Further research is needed to better assess future changes for this variable [Espagne *et al.*, 2021]. Temperature and precipitation changes will also affect the hydrology of the entire Mekong River Basin, leading to discharge changes at the entrance of the Delta, with potential impacts on floods during the wet season, and water scarcity during the dry season.

But for the VMD, the main threat related to anthropogenic climate change is maybe global sea-level rise triggered by the ocean thermal expansion and the melting of glaciers and ice-sheets. Indeed, the vast majority of the Delta stands below 2 m above current sea level, with an average elevation of only ~80 cm, which makes it extremely vulnerable to even small variations in sea level [Minderhoud *et al.*, 2019]. Satellite altimetry data for the period 1993–2018 show an increasing sea-level trend of about 3.6 mm/year on average along Vietnamese coastal areas, and this rate is expected to accelerate in the coming decades. Current median projections of future sea-level rise range from 24 to 27 cm in 2050 and from 44 cm to 73 cm in 2100, compared to 1986–2005, depending on the climate scenario [Espagne *et al.*, 2021]. These projections could even be underestimated, in case of rapid destabilization of polar ice-sheets [Bamber *et al.*, 2019]. Such trend is an existential threat for the Delta, as a 50 cm or 80 cm rise would mean that 29% or 54% of the Delta, respectively, would fall below sea level.

However, climate change is neither the only driver of change in the VMD nor even, at least for the moment, the largest one. Indeed, groundwater extraction triggers rapid elevation loss [Minderhoud *et al.*, 2020; Kondolf *et al.*, 2022], while sediment starvation from upstream dams and sand mining is the main driver of saline water intrusions during the dry season [Eslami *et al.*, 2019]. Sediment starvation also enhances the issue of coastal erosion [2] [Anthony *et al.*, 2015]. In addition, hydropower development has a strong impact on the hydrological regime of the Mekong, including its seasonal variability, and future upstream dam operations may either mitigate or enhance climate impacts on the river discharge.

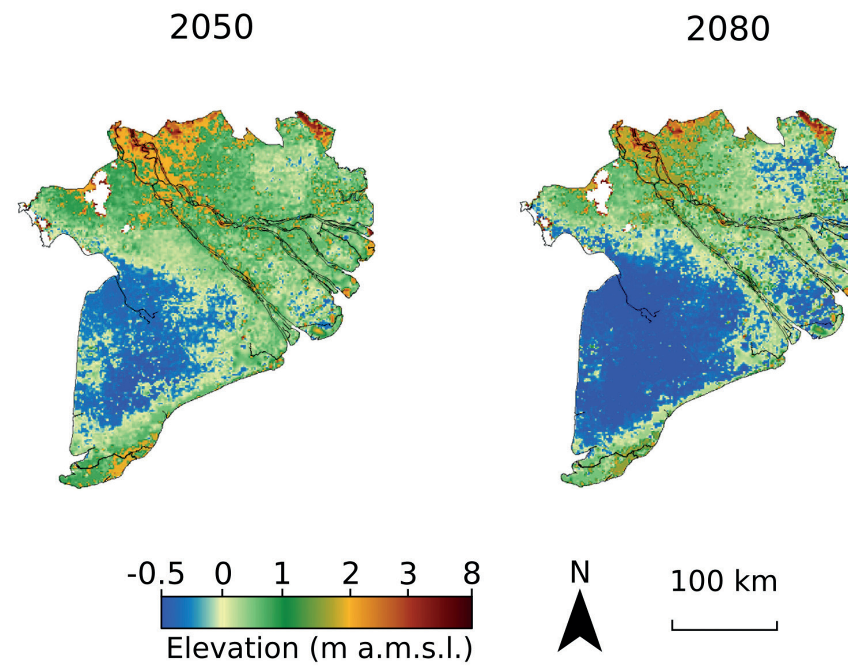
2. Which is also triggered by mangrove deforestation in some coastal areas, see Focus 2.

Two major anthropogenic pressures: extraction-driven subsidence and sediment starvation

Rapid urbanization and intensified food production in the Delta have placed immense pressure on the water resources of the VMD. As a result, groundwater extractions have tremendously increased over the past 30 years, reaching ~2.5 10^6 m^3/day nowadays [Bui *et al.*, 2015; Minderhoud *et al.*, 2017]. Extractions are far from being stabilized and continue to increase, but poor monitoring prevents reliable quantitative estimates. This evolution is the main driver of high land subsidence rates (*i.e.* the gradual lowering of the land surface) in the Delta, as large as 5 cm/year in some places [Nuessner *et al.*, 2019; Minderhoud *et al.*, 2020b]. The highest subsidence rates are recorded in Ca Mau, Bac Lieu, Can Tho, Soc Trang, and Tra Vinh provinces (see Figure 2.5 for the provinces' location)]. As the phenomenon is not compensated by new sediment deposits, because of current low sediment loads in the Mekong River and dykes depriving the Delta of deposition of the remaining sediments on the floodplains during floods, the Delta experiences rapid elevation loss.

Hence, the relevant variable to assess the risk of submersion of the Delta in future decades is relative sea-level rise, *i.e.* the combination of global sea-level rise from climate change and subsidence. Future relative sea-level rise in the Delta will for a large part depend on future groundwater extractions. Should the rate of extraction remain at the present-day level, the average cumulative subsidence could be over 80 cm by 2100 [Minderhoud *et al.*, 2020], which, combined with global sea-level rise and lack of sediments on the floodplains, would cause the majority of the Delta to fall below sea level. The most vulnerable part of the Delta is the low-lying southwest provinces, of which large parts could fall below sea level as early as 2050 [Figure 1.1]. Thus, strongly reducing groundwater extractions actually appears as the most efficient mitigation strategy to reduce subsidence and slow down relative sea-level rise in the next decades.

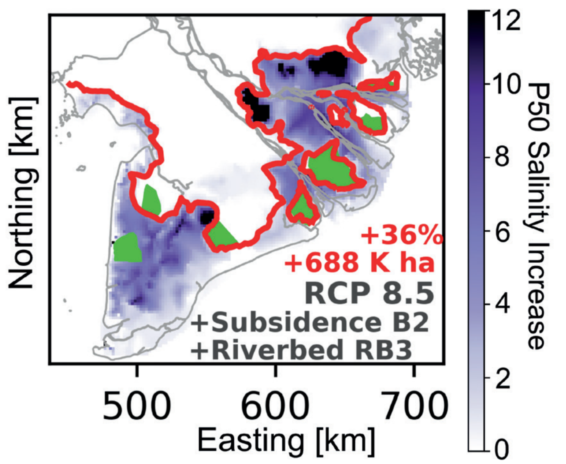
[Figure 1.1]
Projections of future elevation



Projections of future elevation in 2050 and 2080 following 1) extraction-induced subsidence for a scenario where groundwater extractions are stabilized at the 2018 level, and 2) global sea-level rise according to the mid-range (RCP4.5) projection. Elevation is in meters above mean sea level, based on the TopoDEM (Minderhoud *et al.*, 2019). Source: Extracted from Minderhoud *et al.* (2020).

Sediment starvation is another major anthropogenic pressure on the Delta (see Focus 1), with dams and dykes altering the fine-grained, suspended sediment dynamics in the Mekong river and sand mining impacting the coarser-grained sediments in the riverbed. Every delta is made up by sediments and also in a natural situation a delta requires ongoing deposition of new sediments to remain elevated because of natural sediment compaction. In the current situation, with rapid relative sea-level rise, maintaining the altitude of the Delta would require the deposition of much more new sediments than were even available in the pristine state of the Mekong river basin [Dunn & Minderhoud, 2022]. On top of that the amount of suspended sediment reaching the Delta has been strongly reduced by the

[Figure 1.2]
Scenario of increase in saline water intrusion under climatic and anthropogenic drivers



Spatial distribution of P50 (average) salinity increase and the extent of salt intrusion (2 PPT absolute salinity contour line) during the dry season by 2050 under RCP8.5 climate change scenario, subsidence triggered by increasing groundwater extractions and high level of river-bed level incision. The green areas define the existing freshwater zones (mainly by sluice gates); the red percentage is the increase in salinity-affected surface area relative to the present-day conditions, and the red number in thousand hectares [K ha] shows increase in area affected by salt intrusion under that scenario.
Source: Extracted from Eslami *et al.* (2021).

construction of upstream dams, now trapping about 40–90% of the former suspended sediment supply to the VMD [Kondolf *et al.*, 2018]. In addition, dykes prevent most of the remaining suspended sediments in the channels to go to the floodplains [Triet *et al.*, 2017; Thanh *et al.*, 2020]. The combined effects mean that the natural compensation mechanism of the Delta again elevation loss, *i.e.* flood-based sediment deposition, is under the current circumstances no longer functioning [Dunn & Minderhoud, 2022] and requires fundamental changes at both national and basin level to become a viable adaptation strategy against relative sea-level rise[Kondolf *et al.*, 2022].

In addition, the demand for sand for infrastructural projects has led to a large increase in sand mining of riverbed sediments in the estuarine channels of the Mekong river and upstream in Laos and Cambodia. The amount currently extracted is estimated to exceed the remaining fluvial bedload supply [Eslami *et al.*, 2019; Jordan *et al.*, 2019].

Sediment starvation is the main driver of river bank instability [Hackney *et al.*, 2020] and riverbed erosion, resulting in an average lowering of the riverbed of 10–15 cm/year [Eslami *et al.*, 2019]. Lower riverbeds lead to tidal amplification and largely contributed to both city flooding during the wet season and increasing saline water intrusions during the dry season (0.2–0.5 PSU/year over the past two decades) [Eslami *et al.*, 2019]. According to state-of-the-art projections from numerical modelling, climate change and subsidence will contribute to increasing saline water intrusions in future decades, but the main driver remains riverbed erosion, at least up to 2050 [Eslami *et al.*, 2021]. In the worst-case scenario combining the different drivers of salinization, the increase of areas affected by saline water intrusions by 2050 could reach ~40%. The two main regions impacted would be the Ca Mau Peninsula and the river mouth from Soc Trang to Ho Chi Minh City [Figure 1.2]. In such a scenario, some estuarine provinces, for example Vinh Long or Tien Giang, which are currently not affected by saline intrusions in normal years, may be strongly impacted in the future [Eslami *et al.*, 2021].

The problem of saline water intrusions during the dry season is also strongly driven by the declining freshwater supply from the Tonle Sap Lake, which is itself caused predominantly by mainstream hydropower development, shifting the hydrological regime of the Mekong River (see chapter 9 of the GEMMES COP26 report and Focus 3, this report).

Hence, local and regional anthropogenic pressures appear to pose the greatest threats in the first half of the century, while climate change effects will probably dominate in the second half. Since ongoing changes, and especially water challenges (floods, droughts, saline intrusions) are already challenging livelihoods in the Delta (see chapter 7 of the GEMMES COP26 report), authorities have been encouraged to design adaptation pathways that emphasize response capabilities in terms of investments or financial incentives.

1.2 Objectives of the chapter

The research studies on climatic and environmental pressures as well as on adaptation strategies are actually unevenly referenced by the national policies, strategies, and/or legal documents in which governmental departments specify plans and interventions to support adaptation. Over time, an increasingly fast evolution in scientific knowledge risks to outrun development and adaptation policies that are based on outdated and therefore inappropriate understanding of climatic and environmental changes and their drivers. Hence, the consistency between current scientific knowledge on climatic or environmental pressures and the different official or non-official plans for adaptation remains an outstanding matter is an open question. It raises the following questions:

– Are the main pressures, their drivers, and their potential future evolution correctly taken into account?
– Are the plans not only to tackle the consequences of changes but also, when relevant, to address to some extent the root causes of the anthropogenic pressures on the environment in the VMD?

To the best of our knowledge, no study has attempted to systematically review existing adaptation plans or strategies in the VMD and compared with scientific knowledge of current and future pressures. In an attempt to bridge this knowledge gap and to strengthen the coherence between scientific knowledge, policy recommendations or strategies, and practices, we present here a systematic review of existing development or adaptation plans for the VMD, and at the same time seek to address the following questions:

1] Which scientific evidence is cited in support of aspects of key national policies relevant to adaptation?

2] To what extent are the current plans/strategies aligned with current scientific knowledge on current and future climate/environmental changes?

3] What aspects of these key national policies are called into question by discrepancies, if any, between the underlying reasons for the plans and the current scientific assessment of current and future environmental threats?

4] Do the national adaptation plans/strategies tackle the roots of threats when the drivers are not beyond Viet Nam's influence but could be tackled at the Delta level or by regional coordination with upstream countries?

To do so, we took into account the adaptation strategies developed by Vietnamese authorities while also covering the strategies drawn from other organizations. The scope of the review covers the full expanse of the Vietnamese Mekong Delta, and includes data extraction on adaptation/mitigation projects and strategies at the provincial level.

2. Adaptation plans at the scale of the Delta: what is their focus?

2.1 Methodology for the selection of the documents

Definition of terms

For our study, we define adaptation plans or strategies as official or unofficial documents which: i) refer to the Mekong Delta, and ii) set out steps to be undertaken or guidelines for policy making or action plan making to deal with the impacts of climatic and environmental pressures that threaten the livelihoods and sustainable development of the Delta.

Official documents are defined as those officially politically endorsed, while unofficial ones are recommendations from grey literature, especially those produced outside Viet Nam but not currently endorsed by Vietnamese authorities. Only documents written in Vietnamese or English have been considered.

To be included in our review, documents should have one of the following characteristics:
– A substantive focus on adaptation, either through the promotion of specific programs to minimize adverse impacts from climate change or from other environmental changes on the Delta's sustainability, such as: relative sea-level rise; extreme heat; heavy rainfall; saline water intrusions; seasonal flooding, etc.;
– Have climate change as an overarching rationale;
– Specifically address risks that are directly/indirectly impacted or exacerbated by climate change in the time horizon of up to 2050.

Collecting the documents

Using keywords listed in Table 1.1, as well as personal knowledge and advice from GEMMES project partners, policy documents, plans or strategies were retrieved from the following sources:

- Grey literature:
– The Social Dimensions of Adaptation to Climate Change in Viet Nam [Worldbank, 2010]
– The development of regional coordination in the Mekong Delta – Thanh Nien Publishing House (pages 32-41) [Soussan, 2019]
– The Mekong Delta Plan (MDP) [Royal HaskoningDHV *et al.*, 2013], produced in partnership between the Vietnamese and Dutch governments
– The draft Mekong Delta Integrated Regional Master plan (MDIRM) 2020.[3] The final version of the MDIRM was recently approved by the Prime Minister, issued by the Decision 278/QĐ-TTg (February 2022).

3. Prepared for the Ministry of Planning and Investment by Royal HaskoningDHV, the same consultancy firm that wrote the Mekong Delta Plan (2013).

[Table 1.1]

Keywords used to identify adaptation/development plans

Keywords representing climatic/environmental pressures or their drivers	**English:** Climate change, salinity intrusion, subsidence, groundwater, temperature, storm, flood(ed), disaster, sea level rise, sand (extraction) **Vietnamese:** Biến đổi khí hậu, Xâm nhập mặn, Sụt lún, Nước ngầm/nước dưới đất, Nhiệt độ/khí nóng, Bão, (Ngập) Lũ, Thiên tai, Nước biển dâng, (Khai thác) Cát
Keywords that may be related to adaptation actions	**English:** (sea) dyke, irrigation, water resources, shrimp, rice, mangrove forest, water supply, construction standard **Vietnamese:** Đê biển, đê, đê bao, thủy lợi, tôm, lúa, rừng ngập mặn, cấp nước, tiêu chuẩn xây dựng (độ cao xây dựng)

The keywords represent the main climatic/environmental pressures in the Delta, selected for their salience with respect to the GEMMES COP26 report.

- Online research for peer-reviewed article in academic journals (in both English and Vietnamese).

- Online platforms (*các trang mạng điện tử*, in Vietnamese), such as: thuvienphapluat.vn; vbpl.vn, moc.gov.vn; thukyluat.vn, chinhphu.vn, mcrp.mard.gov.vn. Several legal documents published in Viet Nam, and hereafter referred to as official documents[4] (see Box 1.1 for an overview of the Vietnamese legal system), have been selected based on their relevance, then availability.

Documents were then scanned for keywords listed in Table 2.1 using both automated and manual strategies. Identification of salient policy was easy when policy documents made explicit reference to an anticipated threat or when they provided a direct discussion of an anticipated impact of climate change. Such direct references, however, were not sufficient. Indeed, policies not referring to any relevant threat, for example permitting urban expansion or sand extraction in river channels, may govern behaviours that could increase exposure to climate change or favour unsustainable development strategies regarding future environmental pressures. Such policies, relevant for our purpose but which do not directly mention climate change, were identified by the authors.

2.2 Results from the screening process

Of the 27 documents collected, the following documents were excluded due to their inaccessibility:
– Official dispatch 6222/VPCP-KTN (in 2011) of governmental office about managing extraction activities of sand, gravel in the river and usage of groundwater;
– Decision 633/QD-Ttg (in 2020) by the Prime Minister approving the programme to modernize the irrigation system to support the transition and development of sustainable agriculture in the ecosystem zones of the Mekong Delta.

The importance of the documents was then rated by 11 academic researchers and experts

4. See Online Supplementary Material.

[Box 1.1]

Viet Nam's legal system

Viet Nam's legislation consists of a complex system of legal documents issued by different state agencies. Those related to climate change and other environmental stressors include socio-economic and sectoral plans approved by the decisions of the Prime Minister. Resolutions by the government, such as Resolution 120 for the Mekong Delta in 2017, stand above the decision by the Prime Minister and play a leading role in development orientations. Other regulations are systematized and prescribed by specific secondary regulations. Current legal documents issuing is regulated by the Law 80/2015/QH13 about issuing legal documents, amended in 2019 [Table 1.2].

from relevant fields and eventually 19 documents[5] were retained for an assessment of their main orientations and for an 'exploratory screening' based on keywords occurrence.

Overview of the strategic orientations for the Delta development

The 19 documents considered [Figure 1.3] show the evolutions over the past years in development and adaptation strategies in the Delta. Since 2012, under the guidance of the national strategy for climate change mitigation and adaptation, different sectoral plans were endorsed, for instance for transportation, irrigation, groundwater and tourism management or construction. All documents state in their objective and vision sustainable development with adaptation to climate change and sea-level rise (that we assumed to be global sea-level rise). However, electricity planning, although having renewable energy on its agenda, does not mention its links to the objective of reducing greenhouse gas emissions or ensuring a global net-zero target by 2050.

In 2013 the Dutch-funded Mekong Delta Plan (MDP) was finalized and endorsed by the government and development partners. The MDP centres on climate adaptation and development. It introduces a number of innovations: 1] it takes the year 2100 as horizon for back casting and planning; 2] it sees the Delta as a hydrological unit, as whole or as a system since interventions in one place might affect other places; 3] it develops a cross-sectoral or integrated approach. On this basis, a matrix with four scenarios was developed to outline possible futures.[6] The Vietnamese actors interpreted these as pathways [Weger, 2019] and chose to align their efforts to the preferred agro-business industrialization scenario. "Agro-Business Industrialization [is] a shift in policy planning from uncoordinated economic diversification towards agro-business focused specialization. [It] is vital for sustainable socio-economic development of the Delta in the long run." [7] This scenario represents the comparative advantages of the region.

5. See Online Supplementary Material.

6. The matrix has two axes: business-as-usual and economic restructuring (from agriculture to industry).

7. Cited from https://www.mekongdeltaplan.com/mekong-delta-business-platform/trends-and-developments-in-the-mekong-delta

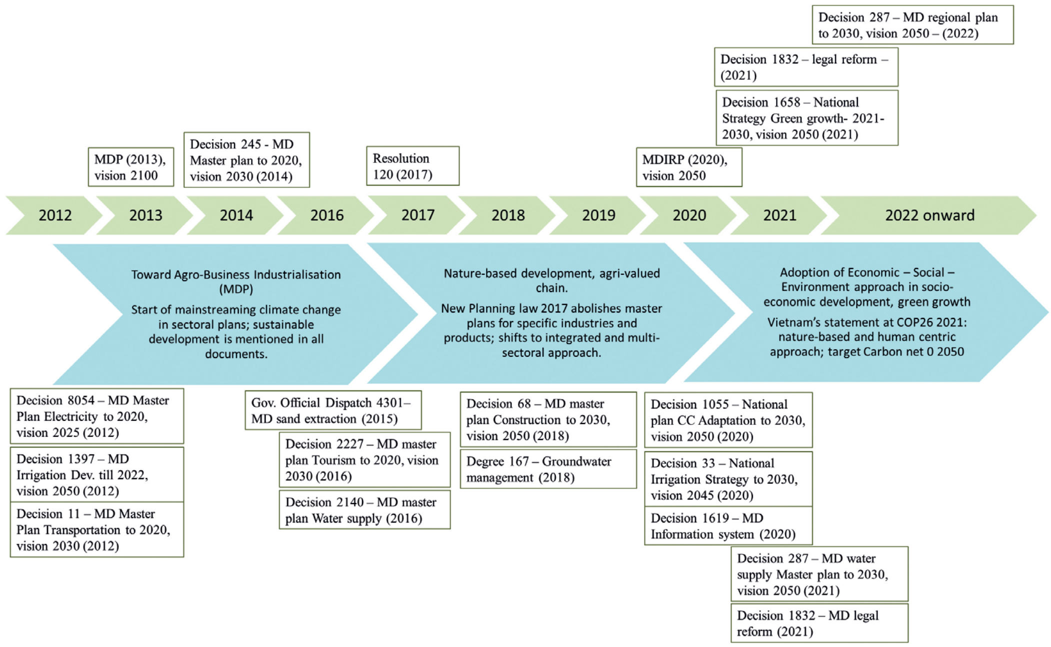
[Table 1.2]

Viet Nam Legal System

(based on Law 80/2015/QH13 about issuing legal documents, amended in 2019)

Viet Nam Legal System (based on Law 80/2015/QH13 about issuing legal documents, amended in 2019)					
Constitution by General Assembly					
Code by General Assembly		Law by General Assembly		Resolution by General Assembly/Government	
Ordinance by Standing Committee of the National Assembly		Resolution by Standing Committee of the National Assembly		Joint resolutions between the Standing Committee of the National Assembly and the Presidium of the Central Committee of the Viet Nam Fatherland Front	
	Orders of the President		Decisions of the President		
	Decrees of the Government		Joint Resolutions between the Government and the Presidium of the Central Committee of the Viet Nam Fatherland Front		
Decisions of the Prime Minister					
Resolutions of the Judicial Council of the People's Supreme Court					
Circulars of the Chief Justice of the People's Supreme Court	Circulars of the Procurator General of the Supreme People's Procuracy	Circulars of ministers, heads of ministerial-level agencies	Joint circulars between the Chief Justice of the Supreme People's Court and the Procurator-General of the Supreme People's Procuracy	Joint circulars between ministers, heads of ministerial-level agencies and the Chief Justice of the Supreme People's Court, and the Procurator-General of the Supreme People's Procuracy	Decisions of the State Auditor General
Resolutions of People's Councils of provinces and centrally-run cities					
Decisions of provincial-level People's Committees					
Legal documents of local administrations in special administrative-economic units					
Resolutions of People's Councils of districts, towns, and provincial cities					
Decisions of district-level People's Committees					
Resolutions of People's Councils of communes, wards, and townships					
Decisions of commune-level People's Committees					

[Figure 1.3]
Some highlights from the development strategies and directions for the Mekong Delta since 2012



In 2014, the Prime Minister approved the *Master plan for socio-economic development of the Mekong Delta key economic region through 2020, vision until 2030* (Prime Minister's Decision 245/QĐ-TTg, approved in 2014). It centres on economic growth and restructuring with sustainability as an afterthought or issue to be integrated. The quantitative targets are on growth and production.

In 2017, the Viet Nam government made a fundamental shift in Delta development by adopting Resolution 120. The resolution outlines the need to move from fighting and exploiting nature to actively living with nature and from a growth-centred viewpoint to an integrated sustainability perspective. The resolution states the direction to the sustainable development of the Mekong Delta, in alignment with the MDP's orientation towards agro-business industrialization. Its vision toward 2100 is stated:

"The Mekong Delta will sustainably, safely and prosperously develop on the basis of high-quality agriculture in combination with services, ecological tourism, and industry, especially processing industry, thereby increasing the value and competitiveness of agricultural products. The infrastructure system will be planned and developed in a uniform and modern manner towards proactivity, intelligence and resilience to climate change to ensure safety upon occurrence of natural disasters. Natural resources will be used in a proper manner. Biodiversity, cultural traditions and history will be preserved and enhanced. People's material and spiritual life will be improved".

The strategic orientation for development focuses on a human-centred development approach, living together and adapting to climate change and sea level rise, and turning challenges into opportunities, ensuring development model to be suitable for natural conditions, biodiversity, culture, people and natural laws, investments with uniform, inter-regional, inter-sectoral and targeted manner and an appropriate road map, and promoting regional and international cooperation. The vision for 2100 of Resolution 120 is similar to the MDP 2013 and the Viet Nam Development Report 2016 in terms of fully developing the key agricultural value chains, including the processing industry, transport and logistics, marketing and branding towards domestic, Asian and global markets, as well as related business services. Instead of 'agro-business industrialization', the concept used now is 'agricultural transformation', with the aim of adapting to the changing climate and water conditions.

Likewise, in 2017, the new Law on Planning was approved thus introducing the regional level as site for planning. It adopts an integrated approach, ensuring the holistic collaboration between sectors related to infrastructure, resources use, and environmental protection. The objective is to achieve balanced, effective and sustainable development. More specifically, the new aspects of this law include the transparency and publicity of the plan, the follow-up principle, and the obligations in collecting public opinions.

A final key change induced by Resolution 120 and the Law on Planning (2017) is the shift from the Ministry of Natural Resources and Environment (MONRE) playing a major coordinating role to the Ministry of Planning and Investment (MPI). While MONRE was in charge of the Resolution's implementation plan, MPI gradually took over the leading role in elaborating the MDIRM and the *"Viet Nam Green Growth Strategy"* (adopted in 2021 but still under revision). On the one hand, this seems to be a shift from moving climate change issues away from the narrow environmental sector and positioning it more centrally in the overall integrated development. On the other hand, this shift from a line ministry to an overarching ministry empowers the climate change agenda and its consideration in high-level decision making. Thus, Resolution 120 not only triggered a policy shift but also a political shift.

Since 2017, Resolution 120 continues to play a founding role in the current strategies and plans for the Mekong Delta. The term 'actively living with nature' was elaborated into embracing and living with floods, brackish water, and saltwater. The term 'actively living with floods' is guiding the *Mekong Delta irrigation strategy for 2021-2030 vision until 2050* (Decision 287/QĐ-TTg, approved in 2020). This motto is not only shifting local perceptions and thoughts but also the institutional approach to adapting to climate change. The approach 'actively living with floods' highlights the importance of accommodating flood events rather than avoiding floods at all costs [Luu *et al.*, 2022]. It builds on recent insights that highlight the benefits of benign floods. It is a shift from 'flood control' to 'controlled flooding'. However, the current implementation of the controlled flooding approach is facing various issues, especially in the objective gap between central and local levels, and the existing argument between management based on the natural flood rhythm and an infrastructure-focused engineering approach, resulting in the high-dyke system [Luu *et al.*, 2022]. Whether or not the agricultural transformations are sustainable, profitable and just, is still under debate.

In 2020 the draft MDIRM was presented. It was one of the tasks in Resolution 120 assigned to MPI and supported by the World Bank. While mentioning the careful consideration between economic development, human development, and environmental protection, in terms of policy, this draft master plan goes a step farther to address the need to link the three aspects of economy, society, and environment in all projects and works. The draft MDIRM promotes the direction towards a sustainable agricultural economy, with aquaculture and fruits development and a reduction of the share of rice cropping in the economy. Greater attention is given to quality of life, equality and justice, and adaptation to climate change and other environmental stressors.

An innovative introduction in the draft MDIRM is the concept of 'agricultural hub centres'. These hubs are more than production, collection and distribution centres to further integrate the value chains. They also form clusters of supporting industries, knowledge institutes, and services providers, and constitute the node in the transport system, which became the centre of attention and budget allocation for the implementation of the draft MDIRM. Consequently, the Ministry of Transport developed an ambitious plan to expand the road network and inland waterways. The Master plan is being translated into investments that are biased towards grey infrastructure: roads, embankments, irrigation systems, hubs, and ports. This resembles the expansive economic viewpoint of the 2014 Master plan which opens up the Delta for further exploitation of its resources. At the moment, each province of the Mekong Delta and Can Tho city are translating the MDIRM into integrated provincial master plans.

The most recent directions to policy development and climate change are based on the net-zero emission commitment by 2050 pronounced by the Prime Minister at COP26. The main commitments of Vietnamese government announced there target future sustainable development of the country with an ambitious agenda to de-carbonize the economy by avoiding new coal plants and transitioning towards clean energy. The country's leader also calls for fairness and justice in climate change issues, suggesting assistance from international partners in human resources, national governance on sustainable development, and providing Viet Nam with preferential green finance and technology.

Pressures and adaptation strategies: what can we learn from a keywords' analysis?

In this first analysis, all documents are at the Mekong Delta or national levels. Those at the provincial level are not included due to the limitation in timing and access. In order to quantitatively assess the relative importance given to the different climatic/environmental pressures and related adaptation strategies in the documents, we performed a manual scan to determine the occurrence of the different keywords listed in Table 1.1. The results are presented in Table 1.3 and further discussed below. We distinguished between two criteria: text portions *assessing* present or future climatic/environmental issues, and text portions dealing with adaptation or mitigation *actions* planned to tackle these issues. Some keywords may occur in both context. These two criteria allow to check whether some pressures might be properly acknowledged, but not tackled by specific actions.

The results show that the environmental problems, such as climate change, sea-level rise, disaster, salinity, flood, and drought, are well mentioned in the text portions on adaptation/mitigation actions. 'Climate change' is

[Table 1.3]

Quotation count from the documents scanned against the keywords listed in Table 1.1

Assessment of climatic and environmental pressures: keywords used	Quotation count			Adaptation or mitigation actions: keywords used	Quotation count
	MDP 2013	Draft MDIRM 2020	All document excluding MDP 2013 and draft MDIRM 2020		
Climate change	33	61	0	Climate change	101
Salinity	49	62	0	Salinity	73
Subsidence	13	56	0	Subsidence	21
Groundwater	12	64	0	Groundwater	36
Temperature/heat	2	8	0	Temperature/heat	0
Storm/typhoon	1	26	0	Storm/Typhoon	17
Flood/inundation	72	97	1	Flood/inundation	50
Sea-level rise	20	44	0	Sea level rise	26
Sand (extraction)	0	7	0	Sand (extraction)	6
				Sand (extraction)	6
				Dyke, irrigation	109
				Agricultural land use (shrimp, rice)	40
				Mangrove forest	16
				Water supply	51
				Construction standard	4

by far the most frequent (101 occurrences), followed by 'salinity' (73 occurrences) and 'flood/inundation' (50 occurrences). 'Sea-level rise' and 'subsidence' are mentioned only 26 and 21 times, respectively, while 'sand mining' is hardly mentioned and 'heat' is absent. However, in official documents, the climatic/environmental keywords were not found in text portions that would provide and assessment of the pressures. This lack of *explicit* reference to the nature and magnitude of the climatic/environmental pressures in official documents prevent a straightforward assessment of the consistency between plans and current scientific knowledge. By contrast, the two Mekong Delta Plans provide more information on environmental projections and on the foundation of their recommendations.

Assessment of climatic/environmental pressures in Mekong Delta Plans

In the Mekong Delta Plan 2013, there are a fair number of quotations mentioning various environmental pressures. However, most details on environmental issues are presented only qualitatively, making it difficult to check if the projections are up-to-date. 'Flood' appears as the most frequent keyword, also associated with mostly quantitative data on present day situation. The MDP 2013 provides four different socio-economic development scenarios.

In the writing process, the 'Agro-Business Industrialization' scenario became the preferred strategy or pathway for the future sustainable development of the Mekong Delta. In general, this plan mentions some environmental pressures based on the back-casting principle:[8] taking into account the existing climatic/environmental pressures, it assesses what could be the trajectory to turning them into resources that can be actively used rather than 'threats' and need to be fought. For instance, it looks at 'salinity' as a resource by turning coastal zones into a brackish economy that optimizes the usage of salt water for aquaculture. However it is unclear whether the future evolution of climatic/environmental conditions are actually taken into account. 'Salinity' for instance is mentioned as 'deep salinity intrusion' for past and present periods, and as 'slight, moderate or dramatic' for future decades under global climate change scenarios. However, no element is provided on potential impacts of such changes on the brackish economy projected for coastal zones. In hindsight, one of the major omissions of the MDP is mentioning land subsidence but not recognizing its magnitude and importance for the Delta. In parallel, the challenges of water pollution are mentioned but the issue is not central in its agricultural, urban and industrial development recommendations.

Contrary to the MDP 2013, the draft Mekong Delta Integrated Regional Master Plan 2020 has taken climatic/environmental projections into account, either for general development directions or for specific projects. Flood and inundation issues receive a lot of attention in the document, which provides quantified data and maps. 'Salinity' and 'saline intrusion' keywords are also frequent, often with quantitative data and maps. Hence, the draft MDIRM (2020) provides more quantitative assessment on climatic/environmental pressures than the MDP 2013, which rather stressed the lack of data.[9] The data used in this report were cited from recent scientific literature, reports of various ministries/organizations (MONRE, MPI, World Bank, IPCC, FAO, etc.), and from some legal national documents (Decision, Decree, etc.).

A high number of quotations were also found for 'climate change', 'sea-level rise', 'subsidence', and 'groundwater'. 'Climate change' is however a tricky keyword in the context of our assessment, since it does not allow to identify immediately which aspect of climate change is actually considered. It is also worth noting that the plans mention sea-level rise without specifying whether it should be understood as *global* or *relative* sea-level rise. Therefore, there is no distinction between the global rise beyond Viet Nam's action and the portion triggered by groundwater extractions which could be mitigated. Nonetheless, we note that the 'groundwater' and 'subsidence' counts are much higher in the draft MDIRM 2020 than in the MDP 2013, which underscores the increased attention for these issues in the more recent plan. Interestingly, 'temperature' or 'heat' are hardly mentioned, while climate models project an important increase of extreme heat conditions in future decades. 'Sand (extractions)' is also barely mentioned, while it is a major issue for saline intrusions and coastal erosion.

8. Backcasting is a planning method that starts with defining a desirable future and then works backward to identify policies and programs that will connect that specified future to the present. The fundamentals of the method were outlined by John (1990).

9. "To date, impacts of upstream development activities on Mekong flows lack substantial quantification." [Royal HaskoningDHV *et al.*, 2013, p. 27].

These findings suggest that the climatic/environmental pressures receiving most attention are the ones having the most impressive and immediate impacts (floods), or those whose increasing impacts are already affecting livelihoods (saline intrusions). Global sea-level rise and subsidence are also well present in both the MDP 2013 and, especially in case of subsidence, draft MDIRM 2020. However, their position is less prominent, particularly in sections on adaptation strategies, probably because they are slow processes happening in the background with gradual impacts rather than through events triggering large immediate damages (*e.g.* floods). We can also assume that the very low occurrence of 'sand mining/extractions' is related to the fact that the link to increasing saline water intrusions is: 1] a recent research finding [Eslami *et al.*, 2019]; and 2] a complex physical process that the population cannot observe by themselves. The impact of sediment starvation on coastal erosion has a long-standing record in the scientific literature (see Focus 2), but in this case causes and damages do not occur at the same places, again making it more difficult to raise political awareness on the issue. The under-consideration for 'heat' can probably be attributed to the absence of obvious major impacts currently. And then there are a number of anthropogenic pressures mentioned but not further developed such as water pollution, biodiversity loss and soil depletion.

Which pressures are tackled by adaptation or mitigation plans?

In terms of quotations for adaptation to climatic/environmental pressures or mitigation of local anthropogenic drivers of change, we found mainly qualitative[10] statements of strategies and solutions. The most frequent keywords are 'dyke' and 'irrigation', *i.e.* projects related to floods or salinity and drought prevention. 'Water supply' is next in line with a high rate of frequency mentioned in the adaptation projects, while other aspects are presented at a smaller frequency. It again confirms the attention given to current common issues of the Delta. Groundwater management and mitigation of land subsidence, sand extraction, and mangrove forests are the least mentioned, and we found no occurrence of temperature and heat-related issues. 'Climate change' has a good number of hits; however, a majority of the quotes is used at general levels of strategy and development approach. Sometimes, climate change, together with sea-level rise, are mentioned as the approach and part of the mainstreaming obligation required by the government, although without much detail on how adaptation should be implemented.

It indicates the need to investigate further available data with more details on the adaptation and mitigation strategies. Often, each legal document before approval is submitted with a report and background data, but that information is often not available publicly. Due to limited time and resources available for this review, this additional information could not be retrieved from other sources. It was therefore not feasible to assess the consistency between current policy and both scientific information available at the time of policy design and/or up-to-date scientific knowledge. In addition, a cursory examination of policy documents in light of current and projected climate or environmental pressures revealed geographic variations in the coverage of policies and variations in the current and projected state of the Delta. Therefore, it was not possible to draw general conclusions and simultaneously comparing all the different po-

10. Some quantitative targets may be found in other documents than those reviewed here. See Focus 5 for instance for targets on rice crops.

licies with the various climate/environmental changes in the Delta.

Therefore, to reduce the scope for a detailed assessment, we selected some of the main environmental stressors and chose several 'hotspots', identified as the provinces which would be first or more severely impacted. Each of these 'hotspots' was then profiled in terms of current pressures and future scientific projections to create test cases describing the current understanding of the nature and extent of future exposure. For each case, relevant policy documents were then examined to describe their consistency with future environmental conditions.

3. Provinces on the front line for relative sea-level rise or saline water intrusions: what are the plans to adapt or reduce their exposure?

Considering that relative sea-level rise is an existential threat for the Delta and that saline water intrusion during the dry season is also a significant source of concern (see Introduction), we have chosen to focus on these two major issues and we have selected 'hotspot' provinces for further investigation, looking at the projects planned at the provincial level. Here the term "project" is used to mention a plan proposal for conducting future project(s) in each hotspot, as identified during the review process. Hereafter, each project is identified by a code, full title or objectives.

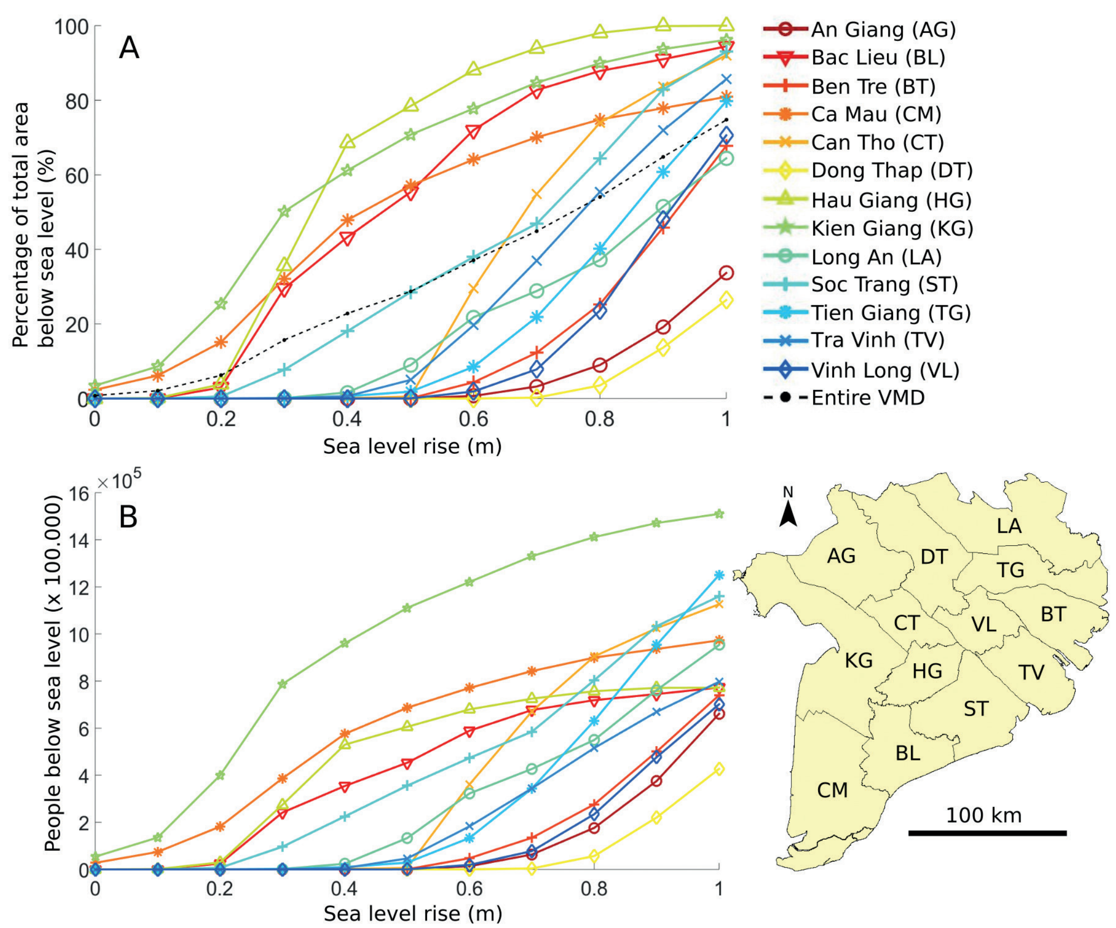
3.1 Selection of hotspots

Projections of future relative sea-level rise from Minderhoud *et al.* (2020) show that Kien Giang, Ca Mau, Hau Giang, and Bac Lieu, being the most low-lying provinces of the Delta, are equally the most at risk of falling below sea level in the coming decades, and hence of permanent submersion. A global sea-level rise of ~30 cm (as will most probably occur in the second half of the century [IPCC, 2021]) would already bring ~50% of Kien Giang and ~30% of the other three provinces below sea level [Minderhoud *et al.*, 2019] [Figure 1.4]. In addition, Ca Mau, Bac Lieu and Hau Giang experience high rates of land subsidence, exacerbating relative sea-level rise and putting large parts of these provinces at risk of submersion as early as 2050 or sooner [Minderhoud *et al.*, 2020].

Projections of saline water intrusions by Eslami *et al.* (2021) under different scenarios of climate change and local anthropogenic drivers show that large salinity increases could occur in the Ca Mau Peninsula and at the river mouth [Figure 1.2]. In a worst-case scenario, some estuarine provinces currently not affected by saline intrusions in normal years, such as Vinh Long or Tien Giang may be strongly impacted in the future.

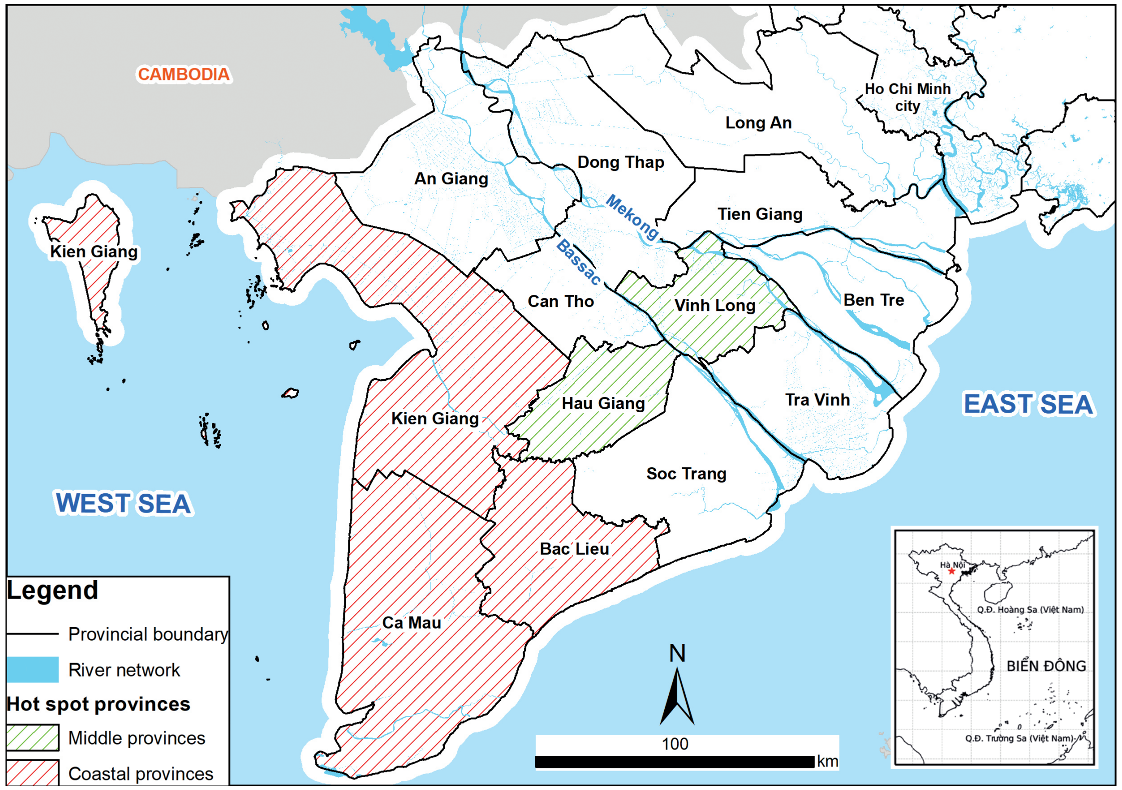
Therefore, we have selected Ca Mau, Hau Giang, Kien Giang, Vinh Long, and Bac Lieu as hotspots for relative sea-level rise and/or increased saline water intrusions [Figure 1.5].

[Figure 1.4]
Exposure of provinces and people to sea-level rise



Province area (a) and estimated number of inhabitants (b) below sea level following sea-level rise up to 1 meter [Minderhoud *et al.*, 2019].

[Figure 1.5]
Map of the selected hotspots



Source: map created by Pham Dang Manh Hong Luan.

3.2 Comparing climatic/ environmental pressures and adaptation plans for hotspot provinces

The documents selected in the first step of the review were scanned again at the provincial level to identify specific projects. To do so, an updated list of keywords was used relating either to the economic sectors or the climate and environment. The results are presented in Table 1.4, and on the radar charts of Figures 1.6 and 1.7.

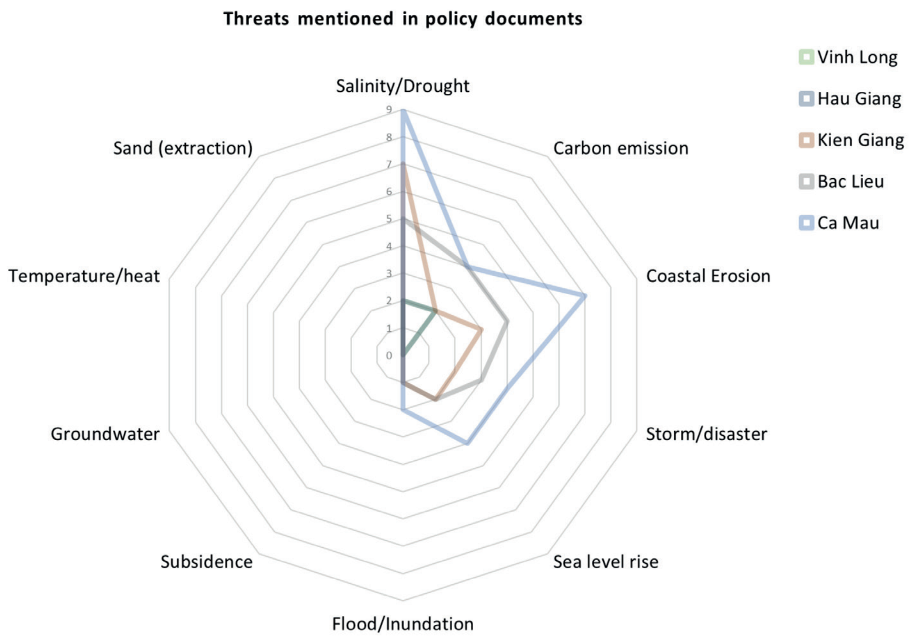
The quick overview provided by the radar charts illustrates that the main focus of the projects are energy and water-related issues, especially in Ca Mau and Kien Giang provinces. The main climatic/environmental threat tackled seems to be salinity intrusions and coastal erosion (in the case of coastal provinces). Rather surprisingly, sea-level rise does not appear so much as a major concern and the issue of groundwater extractions and related subsidence was not found. More details for each province are provided below.

[Table 1.4]
Counts of occurrence of the socio-economic and environmental keywords in each province

		Can Tho	Long An	Tien Giang	Ben Tre	Vinh Long	Tra Vinh	Hau Giang	Soc Trang	Dong Thap	An Giang	Kien Giang	Bac Lieu	Ca Mau	Mekong Delta	Coastal area
Implicitly RELATED Environmental keywords	Coastal Erosion	0	0	3	4	0	4	0	4	0	0	3	4	7	1	2
	Sand (extraction)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sea level rise	0	0	1	2	0	2	0	3	0	0	2	2	4	1	5
	Flood / Inundation	0	0	1	1	0	1	0	1	0	0	1	1	2	4	0
	Storm / Disaster	0	0	3	3	0	3	0	3	0	0	2	3	4	2	3
	Temperature / Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Subsidence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Salinity	0	0	2	2		2	1	3	0	0	3	2	5	6	8
	Carbon emission	2	2	4	4	2	4	2	4	2	2	2	4	4	2	1
	Climate change	3	3	8	7	2	7	3	9	3	3	5	7	9	4	7
Explicitly MENTIONED Environmental keywords	Coastal Erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
	Sand (extraction)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sea level rise	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
	Flood / Inundation	0	0	0	0	0	0	0	0	1	1	0	0	0	3	1
	Storm / Disaster	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2
	Temperature / Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Subsidence	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Salinity / Drought	0	3	3	7	2	6	1	6	1	1	4	3	4	2	1
	Carbon emission	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
	Climate change	0	0	1	3	1	3	0	3	1	1	3	3	3	36	5
Economic sector	Disaster management (Data / Early warning)	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
	Legal framework / Capacity building / Collaboration / Research	0	0	0	0	0	0	0	0	1	1	0	0	0	14	1
	Health care	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Labour / Social protection / Resilience	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1
	Energy	8	5	7	5	2	4	4	6	5	4	9	7	11	3	1
	Planning / Construction Transport / Industry / Tourism	0	0	1	1	0	1	0	1	1	1	1	1	1	11	4
	Forest / mangrove / Biodiversity / conservation	0	0	3	3	0	3	0	4	0	0	2	3	5	3	4
	Dyke / Water resources / Irrigation	0	3	7	7	3	7	3	8	2	2	7	5	7	7	0
	Water supply	1	4	4	5	1	4	4	5	1	3	5	2	4	3	1
	Agriculture / aquaculture	1	2	4	3	1	4	4	5	2	2	5	3	3	10	10
	Approved	1	1	3	4	1	4	1	6	2	2	5	4	7	44	14
	2031–2050	0	0	0	0	0	0	2	0	0	0	3	0	0	1	1
	2025–2030	3	3	6	8	1	7	2	10	2	1	7	9	13	47	17
	2021–2025	9	5	12	12	3	11	6	13	6	6	13	12	19	55	18

Explicitly mentioned' means that, the keyword is found 'written' in either the title or in the objective of the project; 'implicitly related' means that the keyword is implied or implicitly understood by the research team. The first four columns refer to the number of projects scheduled in specific periods (2021–2025; 2025–2030; 2031–2050), and the number of projects already approved.

[Figure 1.6]
Keywords mentioned in policy documents for the five selected provinces



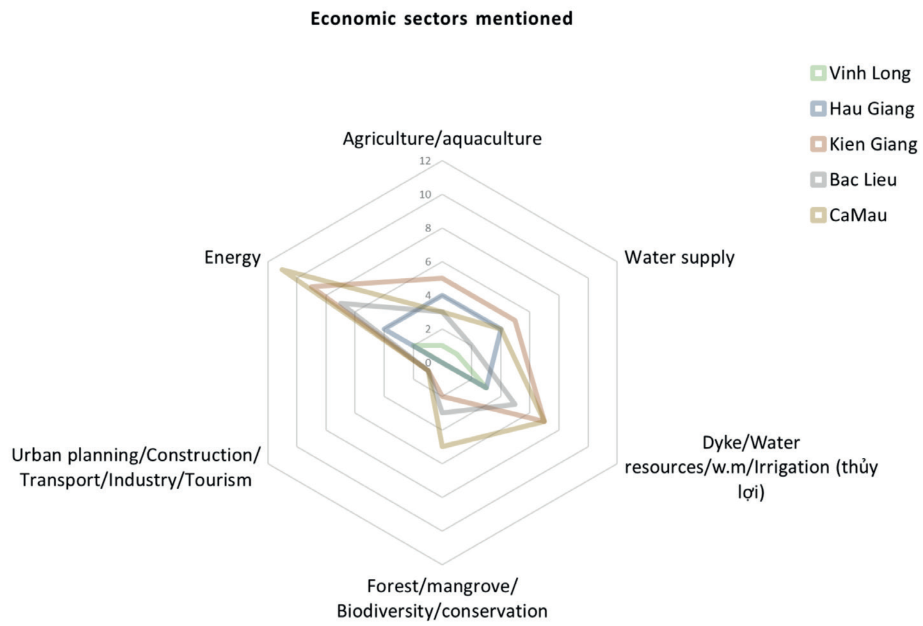
The projects include actions to: i) tackle climatic/environmental pressures: salinity; drought; storm; sea-level rise; subsidence; and temperature; ii) regulate the potential drivers of change: groundwater and sand extraction; iii) and those projects that might contribute to the target of controlling carbon emission. Note that Vinh Long is not exposed to coastal erosion and that the lines for Vinh Long and Hau Giang are superimposed.

Hotspot 1: Ca Mau (coastal areas)

With three borders surrounded by the ocean, the Ca Mau province faces many environmental problems [People's Committee of Ca Mau Province, 2019]: lack of fresh water (water used for domestic and production purposes mainly comes from groundwater and rainwater); coastal erosion and riverbank's landslide becoming more and more severe, triggered by mangrove deforestation and sediment starvation [The Standing Office of Central Committee, 2019]; saline intrusion in groundwater system (due to overexploitation of groundwater) [Huynh, 2019]; and risk of inundation due to weak and insufficient irrigation and drainage infrastructure, especially in some low terrain areas (such as Ngoc Hien and Nam Can districts).

Beyond these immediate issues, the province is threatened in the medium to long term by sea-level rise and land subsidence. With an average elevation of ~0.6 m – compared to an average of ~0.8 m for the entire Delta – submersion is likely to occur. The causes of land subsidence in this province include urbanization, industrialization, and groundwater extraction for aquaculture [Giusto *et al.*, 2021]. In practical terms, it means that 43% of Ca Mau could be at risk of submersion by 2030, and 75% by 2050. Meanwhile, local farmers are largely unaware of the risk and do not fully comprehend this process by continuing to extract groundwater [Giusto *et al.*, 2021]. This sets out an alarm to authorities and policymakers in dealing with these challenges, while capitalizing on the strength of the province such as ecological shrimp farming.

[Figure 1.7]
Economic sectors mentioned in policy documents for the five selected provinces



The review of the documents shows that 19 projects will be running in Ca Mau over 2021–2025. These projects mainly address climate change. However, the dominant keyword appearance of 'climate change' is found in some energy projects and some local projects tackling greenhouse gases emissions mitigation and not adaptation to climate change impacts. Among them, many energy projects have been proposed (by the draft MDIRM 2020) towards establishing some new renewable plants (both solar and wind) to reach the net-zero greenhouse gas (GHG) emission target. Only two projects directly tackle issues such as saline intrusion and climate change impacts. 'Sea-level rise' is identified as one of the main problems to solve and but is implicitly mentioned in only three local projects:

– Er02: Protecting the coastal areas of Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre, Tien Giang, and Kien Giang, which was proposed in Decision 287/2022/QĐ-TTg;[11]
– WM26 and WM27: The investment project to build the West Sea and East Sea dyke lines respectively, which were proposed in Decision 245/2014/QĐ-TTg.[12]

11. 287/2022/QĐ-TTg: Approval of the regional plan for Mekong Delta for the period 2021.

12. 245/2014/QĐ-TTg: Approving the Master Plan on Socio-Economic Development of the Mekong Delta Key Economic region through 2020, vision until 2030.

As is usually the case in the reviewed documents, the projects do not specify if 'sea-level rise' refers to global or relative sea-level. The fact that all three projects aim at protecting the coastline with grey infrastructures, such as dykes, suggests that subsidence is not taken into account and that the projects tackle only global sea-level rise. No project tackling the issue of groundwater extractions and induced subsidence was identified.

The keyword 'saline intrusion' was mentioned explicitly in four projects and several times as the implicit rationale of the reviewed projects. Likewise, 'climate change impact' was both explicitly or implicitly acknowledged as the main problem to either adapt or mitigate in most of the reviewed plans. However, the scale adequacy between threats and plans is unclear. As far as the planned projects have pointed out which environmental pressures are focused on in the projects, it was generally covering a region without pointing out specific districts or scales.

Hotspot 2: Kien Giang (coastal areas)

As a low-lying coastal province, Kien Giang province also faces the existential threat of coastal erosion due to uncontrolled shoreline mangrove harvesting activities, dyke breakage (also due to the disappearance of protective forest) [Trang, 2020]. Changes in sedimentation, climate change, and sea-level rise were concluded to cause negative impacts on the coast [Phong *et al.*, 2017]. This province is also currently facing a shortage of freshwater needed for agriculture and daily life [Vietnam News, 2021].

Twenty-one projects are scheduled for the period up to 2050, most of which are proposed within projects in common with the Ca Mau province. The differences are found in the type of actions (the choice of directions that local authorities have on which action(s) to take) undertaken by local authorities of the two provinces to tackle their environmental problems. For example, in dealing with saline intrusion, while Ca Mau has made policies toward strengthening capacity and shifting cropping models (which are more likely seen as 'soft measures'), Kien Giang has been adhering to the 'hard measures', such as the closure of sluice gates, building dykes against salinity, enhancing monitoring system, freshwater retention, etc. It is worth noting that despite the major risk of relative sea-level rise in the medium term, the threat was hardly explicitly identified as a problem to deal with in the reviewed plans. The issue was implicitly acknowledged only twice in two projects. This suggests that there has been no serious action taken neither by the local authorities nor by the national government toward tackling this environmental pressure in Kien Giang.

Hotspot 3: Hau Giang (middle Delta)

This province was split from Can Tho province in 2004. Currently, it is suffering from poor surface water quality[13] [Hau Giang Department, 2021] and lack of fresh water supply, saline intrusions, and drought [Thu, 2022]. The province is one of the rice centres of the Southwest region with also strengths in fruit trees, aquatic products, shrimp, and livestock. Although it is located in the middle of the Delta, it has actually the lowest mean elevation of all provinces in the Mekong Delta, less than 0.4 m above mean sea level [Minderhoud *et al.*, 2019, supplementary information], making the province very vulnerable to relative sea-level rise. Hau Giang province has a great potential for sand exploitation (the purpose of sand mining is for filling up rivers or reinforcing the riverbank) and faces the problem of increased saline water intrusions driven by channel deepening of the Hau River [Eslami *et al.*, 2019].

13. The result water quality indicator (VN_WQI) round 03rd in 2021 (from 9–11/6/2021) has shown that most of the monitoring station has surface water's quality categorised as 'orange', which means that the water quality is poor, only suitable for navigation and other equivalent purposes, not for aquaculture or domestic-use.

Two projects (proposed by the draft MDIRM 2020) d ealing with salinity were identified, and found to be closely linked to improving agricultural activities and hence related to freshwater supply. However, while no projects were found to further develop sand mining, no project could be found either to reduce sand mining and hence avoid further increasing salinity issues.

Hotspot 4: Vinh Long (middle Delta)

Vinh Long is a strategic location along the economic corridor between Ho Chi Minh City and the Mekong Delta. It is well developed in terms of infrastructure. Sluice gate systems have been installed to expand the freshwater farming areas mainly for rice cultivation. Currently, Vinh Long is considered as one of the most seriously flooded cities, an issue attributed to climate change, river water rise, heavy rainfall, and less efficient drainage system resulting from the deposits in canals [World Bank, 2019]. However, tidal amplification driven by riverbed level erosion [Eslami *et al.*, 2019] also plays an important role in increasing city flooding.

State-of-the art projections of future saline water intrusion show that in a worst-case scenario, assuming high rates of sand mining in the river channels, the province could be strongly affected by 2050 [Figure 1.2]. However, according to the reviewed documents there are not many projects or plans in line with these projections. Only two proposals of projects embedded in the draft MDIRM 2020 mention 'salinity' (WM14: Intermittent fresh-brackish water zone project; and WM20: South Mang Thit water management project). No official plans or projects have been found in the Vietnamese legal documents reviewed to anticipate such evolution or to avoid it through mitigation measures (*i.e.* limiting sand mining). On the Vinh Long province's official website[14], several additional action plans have been found showing that the province has endorsed a decision in 2021,[15] to prevent drought and saltwater intrusion and fight their consequence on production activities and the people's livelihoods. This decision was motivated by the strong salinity intrusions that have occurred during the severe drought of 2020–2021. The planned actions include both non-construction and construction measures, in addition to capacity building, including training plans on drought and saltwater intrusion prevention. Therefore, it appears that in this province actions against salinity intrusions are taken in response to problems experienced during extreme events, although it does not pro-actively consider future projections. The question is whether these actions to fight salinity intrusion are in line with

14. https://vinhlong.gov.vn/

15. Based on Directive No. 36/CT-TTg, dated September 11, 2020, by the Prime Minister. This decision pertains to: i) proactively implementing measures to cope with the risks of drought, water shortage, and saltwater intrusion in the dry season of 2020–2021; and ii) the implementation of Directive No. 29-CT/TU, dated June 29, 2020, of the Standing Committee of the Provincial Party Committee on the implementation of Directive No. 42-CT/TW, dated March 24, 2020, of the Secretariat on "Strengthening the leadership of the Party for the work of preventing, responding to and overcoming the consequences of natural disasters".

the fundamental shift of Resolution 120. It seems the provinces and farmers still prefer freshwater cultivation rather than agricultural transformation to adapt to the saline landscape. They might have good reasons for this but they might also be resistant to change. Action to mitigate saline water intrusion through limiting sand mining was not identified, which is not fully surprising given the fact that the link between saline intrusions and sand mining is a relatively recent research finding [Vinh Long Department of Industry and Trade, 2021].

Hotspot 5: Bac Lieu (coastal areas)

The terrain of Bac Lieu province is complicated in terms of developing infrastructure construction but advantageous in terms of water drainage. Most of the province area is connected to the sea, and therefore faces important salinity problems, in addition to poor quality of freshwater [Nguyen, 2020]. During dry season, salinity increase guides agri-aquacultural practices, especially in some shrimp ponds and rivers, especially in locations close to estuaries, where saline intrusions are stronger. The saltwater-freshwater balance seems to improve for more freshwater due to governmental interventions to enhance the quality of agri-aquacultural activities (embedded in the planning orientation toward improving production activities of the province).

The People's Committee of Bac Lieu Province (2017) mentions the following issues: coastal erosion, which is attributed to the impact of coastal currents; higher tides; waves and winds; and lack of sediments. Interestingly, no reason for higher tides is provided in the document: it could indeed be caused by a change in the tidal regime because of global sea-level rise, but it could also be driven by subsidence, deeper channels or impacts of dykes on the tidal flow. Higher tides are not considered so much as an issue itself, since it facilitates leading saltwater into shrimp areas and salt-making areas. The issue of mangrove forest deforestation [Hong *et al.*, 2019] is also not listed in the drivers of coastal erosion, although some projects of mangrove reforestation can be found on the website of the province.[16]

From 2021 to 2030, 16 projects are supposed to be conducted in Bac Lieu, with the majority of attention toward capitalizing on the renewable energy potential (*i.e.* wind and solar), followed by responding to the impact of climate change (both adaptation and mitigation). As for other low-lying coastal provinces, Bac Lieu is under a great threat of relative sea-level rise and increasing salinity during dry season. Nevertheless, only three plans were found to indirectly tackle 'salinity':

- WM15: Saline-brackish coastal zone projects;
- AG11: Supporting changing crop's structure to adapt to climate change in areas that are affected by drought and saline intrusion;
- CC17: The project develops solutions to cope with drought, water shortage, and saline intrusion due to the impact of climate change in high-risk regions and areas.

No project is found to tackle relative sea-level rise. More importantly, even on the official government website of Bac Lieu, very little information is posted on salinity and sea-level rise. The most relevant issue was posted in 2022 about the scenarios of preventing and controlling drought and saline intrusion status in the dry season in 2021–2022 (issued together with Decision 31/QĐ-UBND 2022).

16. https://baclieu.gov.vn/

4. Conclusions: major environmental constraints are still insufficiently considered

The Mekong Delta is at a crossroad of directions for development while facing severe and growing climatic and environmental changes. In this context, it is crucial to ensure that policies include appropriate adaptation strategies, while tackling the root causes of changes where possible, and based on up-to-date scientific research, data, and insights. This systematic review is a first step to draw an analysis of the consistency between national or regional policies and the scientific knowledge regarding both current and future climatic/environmental pressures threatening livelihoods and sustainable development in the VMD. By analyzing 27 official and unofficial documents, we observe that the development narrative for the Mekong Delta since 2012 has evolved from mainstreaming climate change towards sustainable development to nature-based development focusing on the agri-valued chains, as stated in the Resolution 120 (2017). It has then moved towards integrated and multi-sectoral planning, as guided by Law of Planning (2017), and with stronger commitment towards human-centred development, balancing economic, society, and environment development with an emphasis on green growth (since 2020).

Due to time constraints and the lack of access to background reports of the official plans, strategies, and other types, in-depth analysis of how scientific knowledge is being used in the current plans and policies was limited. Document scanning for specific keywords shows that climate change is well present, however, since climate change has many different physical consequences, it is not always straightforward to assess which aspect is being tackled. Keywords counting illustrates that most attention is put on issues related to water salinization, floods, and inundations. By contrast, the existential threat of relative sea-level rise, putting large parts of the Delta at risk of drowning within decades, is much less addressed and does not appear to receive as much attention as it should. This finding is confirmed by a more detailed projects review for the low-lying coastal provinces. Issues that may arise from future increase in extreme heat conditions are absent. The issue of sediment starvation, especially sand mining, is nearly absent from the documents despite its strong impact on saline water intrusions, which itself is a major topic in the reviewed documents.

These results suggest that climatic/environmental pressures drawing the most attention are the ones already having obvious and large impacts on people and livelihoods in the Delta, whereas relatively slowly increasing risks are much less considered. It could also suggest that those pressures that do not touch upon the vested interests of powerful groups are the ones which receive less attention. Whether at the Delta level or at the provincial level it also appears that adaptation plans tackle the impacts of climatic/environmental changes, but not their root causes when they are actually local and anthropogenic. In particular, the steps required to improving groundwater management and decreasing extractions is barely addressed in the reviewed documents. Yet, many different policies have been enacted over the past two decades to regulate groundwater extractions and avoid land subsidence (see Focus 4). Thus, the issue is far from being ignored, but seems to be considered independently from adaptation or development plans for the Delta. Therein lies the problem, as failing to address the root causes will put the current agro-economical system and all planned future investments at a much higher risk of drowning than is currently foreseen in the adaptation and development plans.

This finding is confirmed in the approved MDIRM, "Mekong Delta: New thinking – New vision – New opportunities – New values", which is based on the draft MDIRM 2020 and was launched in June 2022 by the Vietnamese Prime Minister. Indeed, of the 10 core tasks set out in this new plan only one tackles the protection of environment and fighting the impacts of climate change. Other tasks focus on infrastructure planning, improving supply chains and transports, improving investments and business environment, promoting social welfare and justice, among others. As already highlighted by Kondolf *et al.* (2022), the plan does mention the issue of rapid subsidence and risks of submergence, but it lacks the sense of urgency that an existential threat may actually make some of these objectives utterly unachievable and amplify all other problems in the Delta. This implies that the core task of protecting the Delta's environmental integrity should be given priority over other developments in the Delta, so the Delta may persist and the immediate existential threat can be averted or at least postponed. Even so, the necessary economic 'sacrifices' required to reach a more sustainable Delta (*e.g.* prioritizing Delta elevation by strongly mitigating subsidence drivers and sediment strategies) are not being emphasized as key prerequisites in the future development steps outlined in the approved MDIRM 2022.

As a result, likewise under the new master plan, the risk remains for a continued push for development, prioritizing short- and medium-term economic and livelihoods gains with (too little) attention to mitigation and adaptation of the pressing environmental issues, with the threat that large parts of the Delta will fall below sea level in the coming decades. As the massive extent of the area is too large to protect over such a short period of time, draining excess (salt) surface water will become very challenging and unprotected parts would increasingly face permanent inundation, resulting in long-term economic loss and increased out-migration.

Hence, in the approved MDIRM, the current expectations of future economic development of the Delta and its environmental state and condition (potential imminent drowning) remain in conflict. We consider that the master plan places too much trust in technical adaptation solutions, inadequate consideration to mitigation of damaging local anthropogenic drivers, and too much of the budget for transport. Although an integrated master plan, its project-wise, sector-wise and often province-wise implementation plans seem biased towards opening up and exploiting the Delta's resources. It thereby remains to be seen whether such a piecemeal implementation happens in a coordinated way that will maintain the integrated and coherent nature of the MDIRM 2022. The environmental issues under business-as-usual development may well be overly large-scale to just simply adapt or mitigate through (infrastructural) investments. Indeed, by tackling root causes and mitigation of drivers, the road towards a more sustainable Mekong Delta will likely require considerably higher sacrifices in economic development and short-term profit than currently foreseen in the development plans.

5. Recommendations

5.1 Ensure interface between scientific data and policy makers, including legal procedures

– Reduce the gap between the timing of scientific research and public policies. Such a gap is inevitable, and also to some extent necessary to avoid building policies on not yet-settled science or poor understanding of the processes. However, as climatic and environmental changes are increasing rapidly, this gap should be reduced as much as possible. It is thus essential to understand how scientific knowledge finds its way towards policy and how to accelerate the process, to ensure that policies are informed by up-to-date research.

– Ensure effective coordination mechanisms between scientists and policymakers as well as within each of those groups. So far, the Regional Coordination Council, which should coordinate the Ministries and provinces of the Mekong Delta, is not effective and moreover, it does not have any fiscal responsibility to push for coordinated implementation of the MDIRM. The Council plays a critical role in translating the integrated nature of the MDIRM into coordinated and balanced implementation that goes beyond constructing grey infrastructure.

– Legal documents on adaptation should provide explicitly their scientific grounding. Indeed, the separation between on the one hand official documents for adaptation and development strategies and on the other hand the underlying scientific knowledge considered to build these strategies makes a consistency assessment rather difficult. For further research, a suggestion is to retrieve information on the provinces' official websites, which usually explicitly mention all environmental issues along with solutions and/or action plans. However, such information is usually posted without scientific references and should be compared to the findings of peer-reviewed scientific publications.

5.2 Strengthen adaptation measures

– Future adaptation plans need to better take into account the existential threat of relative sea-level rise. Otherwise, these plans may become rapidly obsolete for not having anticipated the extent and magnitude of future changes.

– More attention is required on addressing the root causes of some increasing pressures, rather than simply adaptation, as to prevent is better than to heal. Many of the plan focus only on adaptation, even though tackling the human-induced drivers of environmental issues can be far more effective and reduce future adaptation needs, making it cheaper in the long run. Some mitigation can be effectively done within Viet Nam own jurisdiction as not all pressures are external to Viet Nam (such as global climate change), calling only for adaptation at the Viet Nam's scale. Apart from some cross-boundary impacts, drivers such as groundwater extraction and sand mining can indeed be effectively mitigated at the local/regional scale, empowering Viet Nam to take matters into its hands.

– The development of a roadmap would be a valuable instrument to assess and foresee cross-disciplinary issues on the road ahead.

Indeed, effective implementation of mitigation and adaptation strategies in a Delta as large as the Mekong Delta, requires inclusive and clear step-wise implementation across numerous disciplines and areas of governance. None of the reviewed plans, even if they recognize the pending pressures [*e.g.*, the MDRP 2020], provides a roadmap to combat the threats of drowning of the Delta.

5.3 Scale up communication and information practices

– When talking about climate change, adaptation plans should explicitly explain which aspects are considered. 'Climate change' is often cited in the reviewed documents, but the lack of explanation of which aspect of climate change is actually addressed makes it difficult to assess which dimensions are actually considered and to ensure that there is no confusion between climate change impacts and other anthropogenic pressures. Hence, we recommend improving explicit acknowledgment and quantification of the pressures addressed in adaptation plans.

– Increase public awareness on medium to long-term threats, and their root causes. Pressures receiving the most attention are the ones with large and immediate visible impact (mainly floods and salinity intrusion). Improved public awareness on medium to long-term threats, and their root causes to allow long-term planning which should be undertaken from now on.

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Part 2

Adaptation options to climatic and environmental changes in the Delta

Abstract

The Vietnamese Mekong Delta (VMD) faces increasing climatic and environmental changes, driven by global climate change and/or human activities in the Delta or upstream in the Mekong River Basin, as summarized in Part 1 of this report. Part 1 has shown that current development or adaptation plans for the Delta seem to consider these pressures insufficiently and – most of all – to mainly tackle current observed impacts without taking the root causes of the phenomena into account. While urgent actions are required to avoid or delay stronger impacts in future decades, Part 2 uses seven Focuses to investigate some opportunities and some of the difficulties hampering the effective implementation of adaptation or mitigation strategies, and provides some recommendations.

Sediment starvation caused by sediment trapping in upstream dams and sand mining has several negative impacts on the VMD, notably increasing saline water intrusions during the dry season and coastal erosion. Focus 1 highlights the role of sand in river systems and people's livelihoods, investigates the different impacts of sand extraction, and explores solutions to avoid or mitigate associated impacts while meeting a growing demand. Focus 2 llustrates the parallel need to protect or restore healthy mangrove belts to preserve the shoreline, and presents some possible strategies to do so.

While reducing sand mining appears to be the most efficient mitigation action to avoid increasing saline water intrusions, strategies to increase fluvial discharge during the dry season could also be considered. Focus 3 investigates whether retention schemes within the Delta or in the Tonle Sap Lake in neighboring Cambodia could be effective strategies. The results of this preliminary study suggest that slowing down the lake's drainage could be effective with reasonable investments. However, more in-depth impact assessments on the large-scale effect of such changes are required.

As one of the most existential threats for the Delta is groundwater extraction-induced subsidence – putting large parts of the Delta at risk of falling below sea level within this century – Focus 4 provides an overview of the current situation regarding practices and policies for groundwater extraction, and proposes some policy recommendations to improve further mitigation efforts.

In addition to the issue of saline water intrusions and risks of submersion, the agricultural sector in the Delta – especially rice cultivation – also faces warmer temperatures and changes in rainfall pattern driven by climate change. Focus 5 presents current trends and policies for rice cultivation in the Delta, and further investigates potential adaptation and mitigation strategies through changes in agricultural practices.

Finally, Focus 6 presents some results from a field study carried out to investigate the social and economic impacts of a sluice gate built to fight salinization-drought events, and Focus 7 documents the potential relationship between environmental changes and migration decisions from the Delta to Ho Chi Minh City. It highlights the fact that migration decisions are multifactorial, and take place within economic and social dynamics that feed the people's aspirations to upward social mobility, leading them towards urban areas, and away from agriculture.

Tóm tắt

Đồng bằng sông Cửu Long của Việt Nam (VMD) đang phải đối mặt với những thay đổi ngày càng tăng về khí hậu và môi trường, do biến đổi khí hậu và / hoặc các hoạt động của con người ở đồng bằng hoặc ở thượng nguồn lưu vực sông Cửu Long, như đã được tóm tắt trong Phần 1 của báo cáo này. Phần 1 đã chỉ ra rằng các kế hoạch phát triển hoặc thích ứng hiện tại cho Đồng bằng dường như chưa xem xét đầy đủ những vấn đề này và – trên hết – chủ yếu là giải quyết các tác động hiện tại mà không tính đến nguyên nhân gốc rễ của các hiện tượng. Trong bối cảnh các hành động ứng phó cần được cấp thiết triển khai để phòng tránh hoặc trì hoãn những tác động mạnh hơn trong những thập kỷ tới, Phần 2 sử dụng bảy Trọng tâm để nghiên cứu một số cơ hội và một số khó khăn cản trở việc thực hiện hiệu quả các chiến lược thích ứng hoặc giảm thiểu, đồng thời đưa ra một số khuyến nghị.

Tình trạng đói phù sa do bẫy phù sa ở các đập thượng nguồn và khai thác cát có một số tác động tiêu cực đến Đồng bằng sông Cửu Long, đặc biệt là làm gia tăng sự xâm nhập mặn trong mùa khô và xói lở bờ biển. Trọng tâm 1 nêu bật vai trò của cát trong hệ thống sông và đời sống của người dân, điều tra các tác động khác nhau của việc khai thác cát và tìm hiểu các giải pháp để phòng tránh hoặc giảm thiểu các tác động liên quan trong khi đáp ứng nhu cầu ngày càng tăng. Trọng tâm 2 minh họa sự cần thiết song song của việc bảo vệ hoặc khôi phục các vành đai rừng ngập mặn để bảo tồn đường bờ biển, và trình bày một số chiến lược khả thi để làm như vậy.

Trong khi việc giảm khai thác cát dường như là hành động giảm thiểu hiệu quả nhất để tránh sự gia tăng của xâm nhập mặn, các chiến lược tăng cường xả phù sa trong mùa khô cũng có thể được xem xét. Trọng tâm 3 xem xét liệu các kế hoạch giữ nước trong vùng Đồng bằng sông Cửu Long hoặc Biển Hồ ở nước láng giềng Campuchia có thể là chiến lược hiệu quả hay không. Kết quả của nghiên cứu sơ bộ này cho thấy rằng việc làm chậm quá

trình thoát nước của hồ có thể có hiệu quả với các khoản đầu tư hợp lý. Tuy nhiên, cần có những đánh giá tác động sâu hơn về tác động quy mô lớn của những thay đổi đó.

Một trong những mối đe dọa hiện hữu nhất đối với Đồng bằng sông Cửu Long là sụt lún do khai thác nước ngầm – khiến nhiều phần của Đồng bằng có nguy cơ xuống dưới mực nước biển trong thế kỷ này – Trọng tâm 4 cung cấp tổng quan về tình hình hiện tại liên quan đến thực tiễn và chính sách khai thác nước ngầm, và đề xuất một số khuyến nghị chính sách để cải thiện hơn nữa các nỗ lực giảm nhẹ.

Ngoài vấn đề xâm nhập mặn và nguy cơ ngập lụt, ngành nông nghiệp ở Đồng bằng sông Cửu Long – đặc biệt là trồng lúa – còn phải đối mặt với nhiệt độ nóng hơn và những thay đổi về lượng mưa do biến đổi khí hậu gây ra. Trọng tâm 5 trình bày các xu hướng và chính sách hiện tại đối với canh tác lúa ở Đồng bằng, đồng thời nghiên cứu sâu hơn các chiến lược thích ứng và giảm thiểu tiềm năng thông qua những thay đổi trong thực hành nông nghiệp.

Cuối cùng, Trọng tâm 6 trình bày một số kết quả từ một nghiên cứu thực địa được thực hiện để điều tra các tác động xã hội và kinh tế của một cống được xây dựng để chống lại các hiện tượng hạn-mặn và Trọng tâm 7 trình bày mối quan hệ tiềm tàng giữa những thay đổi môi trường và các quyết định di cư từ Đồng bằng sông Cửu Long đến Thành phố Hồ Chí Minh. Kết quả làm nổi bật thực tế rằng các quyết định di cư dựa trên đa yếu tố và diễn ra khi các động lực kinh tế và xã hội nuôi dưỡng nguyện vọng của người dân về sự dịch chuyển, dẫn họ đến các khu vực thành thị và tránh xa nông nghiệp.

Résumé

Comme l’a rappelé la Partie 1, le delta du Mékong vietnamien (DMV) est confronté à des changements climatiques et environnementaux croissants, provoqués tant par le changement climatique global que par les activités humaines dans le delta ou en amont dans le bassin du Mékong. La Partie 1 a montré que les plans actuels de développement ou d’adaptation du delta semblent ne pas tenir suffisamment compte de ces pressions et – surtout – s’attaquent principalement aux impacts observés actuellement sans toujours tenir compte des causes profondes des phénomènes. Alors que des actions urgentes sont nécessaires pour éviter ou retarder des impacts plus importants dans les décennies à venir, la Partie 2 propose sept Focus pour étudier certaines opportunités et difficultés entravant la mise en œuvre efficace de stratégies d’adaptation ou d’atténuation, et fournir quelques recommandations.

L’appauvrissement en sédiments causé par le piégeage des sédiments dans les barrages en amont et l’extraction de sable a plusieurs impacts négatifs sur le DMV, notamment l’augmentation des intrusions salines en saison sèche et l’érosion côtière. Le Focus 1 souligne le rôle du sable dans les systèmes fluviaux et les moyens de subsistance des populations, étudie les différents impacts de l’extraction du sable et explore des solutions pour éviter ou atténuer les impacts associés tout en répondant à une demande croissante. Le Focus 2 illustre la nécessité parallèle de protéger ou de restaurer des ceintures de mangroves saines pour préserver le littoral, et présente quelques stratégies possibles pour y parvenir.

Si la réduction des extractions de sable semble être l’action d’atténuation la plus efficace pour éviter l’augmentation des intrusions salines, des stratégies visant à augmenter le débit fluvial pendant la saison sèche pourraient également être envisagées. Le Focus 3 étudie si des programmes de rétention dans le delta ou dans le lac Tonle Sap au Cambodge voisin pourraient constituer des stratégies efficaces. Les résultats de cette étude préliminaire suggèrent que le ralentissement du drainage du lac pourrait être efficace avec des investissements raisonnables. Cependant, des évaluations d’impact plus approfondies sur l’effet à grande échelle de tels changements sont nécessaires.

L’une des menaces les plus existentielles pour le delta est la subsidence induite par l’extraction d’eau souterraine – mettant de grandes parties du delta en danger de se retrouver sous le niveau de la mer au cours de ce siècle. Aussi, le Focus 4 fournit un tour d’horizon de la situation actuelle concernant les pratiques et les politiques d’extraction d’eau souterraine, et propose quelques recommandations politiques pour améliorer les efforts d’atténuation.

Outre la question des intrusions salines et des risques de submersion, le secteur agricole du delta – en particulier la riziculture – est également confronté à des températures plus élevées et à des modifications de la pluviométrie en raison du changement climatique. Le Focus 5 présente les tendances et les politiques actuelles en matière de riziculture dans le delta, et étudie les potentielles stratégies d’adaptation et d’atténuation par le biais de changements dans les pratiques agricoles.

Enfin, le Focus 6 présente certains résultats d’une étude de terrain réalisée pour étudier les impacts sociaux et économiques d’une écluse construite pour lutter contre les épisodes de salinisation-sécheresse, et le Focus 7 documente la relation potentielle entre les changements environnementaux et les décisions de migration du delta vers Ho Chi Minh Ville. Ce dernier Focus souligne le fait que les décisions de migration sont multifactorielles et s’inscrivent dans des dynamiques économiques et sociales qui alimentent les aspirations des populations à l’ascension sociale, les conduisant vers les zones urbaines et les éloignant de l’agriculture.

Focus 1

Sand mining and climate adaptation

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Abstract

Sand mining is the main driver for riverbed incision and coastal erosion in the Mekong Delta, aggravating the extent and duration of saltwater intrusions, which negatively impact both agricultural production and freshwater supply. Sand mining also poses a serious threat to aquatic biodiversity. Therefore, resolving challenges currently posed by sand mining is critical to enhancing sustainable development, ecosystem health and climate change adaptation. River sand is a valuable resource that supports many dimensions of economic development. Demand for aggregates in Southern Viet Nam is expected to significantly increase over the next 30 years, to support economic growth and meet growing demands for infrastructure and urbanisation. However, supplies from the Mekong Delta's channels are diminishing dramatically due to the trapping effect of hydropower reservoirs, and unsustainable sand mining in upstream countries. Viet Nam can learn and adapt lessons from countries that have made a shift away from the exploitation of river sand, notably by relying more on alternative sourcing and alternative materials, while improving the sustainability performance of crushed sand. In this Focus, we highlight the role of sand in river systems and its benefits to livelihoods and ecosystem health, as well as the impacts of sand extraction on communities, biodiversity and climate resilience. We then explore solutions to improve monitoring of in-channel sand resources; strategies to avoid and mitigate related water and climate risks; and options to meet the growing demand for construction and land filling which are both economically viable and more sustainable for people and nature.

Tóm tắt

Khai thác cát là nguyên nhân chính gây ra tình trạng rạch lòng sông và xói mòn bờ biển ở đồng bằng sông Cửu Long, làm trầm trọng thêm mức độ và thời gian kéo dài của xâm nhập mặn, tác động tiêu cực đến cả sản xuất nông nghiệp và nguồn cung cấp nước ngọt. Khai thác cát cũng đe dọa nghiêm trọng đến đa dạng sinh học môi trường nước. Do đó, giải quyết những thách thức hiện nay xung quanh khai thác cát là rất quan trọng để tăng cường phát triển bền vững, sức khỏe hệ sinh thái và thích ứng với biến đổi khí hậu. Cát sông là nguồn tài nguyên quý giá hỗ trợ nhiều mặt cho phát triển kinh tế. Nhu cầu cát tổng hợp ở miền Nam Việt Nam dự kiến sẽ tăng đáng kể trong 30 năm tới nhằm hỗ trợ tăng trưởng kinh tế và đáp ứng nhu cầu ngày càng tăng về cơ sở hạ tầng và đô thị hóa. Tuy nhiên, nguồn cung từ các kênh của đồng bằng sông Cửu Long đang giảm đáng kể do hiện tượng bẫy cát của các hồ thủy điện và việc khai thác cát không bền vững ở các nước thượng nguồn. Việt Nam có thể học hỏi và điều chỉnh các bài học từ các quốc gia đã chuyển hướng từ khai thác cát sông, đặc biệt là bằng cách dựa nhiều hơn vào nguồn cung ứng thay thế và các vật liệu thay thế, đồng thời cải thiện tính bền vững của cát nghiền. Với Trọng tâm này, chúng tôi nhấn mạnh vai trò của cát trong các hệ thống sông và lợi ích của nó đối với sinh kế và sức khỏe hệ sinh thái cũng như tác động của việc khai thác cát đối với cộng đồng, đa dạng sinh học và khả năng chống chịu với khí hậu. Sau đó, chúng tôi tìm hiểu các giải pháp để cải thiện việc giám sát tài nguyên cát trong kênh; các chiến lược để phòng tránh và giảm thiểu rủi ro liên quan đến nước và khí hậu; các phương án để đáp ứng nhu cầu ngày càng tăng về xây dựng và lấp đất vừa hiệu quả về kinh tế, vừa bền vững hơn cho con người và thiên nhiên.

Résumé

L'extraction de sable est le principal facteur d'incision du lit des rivières et d'érosion côtière dans le delta du Mékong, aggravant l'étendue et la durée des intrusions salines, avec des impacts négatifs sur la production agricole et l'approvisionnement en eau douce. L'extraction de sable constitue également une menace sérieuse pour la biodiversité aquatique. Il est donc essentiel de résoudre les problèmes actuels liés à l'extraction du sable pour améliorer le développement durable, la santé des écosystèmes et l'adaptation au changement climatique. Le sable de rivière est une ressource précieuse qui intervient dans de nombreuses dimensions du développement économique. La demande de granulats dans le sud du Viet Nam devrait augmenter considérablement au cours des 30 prochaines années pour soutenir la croissance économique et répondre à la demande croissante pour les infrastructures et l'urbanisation. Cependant, l'approvisionnement issu des bras du fleuve dans le delta du Mékong diminue considérablement en raison de l'effet de piégeage des réservoirs hydroélectriques et de de l'extraction de sable non durable dans les pays en amont. Le Viet Nam peut tirer des leçons – en les adaptant – des pays qui se sont détournés de l'exploitation du sable de rivière, notamment en s'appuyant davantage sur des sources et des matériaux alternatifs, tout en améliorant les performances de durabilité du sable concassé. Dans ce Focus, nous soulignons le rôle du sable dans les systèmes fluviaux et la santé des écosystèmes, ainsi que les bénéfices qu'il apporte aux populations pour leurs moyens de subsistance. Nous exposons également les impacts de l'extraction du sable sur les communautés, la biodiversité et la résilience climatique. Nous explorons ensuite des solutions pour améliorer la surveillance des ressources en sable dans les bras du fleuve ; des stratégies pour éviter et atténuer les risques liés à l'eau et au climat ; et des options pour répondre à la demande croissante pour la construction et le remblayage qui soient à la fois économiquement viables et plus durables pour les populations et la nature.

1. Introduction

The GEMMES COP26 report [Espagne *et al.*, 2021] identified sand mining as a key driver of rapidly increasing salt intrusions into the Mekong River Delta channels and agricultural land – making it a growing concern, and tackling it a critical component of an integrated climate resilience approach to the Mekong Delta. This chapter aims to assess current scientific knowledge on the impact of sand mining in the Delta, and provide recommendations from that perspective to improve the way this resource is managed, building on the GEMMES COP26 report.

Prior to 2015, data on the impacts of sand mining on the Mekong Delta were limited, but a number of scientific papers and reports have been published in recent years, providing valuable material for this assessment. Outputs from an ongoing project – namely *"Drifting Sands: Mitigating the impacts of climate change in the Mekong Delta through public and private sector engagement in the sand industry"* ("IKI sand project") – provided important information, while the reports on sand mining & sustainability [Peduzzi *et al.*, 2022] contribute a global perspective that has helped to shape this chapter.

The drivers affecting the resilience of the Mekong Delta are numerous and complex. Some of the drivers impact the dynamics of the whole river basin (*i.e.* land-use changes, hydropower and irrigation dams, and sand mining), affecting water, sediment, nutrient flows and the movement of species. Meanwhile, others impact the Delta directly (*i.e.* dikes and channels for flood and salt management, drainage and irrigation infrastructure, groundwater pumping, conversion of mangroves and sand mining). The fact that they all operate at different geographic and temporal scales, fall under a wide range of scientific disciplines, and affect an even wider range of stakeholders and economic sectors, makes it extremely difficult to articulate policy responses that integrate all dimensions of the problem and address its root causes, rather than just its symptoms. This often results in an oversimplification of the issues and may explain why it has taken so long to identify sand mining as a key driver of both erosion and salt intrusions in the Mekong Delta. A recent scientific synthesis describes the existential crisis facing the Mekong Delta, and urges the strict regulation of all sediment mining as one of six key recommendations to managers [Kondolf *et al.*, 2022]. While the impacts of dams on sediment flows across the Mekong Delta are real and significant, they are currently second to those of sand mining. In addition, the impacts of sand mining, hydropower dams, groundwater extraction on relative sea-level rise, and the increased intensity of waves, longshore currents and storms due to climate change are cumulative and mutually reinforcing. Sand mining does not only amplify the impacts of hydropower reservoirs on the physical integrity of the Mekong Delta, it also increases the rapidity at which the impacts of reservoirs will materialize in the Delta, because it removes the sand stored in channels that could have been remobilized by the river to compensate temporarily for the sand trapped in reservoirs [Bravard and Goichot, 2013; Anthony *et al.*, 2015]. Considering all this, it is clear that a policy framework that integrates the challenges of sand mining into wider climate and water risk mitigation measures in national, basin-wide and Delta-specific plans – and suggests ways to coordinate actions taken by different ministries, notably in the frame of Resolution 120 – is urgently required.

This chapter focuses on sand mining in the Mekong River. It includes an analysis of extraction in the entire lower Mekong, and a deeper assessment of sand mining in the Delta – including its channels, as well as the coast and subaquatic parts of the Delta. In principle, the study includes both sand and gravel bundled under the single term 'sand mining'. However, gravel that used to occur naturally in the Mekong Delta channels is now very rarely found, and only in very small volumes, due to over-exploitation. In-channel exploitable deposits include all riverine components of the active bed: channels, banks and floodplains. Coastal deposits include beaches, dunes, and shallow seabed areas associated with the sub-aquatic part of the Mekong Delta.

2. Sand mining in the Mekong delta

2.1 Sand in Nature

A general principle governing sand mining is that the extraction of naturally occurring sand stocks has much greater impacts in dynamic ecosystems, like river channels and coastlines, and that these impacts can extend very far from the extraction site. They can also take years – even decades – to unfold completely. While impacts also occur in static ecosystems – such as fossil deposits or rock quarries – they tend to remain much more localized and easier to assess and mitigate [Peduzzi *et al.*, 2022].

Sand plays a key role in deltas

In its natural state, the Mekong generated a large volume of coarse sediment load compared to many other large rivers. These high inputs of coarse sediment were moving in suspension in the lower part of the water column of the mainstem stretches, where the river runs on bedrock, creating high stream-energy. As this process was not acknowledged, monitoring techniques were not appropriate. This is important, as it explains why large volumes of sand that were neither in the upper part of the water column and monitored as suspension load, nor at the bottom of the river and monitored as bedload, remained unaccounted for. It also explains the relatively large size of the Mekong Delta, as well as the quantity of sand that riparian economies have benefited from extracting over the past decades. It also indicates that the cumulative trapping effect of large hydropower reservoirs and sand mining are affecting the Mekong Delta faster than anticipated, simply because the river develops high stream-energy, yet there are fewer sand deposits in the channel to remobilize, and thus less buffering effect.

Sand plays a key role in river systems and, in particular, in deltas. Sand deposits absorb the energy from waves. They act like a shield, consolidating the coast and providing conditions for mud to accumulate. Mud provides filling material to grow and compensate for natural land subsidence, as well as nutrients for mudflats, swamplands and mangroves. Sand and mud offer complementary benefits, providing conditions for the Delta to prograde and gain altitude, making it resilient and productive.

Impacts of sand mining only revealed in recent research

The impact of sand mining on sediment flows was largely ignored by Mekong River basin managers until 2010, when research gradually incorporated sand mining to sediment trapping by hydropower dams as a key additional driver of sediment decline [Koehnken, 2015]. Overwhelmingly, the research documented a river in the process of undergoing substantial changes with respect to sediment transport and sediment dynamics. Major findings included:

– The suspended sediment load estimate of the river at Kratie was revised to ~72 Mt/year compared to previous estimates of up to 160 Mt/year made in the 1990s, presumably due to the capture of sediments by the Lancang Cascade hydropower project and other tributary dams [Koehnken, 2015];

– Sand comprised up to 20% of the suspended load of the river at Kratie, and was transported as bedload, and as graded suspension during periods of high flow [Bravard *et al.*, 2014];

– Aggregate extraction in the Lancang-Mekong Basin exceeded 50 Mt in 2011/2012 with 90% of the extracted material consisting of sand, with over 80% of the extraction occurring in Cambodia and Viet Nam. The magnitude of sand extraction in 2011 exceeded the estimated amount of sand being transported in the river in suspension and bedload by ~25 Mt/year [Bravard *et al.*, 2013];

– The Mekong and Bassac channels in the Delta deepened considerably between 1998–2008, by 1.4 m on average with a net loss of ~200 Mm^3 of material, with the results strongly suggesting that the channel-deepening was related to sand mining and associated readjustment of the channel [Brunier *et al.*, 2014];

– The Delta coast line underwent extensive change between 2003 and 2012, with high-resolution satellite images showing that much of the Mekong Delta had become prone to erosion, with shoreline retreat affecting over 50% of the > 600 km-long coast, and as much as 90% of the muddy South China Sea coast. The decreasing supply of river sediment to the coast was deemed to be the prime cause of this erosion – most likely due to existing dam retention of sediment, massive channel-bed sand mining in the Delta, and increasing up-channel mud storage to the detriment of the coast. [Anthony *et al.*, 2015].

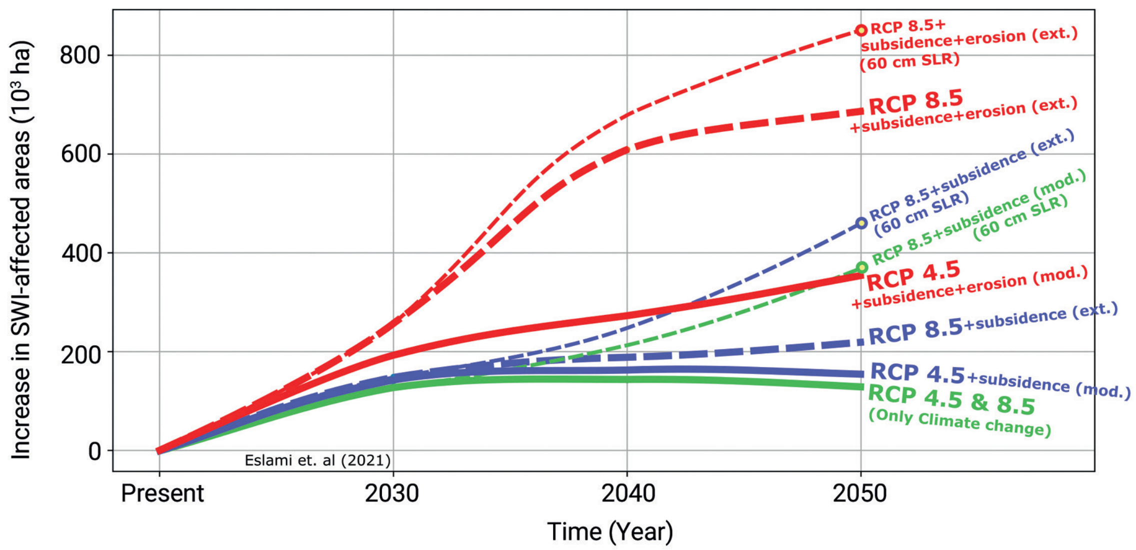
Collectively, the investigations showed the Mekong was in a state of rapid change, including bank erosion, bed incision, and alterations to the pattern and quantity of sediment delivered to the Delta and the sea. Sand mining was identified as a key driver of these changes.

Over the following decade, additional scientific research has confirmed the gravity of the situation along the Mekong, highlighting a rapidly increasing trend in riverbed incision and erosion, and shedding further light on the impacts of sand mining. A series of publications [Eslami *et al.*, 2019a & b, 2021a & b] detailed the rapid changes in the dynamics of tides and salinity in the Delta [Figure 2/1.1], and linked these closely to alterations in riverbed levels, which are largely influenced by sand mining. They showed that tidal amplitude has been on the rise since 2004/2005 at a rate of 2–3 cm/year: this is orders of magnitude larger than sea-level rise. The primary driver is actually riverbed incisions of 10–20 cm/year. The research also showed that the impact of the two extreme drought events of 2016 and 2020 were significantly exacerbated by this riverbed lowering.

Additional work found that the volumes of material extracted from the Mekong in Cambodia had been increasing steadily over the period from 2016–2020, by around 8 Mt/year. Estimates for 2020 suggest 59 Mt of sand and gravel were extracted in the reach between Kampong Cham and the border with Viet Nam [Hackney *et al.*, 2021] – rates that are estimated to exceed the current natural supply of sand by a factor of nine, and exceed official extraction estimates by a factor of three. These rising extraction rates have been driven by the expansion of the urban area around Phnom Penh, infilling of wetlands, and land reclamation projects. This increased extraction has resulted in a lowering of the riverbed levels at the apex of the Mekong Delta by 0.26 m/year. [Hackney *et al.*, 2021], which has significantly altered the hydrology, including the magnitude and timing of the flow reversals in the Tonle Sap Lake connected to the river [Ng and Park, 2021; Chua *et al.*, 2022]. Furthermore, continual bed-level lowering leads to the destabilization of riverbanks and increased likelihood of failure [Hackney *et al.*, 2020]. Results suggest that the majority of unplanted riverbanks along the Cambodian stretch of the Mekong will transition to a phase of instability when the riverbed is lowered 3 m relative to the 2014 bathymetry levels: at current rates, this threshold will be reached by 2029. Recent developments and reclamation projects in Phnom Penh directly at the apex of the Delta could also dramatically alter the partitioning of flow and sediment through the Mekong, Bassac and Tonle Sap.

Sand and gravel mining target the grain size range of the sediment load that is fundamental to the physical integrity of the coastline. It has been challenging to get managers to acknowledge this, as since the 1960s, monito-

[Figure 2/1.1]
Projections of increase in areas affected by saline water intrusion



Various projections of salt intrusion in the Mekong Delta under scenarios of climate change (sea level rise & upstream discharge anomalies), extraction-induced land subsidence [Minderhoud *et al.* 2020] and riverbed level incision. Source: Eslami *et al.* (2021b).

ring efforts have concentrated on silt and clay. In addition, river managers were not alerted because sand deposits remained visible along the banks of the river and the coast. Thus, there was no perceived sand shortage and no regulation on sand extraction. In the meantime, both the total sediment loads and the relative proportion of the coarse versus fine fraction were altered, affecting both the resilience of the Delta and the characteristics of its ecosystems [Bravard, 2018]. Key documents like the MRC strategic plan or the Mekong Delta Plan 2030 with a vision to 2050 do now include the issue of sediment management, but the relative importance of sand in monitoring efforts remains limited.

As a result of decades of increasing extraction volumes at rates that have long exceeded diminishing replenishment rates, the riverbed has lost elevation in many stretches of the lower Mekong – both in Cambodia and Viet Nam – which is now affecting water levels. As the riverbed is incising into fossil sand deposits, these non-replenishable stocks are now being extracted, in the absence of monitoring and allocation of quotas. Doing so affects the stability of the riverbed, which causes rampant erosion and significant losses to infrastructure and other assets – losses that, too often, are still solely attributed to climate change. While climate change should certainly be factored in, it is at most a significant aggravating factor in riverbed incision of the Mekong Delta and associated erosion, rather than the main driver.

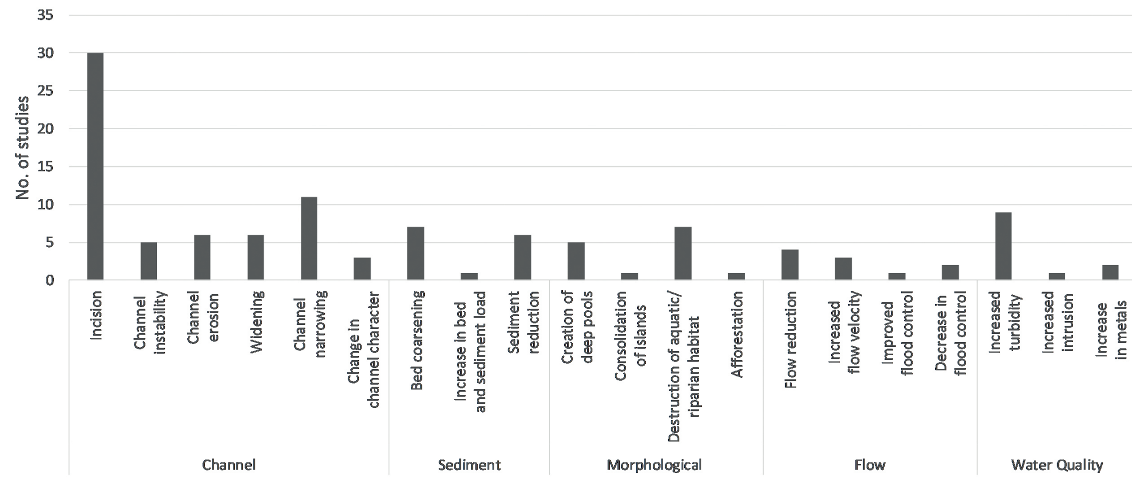
Impacts on the Tonle Sap Lake

The Tonle Sap Lake is a key dimension of Cambodia's food security and economic development, and boasts important social, cultural and environmental values [Lamberts, 2006; Hap *et al.*, 2006; Campbell *et al.*, 2006]. During the dry season, draining the lake as water levels in the Mekong fall helps to maintain higher water levels in the Delta region (see Focus 3). Extracting sand from the Mekong and Bassac channels is causing riverbed incision, which lowers the Mekong riverbed at Phnom Penh in relation to Tonle Sap. This could potentially decrease the water, sediment and nutrient flows between the Mekong River and Tonle Sap Lake. The first and most obvious impact is a reduction in the water level of the lake, and in the area of the submerged floodplain, along with the duration of the inundation. Note that the annual production of wild fish in the Tonle Sap is largely dependent on the height and duration of the inundation that year, or the previous year. Less inundation of the Tonle Sap lake also reduces its buffer effect on flooding in the Delta, which translates into more sudden and higher flood levels downstream from Phnom Penh, with significant implications for Viet Nam's climate adaptation strategy. However, despite significant impact, this issue has not been well covered in the scientific literature [Fruchart, 2009; Ng &Park, 2021; Guan & Zheng, 2021; Chua *et al.*, 2022].

Impacts on mangroves

The coastal zone is replenished by river and coastal sediments that are remobilized by waves and longshore currents. Where wave energy is low, or mud supply high, mangroves prosper, trap sediments, and gain elevation and land over the sea. Beach ridges create calm areas behind which mud can be deposited and colonized by mangroves. Long stretches of coast in the Mekong Delta, like the southern coast of the province of Ca Mau, are protected from high wave energy by sandbars offshore. These are below the mean sea-level and invisible from the surface, yet they play a key role in sustaining the mangroves. Sand, mud and mangroves work in tandem to protect the coast from erosion. The reduction of sand delivered to the coast due to sand extraction or entrapment behind dams, groins and other coastal infrastructure, affects the resilience of mangroves and their ability to play a protective role against climate change, and to host biodiversity.

[Figure 2/1.2]
Impact associated with sand mining



Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research [Koehnken *et al.*, 2020].

Impacts on biodiversity: a key knowledge gap

Fluvial sedimentary landforms provide different types of habitat, which play different roles during floods (refuges) and low flows. Gravel and sand deposits in the riverbed provide habitat for macro-invertebrates, and are often used by fish as spawning grounds. Sandy fluvial landforms allow the encroachment of riparian vegetation. Also, sand participates in the self-purification of water, thus improving water quality. Although sand mining is associated with a wide range of physical impacts on rivers [Figure 2/1.2], a systematic review of the scientific literature shows that the ecosystem impacts are mostly inferred due to physical changes. Only very few papers directly document impacts on the ecosystem [Koehnken *et al.*, 2020], and the impacts of sand mining on the Mekong's biodiversity are seriously understudied.

Part of the reason for this is that the complex interactions between sand mining and changes in landforms are not always well understood. They often unfold over large distances and several decades, and require interdisciplinary approaches, which challenges research methods. Additionally, the changes may be induced by several stressors acting in a cumulative manner (dams, dikes, land-use change, climate change, etc.). As they affect a wide range of species that have very different biological cycles, this makes demonstrating the cause-effect of sand mining difficult.

2.2 Sand and People

Sand extracted from the Mekong is critical for the construction industry, which is heavily dependent on these resources since there are currently few workable alternatives. Sand is used in the construction of real estate, transport, manufacturing, agriculture, aquaculture and flood mitigation infrastructure – which all provide benefits to communities – and supports development and associated employment. Sand mined from the Mekong River is also used to fill in wetlands, reclaiming land to expand housing and industrial zones. Viable alternatives for those different uses need to be assessed, while the demand for sand from rivers – and its contribution to GDP – should be weighed against competing needs from ecosystem functions, livelihoods, water supply and flood control.

Rivers: a preferred source

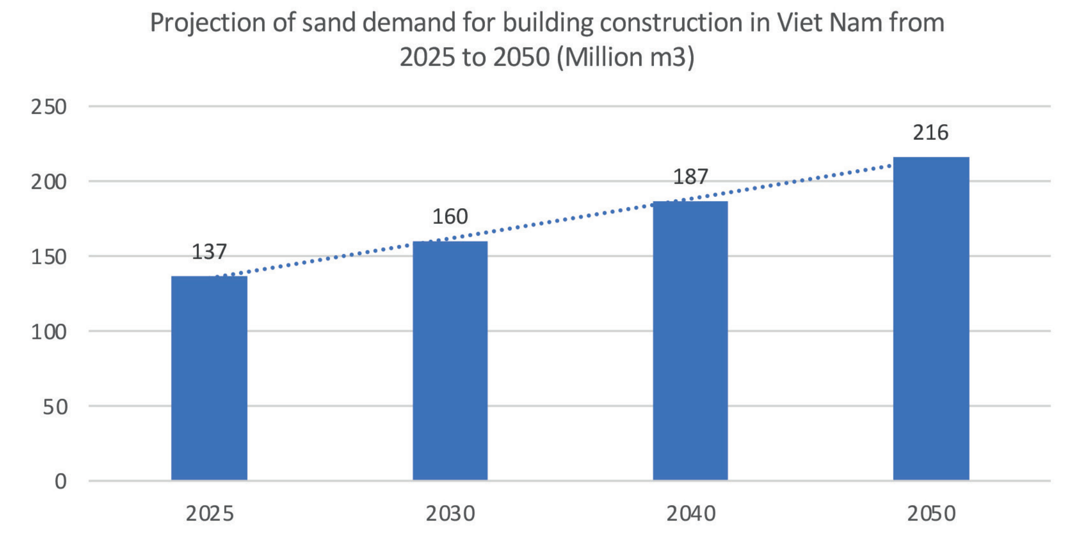
Worldwide, rivers are a preferred source of sand and gravel for several reasons: the energy in a river grinds weathered rocks into gravels and sands, and the material produced by rivers tends to consist of resilient minerals of angular shape that are preferred for construction. Deposits of river sand also offer the advantages of being naturally relatively well-sorted by grain-size, easily accessible, and can be transported inexpensively using barges [Koehnken & Rintoul, 2018]. This advantage is clear for cities like Phnom Penh, Ho Chi Minh City and Can Tho, which have relied on sand extracted cheaply from nearby river channels. In addition, mining sand from rivers has often been seen as providing additional benefits, including aiding navigation and improving the conveyance of flood waters.

It is also worth noting the paradox of sand, which is considered a nuisance by hydropower dam operators because trapped sand reduces the water storage capacity and lifetime of reservoirs. However, this sand-trapping creates an even larger loss for the riparian population of the Mekong. While precious sand resources are lacking downstream, sand that is trapped in reservoirs can rarely be used to meet the demand from the construction industry. Firstly, most hydropower dams are built in steep narrow valleys far from the demand centers in large cities downstream. Secondly, reservoirs trap all grain sizes at once (when rivers naturally deposit different grain sizes in different places), and the silt and clays tend to harden once deposited. And thirdly, accessing sand stocks in the bottom of a reservoir requires the level of the reservoir to be drawn down and electricity production to be stopped. All this highlights a critical point: the management of river sand resources reveals a conflict between the energy and construction sectors.

The importance of sand to the economy

As the Mekong countries continue their rapid economic development, they all face significant trade-offs between short-term socio-economic gains, and the healthy ecosystems which underpin those very gains. Demand for aggregates is expected to increase significantly over the next 30 years to support economic growth and meet rising demand for infrastructure and urbanization. As floods and the availability of freshwater become key limiting factors for socio-economic development, sand mining needs to be considered from the perspective of a trade-off with agricultural productivity, energy generation, urbanization and freshwater supply.

[Figure 2/1.3]
Viet Nam national projection of sand demand for building construction from 2025 to 2050



Source: Ministry of Construction, Viet Nam.

Stocks, trends and demand

The Viet Nam Institute for Building Materials from of the Ministry of Construction estimated the total national natural sand reserves of Viet Nam in 2017 to be around 2 billion m^3, including 692 Mm^3 for construction. The total sand demand for landfill for the period 2016 to 2020 was estimated at between 2.1 and 2.3 billion m^3 [Decision No. 1266/QĐ-TTg, 2020; Hung *et al.*, 2014]. Today, construction sand supply for both HCMC and the Mekong Delta mainly comes from the Dong Nai River. The main river sand production provinces in southern Viet Nam are Dong Nai, Binh Duong, Binh Phuoc, and Tay Ninh. The channels of the Mekong Delta supply most of the sand used for land filling, with the exception of An Giang and Dong Thap provinces, which extract coarser sand that is suitable for construction [RECERD, 2022]. The reliability of stock estimations in the Vietnamese Mekong Delta – as well as the volumes that have been extracted since these estimations were published – are unclear. Volumes extracted directly from the riverbed of Mekong Delta channels in Viet Nam have been estimated at 583 +/- 121 Mm^3 over the period 2008–2018 [Vasilopolous *et al.*, 2021]. In recent years, some provinces with limited exploitable river sand stocks have stopped issuing mining licenses. In addition to river sand, the Mekong Delta also has offshore sand reserves. However, the use of sea sand is restricted by the fact that it must be washed for most construction applications because of salt, making it more expensive; its exploitation also runs the risk of further exacerbating coastal erosion and loss of habitats, such as beaches, sand dunes and mangroves.

The demand for aggregates is correlated to population, urbanization and economic growth. In Viet Nam this demand is estimated at about 4 tons/capita, which translates to 400 Mt/year nationally – at least one quarter of which is used in the combined Viet Nam Mekong Delta and greater Ho Chi Minh City region. While the sand component of this may be over 30 Mt/year, there may also be unquantified supplies from non-river sources. [O'Brien & Hoddinott, 2021]. From 1993 to 2017, Viet Nam exported sand to 29 countries for a total recorded export value of 963 million US dollars [OEC, 2020]. The respective volume of river sand versus other sources is not specified. The government of Viet Nam restricted construction sand export from 2009 (Clause 2, Circular 18/2009/TT-BXD, 2009), and exports of both construction and leveling sand were officially prohibited in 2017 (Notification no. 278/TB-VPCP, Nguyen, 2017). The Ministry of Construction forecasts that demand for construction sand will continue to increase, from 137 million m^3 in 2025 to 216 million m^3 in 2050 [Figure 2/3.3]. In Cambodia, the demand for aggregates is estimated at some 45 million m^3/year [Marschke *et al.*, 2021]. Despite the uncertainties in monitoring of sand reserves and use, it appears that total sand demand is significantly outstripping river supply in the Mekong and Dong Nai rivers, while the trapping effect of hydropower reservoirs has significantly diminished the natural ability of rivers to replenish stocks. Future urbanization and plans for massive infrastructure development in both Cambodia and southern Viet Nam – as well as the maintenance and upgrading of existing infrastructure – will only further intensify demand for sand, increasing market prices and the construction industry's eco logical footprint [O'Brien & Hoddinott, 2021].

2.3 Policies & regulation in Viet Nam

In Viet Nam, the extraction of minerals is covered by the Mineral Law of the National Legislative Assembly, No 60/2010/QH12 of 2010, which classifies river sand as a mineral for use as common construction material. Crucially, there is an article that requires investment decisions to be guided by master plans that take socio-economic effectiveness and environmental protection into account.

The Prime Minister decision (No 1266/QD-TTg) frames *Viet Nam's Construction Materials Development Strategy 2021–2030*, with Orientation to 2050, and provides general requirements, including that natural sand should only be used for concrete and not for leveling applications, and cannot be exported outside Viet Nam. It encourages increased use of crushed sand or recycled sand, setting a target to replace at least 40% of natural sand in construction by 2030, and encourages private investment in the building materials sector. It also calls for a further increase beyond that, with a target for all construction projects to use a minimum of 60% of crushed sand or recycled sand between 2031–2050. It also sets technical regulations and standards for environmental protection, including rehabilitation and restoration of concessions after exploitation.

The Government Decree 23/2020/ND-CP: *"Management of Riverbed Sand and Gravel and Protection of Riverbeds, Banks and Terraces"* details the authorization process, and outlines specific operational regulations – including operation approval based on reasonable distance from river banks and alteration of riverbed, prior submission of an environmental assessment report, and approval by both the Ministry of Natural Resources and Environment and the provincial authority.

Decree 36/2020/ND-CP, *"Penalties for Administrative Violations against Regulations on Water and Mineral Resources"* details potential penalties for violations, including warnings, fines or suspension of the mineral exploration license or the mineral extraction license for 1 to 12 months; violators can be fined up to VND 1 billion (€36,400) for an individual and VND 2 billion (€72,800) for an organization.

Decree 04/2022/NĐ-CP, *"Amending and supplementing a number of articles of the decrees on sanctioning of administrative violations in the field of land; water and mineral resources; hydrometeorology; surveying and cartography"*, includes tougher penalties on entities for violation of regulations on mineral resources, including the suspension of their exploration or mining of minerals for 1–24 months, as well as enforced implementation of environmental remediation of mining areas, and solutions to restore land and environment. Importantly, application of the regulation has been extended to the exploitation of sand and gravel in both inland waters and coastal areas.

Environmental legislation in Vietnam operates under a different framework to that of natural resources and construction, and offers a complementary regulatory framework restricting the use of alternatives to natural sand. The 2014 Law on Environmental Protection, 55/2014/QH13, despite being comprehensive, does not mention protection of the environment in the specific context of the exploitation of river sand, yet it does provide a general reference to compensation in the event of environmental damage. In November 2020, the National Assembly approved the Revised Law on Environmental Protection, implicitly encouraging the use of recycled aggregates, and gives a stronger enforcement role to communities.

All these policies and regulatory actions may lead to a more coordinated approach to sand mining, including promoting alternatives to natural sand as well as an increase in the cost of extracting river sand, which includes externalities. However, shortcomings in the enforcement of these policies – including fine ceilings that are much too low in comparison to profits made by the concession holders and operators – mean that in the absence of other more ambitious policy and legal measures, they may not be sufficient to drive real, meaningful and sustainable change in how sand resources are mined, transported and used in Viet Nam.

3. Recommendations: directions for a way forward

The challenge for the Vietnamese authorities is to sustainably manage sand exploitation without possession of the appropriate technical and policy tools to address all the various dimensions of mining natural sand – including monitoring the impacts on both fluvial and coastal processes, managing stocks, defining and regulating quotas, and promoting incentives for the national industry to explore more responsible options to meet the growing demand for sand, while promoting conditions for significant investment in sustainable, affordable and scalable alternatives. Enabling these regulatory authorities to take meaningful action therefore requires assigning responsibilities and appropriate resources in five critical areas: resource availability assessments, resource allocation and access regulation, alternative production and adoption, and impact assessment and monitoring [Peduzzi *et al.*, 2022].

Recommendations in this report focus on actions that can be taken by governments at different levels. However, the involvement of industry, the private sector, and civil society will be vital to their implementation.

3.1 Call for systemic change

Considering its numerous roles and values in supporting economic development, delivering ecosystem services, maintaining biodiversity, and providing livelihoods within communities in one of the most vulnerable places to climate change in the world, the management of natural sand in rivers and deltas is clearly central to overall development and sustainability agendas. As awareness increases about the importance of sand mining to the economy of the Mekong Delta and the wider Ho Chi Minh City agglomeration, the food security of millions, and exposure to water and climate disasters, its strategic dimension in relation to other natural resources is being reconsidered; this may lead to revising the governance framework to manage its exploitation accordingly.

Most economic indicators confirm that demand for sand will only intensify, while business-as-usual will inevitably lead to an environmental, social and economic crisis. The shortages that result from restricting the supply of river sand aggregates can result in various consequences, such as surging prices, delays causing increased costs for housing and construction projects, intense pressure by vested interests on political bodies, and increase of illegal sand extraction [O'Brien & Hoddinott, 2021]. Policy and regulatory measures should take these secondary effects into account and take steps to ensure that these actions – including the ones targeting river sand regulation – are compatible and mutually reinforcing with other national objectives.

This section seeks to rethink sand extraction, sourcing and recycling practices, as well as uses and applications that are better aligned with Viet Nam's national climate adaptation plan. The UNEP [Peduzzi *et al.*, 2022] report on Sand & Sustainability served as a key reference to shape recommendations, yet it needed to be adapted to the specific context of the Mekong Delta, referring to national socio-economic and legal and governance frameworks as well as local knowledge.

3.2 Monitoring and reporting stocks and impacts

At the scale of the Mekong basin, sediment monitoring was neglected for too long despite researchers highlighting the limited amount of reliable data [Walling, 2005; Bravard and Goichot, 2013; Bravard *et al.*, 2013; Brunier *et al.*, 2014; Anthony *et al.*, 2015; Tamura *et al.*, 2020]. Attention has concentrated on monitoring the suspended sediment load at the expense of bedload. As for the monitoring of impacts, more effort was devoted to riverbank erosion, due to its visible consequences. The monitoring of the much less visible erosion of the riverbed has, until very recently, received considerably less attention. However, in recent years there has been significant improvement in our knowledge, with riverbed/bank and coastal erosion processes now clearly linked to coarse sediment starvation [Brunier *et al.*, 2014; Anthony *et al.*, 2015; Eslami *et al.*, 2019b; Jordan *et al.*, 2019; Hackney *et al.*, 2021; Vasilopoulos *et al.*, 2021].

However, all these studies probably underestimate the actual extraction figures, and despite the existence of significant amounts of scattered data, the precise volume of exploitable sand stocked in the VMD remains unknown. The methods to monitor bedload are more difficult, costly and prone to errors, and normally involve monitoring bed-form changes in high-resolution surveys as a proxy to estimate bedload transport. A Mekong Delta-wide sand budget derivation effort is currently being implemented to address this gap (IKI Project). The objective is to measure sand volumes entering the VMD from the Mekong (Tien) and Bassac (Hau) channels as bedload, and evaluate the in-channel stock as well as the sand discharged to the coast through the estuary outlets. The study also aims to gain more insights into extraction estimates based on remote sensing techniques [*e.g.* see Hackney *et al.*, 2021; Gruel *et al.*,2022], which have not been deployed at the Delta scale so far. Furthermore, under the same *IKI sand project,* a technical guidance tool called the River Geomorphic Stability Plan is also being developed. This effort will identify areas of the Mekong Delta prone to change, and will devise sand extraction quotas that are compatible with preserving the long-term geomorphological stability of the river-estuarine system. These tools aim to guide sand extraction policies towards a sustainable permit regime, compatible with the current river sedimentation budgets. As the ripple effects of sand mining and hydropower travel downstream to Viet Nam, a solid framework for monitoring and reporting river sand stocks is essential to ensure that natural river sand resources are well accounted for and managed. Whenever possible, monitoring impacts should be combined with monitoring the extraction activities themselves. UNEP/GRID-Geneva announced at the UN Ocean conference that it is in the final stages of developing a platform which makes use of Artificial Intelligence to enable countries to track marine sand extraction. Monitoring sand extraction and disrupting illicit supply networks will also require mapping sand distribution networks, including sand extraction and end-use sites [Sickmann and Torres, 2020]. Provenance analysis of natural sediment flows could be a promising avenue here. An accurate and transparent account of the sand budget is a fundamental step towards establishing a sustainable supply chain to support the growing economy, and anticipate physical, regulatory and reputation risks.

3.3 Alternatives to river sand

Promoting the production of high-quality manufactured sand from hard-rock quarries is a measure that has been deployed with significant success in other countries. The indications are that there are some hard-rock resources in southern and central Viet Nam, which could supply the Delta and HCMC. As the price of river sand continues to climb in the face of shortages compared to demand, manufactured sand will become more competitive. In addition, the advantages of manufactured over natural sand include the ability to produce sand with exactly the right shape and gradation.

While they may be more sustainable overall than extracting natural river sand, some of these alternatives may also have environmental drawbacks, which need to be assessed on a case-by-case basis. However, offsetting factors include its lower overall environmental impact and the fact that it is much easier to regulate and police relatively few quarrying points, as opposed to the vast area of the VMD [O'Brien & Hoddinott, 2021].

The sorting and recycling of demolition waste will also be essential to keeping the use of sand within sustainable limits, and can – depending on location of the recycling unit – be less expensive to procure than primary mineral materials. Netherlands and Belgium satisfy over 20% of their national needs with recycled aggregates.

3.4 Implications for flood management

Given the increasing price of scarcer landfilling material – and the fact that reclaiming large areas of wetlands and floodplains reduces the space for storing floodwater and thus increases flood risk – it may be worth exploring the cost of building real estate, transport infrastructure and even industrial zones on elevated platforms, or decks on posts or stilts, or floating structures. If one factors in the externality costs of building and maintaining flood control infrastructure, the full cost of flood damage, and the benefits of floodplains connected to river channels, these alternative solutions may well be cost-effective, and could significantly reduce the demand for aggregates to reclaim additional land.

3.5 Encouraging sand sustainability through economic levers

Without external action in the sand market, the costs of river sand for construction and land reclamation will be equal to the costs of extraction (typically less than US$ 1/ton). The result is that an irresponsible operator can rapidly exploit an area and accrue considerable profits. Internalizing externalities, by using legislation and regulation to establish and enforce the true level of river sand costs, can provide the economic incentive to accelerate investment in alternatives, promoting a faster transition to a circular economy and improving climate resilience. Financial incentives to use responsibly sourced sand throughout the construction value chain could also be established. A "responsibly-sourced" certificate for legally extracted sand and aggregates could be introduced as an auditable requirement for project developers. Enshrining these forms of supply chain-accountability for responsible sourcing can enable greater transparency, and overseeing the efficiency with which these resources are being sourced, transported and consumed.

3.6 Improving policy and legal frameworks

The delegation of powers of authorization, monitoring and supervision to local authorities remains imprecise, and may allow some provinces to set different and sometimes incoherent license conditions and royalty fees. Meanwhile, relying on self-declaration from sand mining operators or invoiced volumes for calculating royalty payments to provinces creates a temptation to grossly underdeclare, and sell material without traceable invoicing. In addition, the penalties in force for non-compliance may be insufficient to deter larger operators intent on continuing illegal extraction. Certain measures could be taken to help transform the sector, including the introduction of more inclusive and participatory governance structures, which would give local communities a louder voice in the process, and the implementation of regulatory incentives for customers to use more sustainable, responsibly-sourced alternatives to natural sand – including mandatory recycling quotas, tax cuts etc. The 2030/2050 targets for replacing natural sand with manufactured sand and recycled materials could also be more ambitious in both timing and quantity, based on the case study achievements in 12 countries [O'Brien & Hoddinott, 2021].

3.7 Avoid impacts, restore ecosystems and compensate losses

The extraction of sand from riverbeds comes at a price to the natural systems on which communities depend. Often, the impacts are complex, indirect, and occur far beyond the boundaries of the extraction site for decades into the future. Preserving natural ecosystems is much less costly than restoring them [Peduzzi *et al.*, 2022]. Ignoring the large-scale and long-term consequences of mining activities comes at a high cost, resulting in expensive and lengthy restoration initiatives that rarely lead to a complete recovery [Jones *et al.*, 2018]. Such has been the case with restoration of the Mississippi Delta – one of the most expensive restoration programs in the world – which has required over US$ 50 billion in government grants and been a significant drag on Louisiana's economy [Coastal Protection and Restoration Authority of Louisiana, 2017]. Therefore, it is worthwhile ensuring that sand and aggregate mining projects fully take the risks to biodiversity and ecosystem services into account via four stages of mitigation: avoidance, minimization of impacts, restoration, and offsetting [Peduzzi *et al.*, 2022].

3.8 Lessons from around the world

River extraction remains an important source of aggregates in many countries, and can be carried out in harmony with nature if thorough impact assessments are conducted and extracted volumes remain within annual sediment deposition rates. Improvements in the management of river extraction are possible, and illegal extraction can be phased out. A key factor of success is consistency in treatment, authorization and enforcement, which can be achieved by having a single responsible authority, acting as a highly visible regulatory body for the river basin, as well as close collaboration between authorities along the length of the river. This is ideally accompanied by a certification process that only allocates concessions to proven and responsible operators, whose operations are strictly supervised, and with clear, meaningful penalties for any permit infringements. In many countries, technical guidelines for river extraction concessions define when and where extraction can take place in considerable detail, accompanied by hot-line "whistle-blowing" that local communities and NGOs can use to report irregularities. Another common success factor was the active role played by an aggregates industry or professional association in coordinating efforts to develop a more responsible aggregates supply sector. The current situation in the VMD is that provincial authorities seem to be responsible for both authorization and enforcement. Given the urgency of the situation, it is recommended that mineral ownership, authorization, monitoring, policing and enforcement are all instituted at national governance level, enabling the Vietnamese government to delegate authorization, monitoring and enforcement duties to a single Mekong Delta Authority.

4. Conclusion

The scale and impact of sand mining have not been sufficiently addressed by climate research or policy, despite being critical to the resilience of the Mekong Delta. In the face of the mounting climate crisis confronting the increasingly vulnerable Delta, the key role of sand in keeping it from sinking and shrinking requires stakeholders and decision makers to take a more inclusive approach to climate adaptation. It is time to add construction to the usual nexus of water, food and energy, since the industry is central to growth and development in the region – and yet is not sufficiently incorporated into climate action in the Mekong river basin. And at the heart of the construction industry is sand mining. Addressing sand mining – as part of a holistic, systemic effort to build a more resilient Delta – could be a cost-effective way to address the climate exposure of both the Mekong Delta and some of the planet's most vulnerable communities. The sustainability of a delta cannot be guaranteed if its vertical and horizontal growth is compromised: in other words, if the sediment contribution from its river system cannot keep up with subsidence and global sea level-rise and ocean-forcing agents. In the case of the Mekong Delta, sand is key to maintaining both the coastline and the morphological stability of the estuaries, and preventing salt from intruding further inland.

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Focus 2

Mangroves against coastal erosion?

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Abstract

The question of the rampant erosion of the shorelines that edge the Mekong River Delta has assumed increasing importance over the last few years. One of the issues pertinent to this question is how it is related to mangroves. As a result of earth monitoring and numerical modeling, it has been inferred that – once erosion sets in following sustained deficient mud supply to the coast – the rate of shoreline change is independent of the width of the mangrove belt. Numerous studies have shown that: 1] mangroves promote coastal accretion where fine-grained sediment supply is adequate, 2] a large and healthy belt of fringing mangroves can efficiently protect a shoreline by inducing more efficient dissipation of wave energy and sediment trapping than a narrower fringe, and 3] mangrove removal contributes to the aggravation of ongoing shoreline erosion. We fully concur, but draw attention to the fact that mangroves cannot accomplish their land building and coastal protection roles under conditions of a failing sediment supply, subsidence and prevailing erosion. The present focus underlines some possible strategy to mitigate risks induced by subsidence and sediment deficit. While a large flux of sediment is mobilized along the continental shelf by oceanic forcing, there is a way of buffering large scale issues by first optimizing oceanic sedimentation and by secondly restoring an active and healthy mangrove belt. The restoration of oceanic sedimentation could benefit from hybrid (gray/green) techniques. The restoration of an active mangrove belt could result from landward strategies combining shrimp ponds with mangrove forest coverage, which could constitute a win-win solution.

Tóm tắt

Sự xói mòn đường bờ biển tại Đồng bằng sông Cửu Long ngày càng tăng trong vài năm qua. Rừng ngập mặn có thể là một trong những yếu tố ảnh hưởng đến hiện tượng xói mòn. Kết quả quan trắc và mô hình hoá chỉ ra rằng tốc độ thay đổi đường bờ biển không phụ thuộc vào chiều rộng của vành đai rừng ngập mặn trong điều kiện xói mòn xảy ra sau khi lượng bùn cung cấp cho bờ biển bị thiếu hụt kéo dài. Nhiều nghiên cứu cho rằng: 1] rừng ngập mặn thúc đẩy bồi tụ ven biển nơi cung cấp đầy đủ trầm tích hạt mịn, 2] rừng ngập mặn với vành đai rộng lớn giúp bảo vệ hiệu quả bờ biển nhờ vào khả năng tiêu tán năng lượng sóng và giữ trầm tích hiệu quả, và 3] sự suy giảm diện tích rừng ngập mặn sẽ gia tăng tình trạng xói mòn bờ biển. Tuy nhiên, trong điều kiện sụt lún và xói mòn mạnh thì rừng ngập mặn vẫn không đủ khả năng giữ nền đất của chúng, cũng như bảo vệ bờ biển. Nghiên cứu này nhằm khái quát một số chiến lược khả thi trong giảm thiểu rủi ro do sụt lún và thâm hụt trầm tích. Giải pháp đầu tiên là tối ưu hóa trầm tích đại dương và sau đó là khôi phục một vành đai rừng ngập mặn có tính vững chắc. Việc phục hồi trầm tích đại dương có thể được hưởng lợi từ các kỹ thuật lai (hybrid techniques gray/green). Việc khôi phục các vành đai rừng ngập mặn có thể kết hợp với phát triển nuôi trồng thuỷ sản (như nuôi tôm), điều này có thể tạo thành một giải pháp đôi bên cùng có lợi.

Résumé

La vulnérabilité du littoral du delta du Mékong à l'érosion côtière a pris une importance croissante au cours des dernières années. L'une des questions les plus pertinentes est celle du rôle des mangroves dans la protection du littoral. Grâce à la surveillance par télédétection et à la modélisation numérique, nous avons pu montrer qu'une fois que l'érosion s'installe à la suite d'un apport insuffisant de sédiments à la côte, le taux d'érosion du littoral est indépendant de la largeur de la frange de mangrove. De nombreuses études ont montré que : 1] les mangroves favorisent l'accrétion côtière lorsque l'apport de sédiments est adéquat, 2] sous ces conditions, une large bande côtière de mangrove (plusieurs centaines de mètres) peut protéger efficacement le littoral en induisant une dissipation plus efficace de l'énergie des vagues et un piégeage des sédiments, ce que ne permet pas une frange plus étroite, et 3] l'élimination des mangroves contribue à l'aggravation de l'érosion du littoral. Autrement dit, les mangroves ne peuvent pas remplir, à elles seules, le rôle de construction des terres et de protection des côtes dans des conditions de déficit sédimentaire, de subsidence et d'érosion dominante. La présente étude met en évidence certaines stratégies possibles pour atténuer les risques induits par la subsidence et le déficit sédimentaire. Puisqu'un flux important de sédiments est mobilisé le long du plateau continental par le forçage océanique, l'effort doit porter sur le piégeage de ces sédiments à l'aide de techniques mixtes d'éco-ingenierie, suivi de la restauration d'une bande de mangrove active et saine. La restauration de la sédimentation océanique pourrait bénéficier de techniques hybrides (gris/vert). La restauration d'une ceinture de mangrove active pourrait se faire par des stratégies à l'intérieur des terres combinant des étangs à crevettes et une couverture forestière de mangrove, ce qui pourrait constituer une solution gagnant-gagnant.

1. Mangroves and coastal erosion in the Mekong Delta

The Mekong Delta is rich of about 600 km of coasts. This ecosystem has undergone natural, and heterogeneously distributed, phases of erosion and accretion for centuries. But the overall human pressure by local and external activities is considerably altering the resiliency of the ecosystem with counter productive effects on the socio-economic sectors of the delta. Some reversible and win-win strategies can be projected and are discussed here bellow.

1.1 The mangrove belt, a rich bio-physical ecosystem

Mangrove forests are one of the most widespread coastal ecosystems in the intertropical fringe, where they naturally grow along muddy coastlines. Mangroves have always been a rich ecosystem, and have given rise to strong interactions with human societies over the centuries, particularly along the coast of the Mekong Delta.

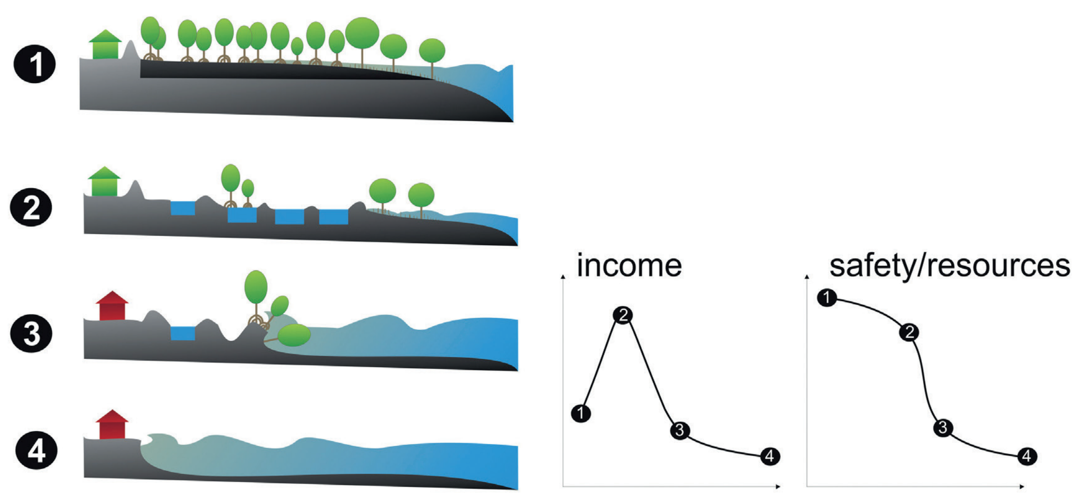
Mangroves are a reservoir of biodiversity; they constitute privileged zones for the first stages of life of many aquatic animal species, including fish, shrimps and crabs. Managed with care, mangrove areas offer a high potential for fishing. Mangroves are also dense coastal forests that are particularly effective in attenuating and dissipating the energy of ocean waves, thus contributing to the protection of inhabited areas and local communities from tropical storms, cyclones and tsunamis. In natural conditions and when the input of fluvial/oceanic sedimentation is active, mangrove forests can be very resilient ecosystems, with the capacity to regenerate spontaneously a few years after episodes of intense erosion, such as during *El Niño* events [Gratiot *et al.*, 2008; Anthony and Gratiot, 2012; Nardin *et al.*, 2021]. As an example, the 1500 km coastline of the Guyanas suffered average additional erosion of 50 m during the severe 1997–1998 *El Niño* phase, but the mean shoreline position has since resumed the trends defined by the combined effect of the nodal tidal cycle and sea-level rise due to global warming, following a resiliency period of about three years.

Mangroves play a key role in global biogeochemical cycles, through soil carbon sequestration in the biomass (roots, trunks, branches, leaves) and in the muddy sediments on which they are rooted. In this respect, mangroves are receiving renewed interest as a carbon sink, with high potential to mitigate the deleterious effects of climate change [Krauss *et al.*, 2017].

Finally, mangrove forests provide various direct services for local communities: they are a source for traditional medicine, provide timber for housing and are used for charcoal making as a source of energy [Veettil *et al.*, 2019]. More specifically in Viet Nam, Tran *et al.* (2021) quantitatively assessed the positive impacts of Buddhist doctrines on reducing the negative trend of vegetation change to maintain mangrove ecosystems.

According to a study conducted by the Institute of Environmental Economics in Southeast Asia [EEPSEA, Thuy and Luat, 2017], the total economic value of mangrove ecosystem services in the Mekong Delta in 2017 was estimated at more than a hundred USD million, equivalent to an average of about 900 USD

[Figure 2/2.1]
Development of income, flood safety and resources for communities along mud-mangrove coasts



1. Natural mangrove forest with small fishing or agricultural communities, 2. Large-scale mangrove cutting and intensive aquaculture, 3. Reduction of pond yield and start of coastal erosion, 4. Large-scale coastal erosion and increasing salinity intrusion[from Wesenbeeck *et al.*, 2015].

per hectare annually. Of these, the «invisible» value that mangroves bring accounts for nearly 70% of the total value, including those that cannot be measured in money.

1.2 Mangrove ecosystems as contributors to delta resilience

Mangroves are a key biological component of many tropical deltas, and intrinsically depend on large-scale equilibria. At a regional scale and on a time-scale of thousands of years, deltas are formed by the oceanward accumulation of muddy sediments produced by the erosion of mountain watersheds. The formation of deltas crucially depends on sustained sediment supplies, in order to maintain delta shoreline position and to balance natural subsidence, *i.e.* the gradual lowering of the land surface, resulting from the compaction of sediments [Anthony *et al.*, 2015].

At a regional scale, mangrove deforestation along the Mekong Delta has been deliberately undertaken in favour of urbanization, farming, and aquaculture, among other human activities. At country scale, hundreds of thousands of hectares have been lost to shrimp, making it the main cause of mangrove deforestation [Thuy and Luat, 2017]. This situation is not specific to Viet Nam and similar practices have been observed in many countries, with similar harmful medium- and long-term effects in Thailand and Southeast Asia [Winterwerp, 2005; Winterwerp *et al.*, 2020], Guyana [Anthony and Gratiot, 2012], and to a lesser extent in French Guiana [Brunier *et al.*, 2019] for example. Anthropogenic mangrove removal can durably modify the morphodynamics of muddy shore faces [Brunier *et al.*, 2019]. In most cases, the fragmentation of mangroves to establish human activities – such as aquaculture for fish or shrimp production – results in an immediate increase in profits. But large-scale mangrove cutting and intensive aquaculture disrupt the biophysical equilibrium, and quickly (5–20 years) result in the reduction of pond yield and the onset of coastal erosion, first at local scale, then at large scale, with an associated increase in saline intrusion [Wesenbeeck *et al.*, 2015]; [Figure 2/2.1]. In other words, the immediate increase in profits at the early stages is untenable, and converts into poverty and disillusionment in the medium to long term.

1.3 The Mekong mangrove ecosystem under pristine conditions

The Mekong Delta has prograded over the last 6000–7000 years in response to the stabilization of sea-level following the rise that occurred during the deglaciation period. But once a delta is prograding, how do mangroves become established?

The accumulation of mud along the shore creates optimum conditions for mangrove colonization under two conditions: first, that the geomorphology of the mudflat has a convex longshore profile that gently dissipates wave energy; second, that the mudflat surface reaches an elevation around or above the Mean Neap Tide High Water Level [Fiot and Gratiot, 2006; Proisy *et al.*, 2009]. Once established, mangrove forests participate actively in shoreline protection and sediment trapping. But mangrove forests can only contribute secondarily to the dynamic equilibrium of deltas and cannot survive without this fundamental balance between sediment flux from Land to Ocean [Anthony and Goichot, 2019], and a moderate rate of subsidence[1] and compaction[2]. This adjustment of the mangrove ecosystem to large-scale hydro-sedimentary conditions was highlighted by Gratiot *et al.* (2008) from studies conducted at regional scale along the 1600 km coastline of the Guianas. The authors demonstrated that the 18.6 year tidal cycle causes a decadal fluctuation in the mean high-water level, which oscillates by a few centimeters at decadal scales. The 18.6 year cycle is caused by the oscillation of the orbital surface of the Moon around the Earth. This oscillation is reflected in the rapid (typically over a one-year period) adjustment of the mangrove forest, which erodes during phases of higher sea level and progrades when the mean sea level decreases. In the Mekong Delta – but also in other muddy coasts in the world – mangroves can no longer accomplish their land building and coastal protection roles under conditions of failing sediment supply, subsidence, climate-induced sea level rise and prevailing erosion.

1.4 The main processes and threats driving present-day deltas

At present day, mangrove ecosystems are particularly affected by groundwater extraction. The intense withdrawal of water from the aquifer to support various industrial, urban and agricultural activities is leading to subsidence of the Mekong Delta at unprecedented rates (chapters 7 and 9 in GEMMES COP26 report, Espagne *et al.* (2021)). While natural subsidence of deltas by compaction of soft, unconsolidated sediments, leads to a sinking of a few mm/year, anthropogenic subsidence leads to a sinking of several tens of mm/year and is undoubtedly the most critical cause to be addressed to ensure the survival of the Mekong Delta.

Survive or subside? This is the question that Day and Giosan (2008) already asked in a study conducted 15 years ago, in which they warned about the vulnerability of deltas and the importance of preserving the hydro-sedimentary balance between the supply of sediment and subsidence. The study focused on the evolution of the Mississippi Delta (USA), but is echoed in a number of recent studies published on the Mekong Delta hydrosystem. In a very recent multidisciplinary study published in Science [Kondolf *et al.*, 2022], some renowned Mekong Delta scientists are encouraging politicians to address the causes of subsidence (predominantly groundwater extraction) and not the symptoms (coastal erosion, flooding, salinization). They present two scenarii that would lead to very contrasting pathways for the Mekong Delta and its ~ 18 million inhabitants. According to their study, the 'Business As Usual' scenario (pursuing trends of groundwater extraction) will lead to the submergence of over 90% of the Delta, while a best-case scenario (drastic reduction of groundwater extraction) will result in 0.15m of subsidence, which would inundate about 10% of the Delta [Schmidt *et al.*, 2021]. It is thus time to act for a sustainable Delta.

In addition to the list of aggravating factors for the risk of delta flooding (*i.e.* extraction induced subsidence, global sea level rise and natural compaction), the question of listing possible mitigating factors is urgent. Restoring large-scale sediment flux along the Mekong hydrosystem by avoiding the construction of new high impact dams is probably the most ambitious and beneficial action [Kondolf *et al.*, 2022]. This action depends on regional governance involving many actors from different countries.

1.5 Some adaptation options to restore sedimentation in the Delta

Other actions could also have a high impact and are less complex to implement, as they depend on the national policy conducted by the Vietnamese to preserve the Mekong Delta. Two actions are identified by Dunn and Minderhoud (2022), namely the restoration of fluvial sedimentation (sand and mud) and the activation of organic sedimentation. The present focus concerns mud, which is the main substratum for mangrove trees; sand dynamic and sand mining is an important issue that is specifically discussed in the Focus 1 of the present report.

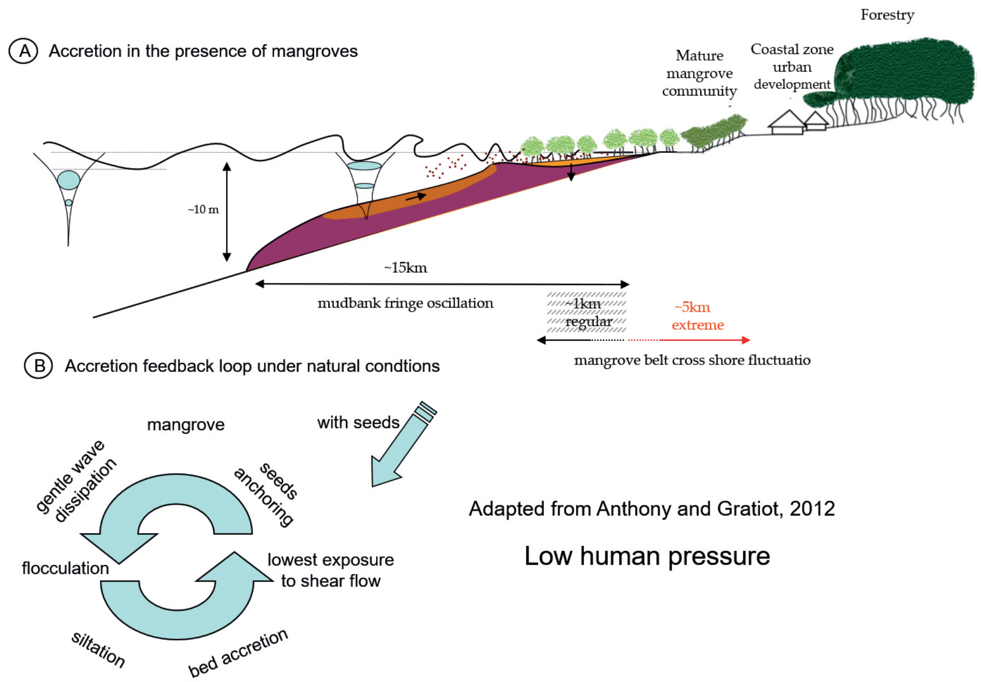
Fluvial sedimentation can be seen as a nature-based geoengineering technique, which consists in defining areas close to the main branches of the Mekong rivers and optimizing the connectivity of the river water to these areas, to encourage the trapping and deposition of fine sediment particles. According to Dunn and Minderhoud (2022), vegetation growth in designated fluvial sedimentation areas could have a double positive impact: on the one hand, vegetation enhances sedimentation by reducing the speed of water flow and turbulence; on the other, the biomass accumulated in the plants of the riverbanks provides sediment.

Organic sedimentation corresponds to the accumulation of organic matter (for example

1. Subsidence is a general term for downward vertical movement of the Earth's surface.For further information, please refer to chapter 9 of GEMMES COP26 report.

2. In sedimentology, compaction is the process by which a sediment progressively loses its porosity due to the effects of pressure from loading and water release.

[Figure 2/2.2]
Accretion and mangroves



Mud-bank and mangrove dissipation of wave energy (a), and the attendant accretion feedback loops (b). Mud banks and their dense mangrove forests generate efficient wave-energy dissipation. Ocean wave energy is spent in recycling the outer fringes of the mud-bank substrate, leading to liquefaction and progressive accretion of mud. Closer inshore, the remaining energy is gently dissipated by mangroves, with a positive effect on flocculation, *i.e.* particles aggregation in flakes (Furukawa *et al.*, 1997) and oceanic sedimentation. By promoting consolidation of the muddy substrate, mangroves further significantly contribute to enhancing the resistance of this substrate (Fiot and Gratiot, 2006), which itself ensures seed anchoring [from Anthony and Gratiot, 2012].

the organic residue of rice cultivation). Traditionally, fluvial sediment deposition is considered to be the main driver of delta elevation gain and organic accumulation is considered less important for deltas globally. Dunn and Minderhoud (2022) reveal that given the extreme decreases in fluvial sediments in the Mekong river in recent decades, in situ organic matter accumulation could contribute equally or more to elevation gain in the Delta compared to fluvial sediments (~0.5–1.0 mm/year for both processes). This could mean a substantial shift in sustainable delta management, from a primary focus on fluvial sediments towards additionally stimulating in situ organic sediment production and retention.

A third option exists:

Oceanic sedimentation, through mangrove belt restoration. This mechanism – which combines oceanic sediment trapping with organic matter trapping in mangrove biomass – is not new, and corresponds to a

natural biophysical coupling under pristine conditions. It could be seen as a nature-based solution, which combines the two typologies (fluvial and organic sedimentation) proposed above by Dunn and Minderhoud (2022). This coupling (cross-sectional) leads to accretion feedback loops under natural conditions, which have been described by Anthony and Gratiot (2012) and reported in Figure 2/2.2.

Oceanic sedimentation can only take place when the coastal biophysical equilibrium between sediment flux, compaction and mangrove is functioning. By trapping several centimeters of mud each year (pure oceanic sedimentation), and by increasing the biomass in mangrove (mangrove organic sedimentation), the process could even contribute actively to balancing regional coastal subsidence and climate-induced sea-level rise, as observed in French Guiana [Proisy *et al.*, 2009] or in Tampa Bay, USA [Krauss *et al.*, 2017]. The capacity to maintain a rapid and large-scale mud-bank colonization strategy is thus fundamental if mangroves are to continue playing this important role of coastal protection.

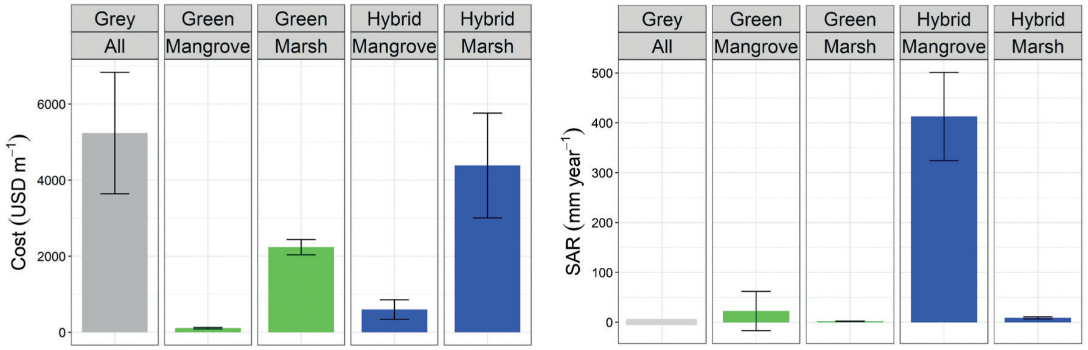
Along the ~600 km long Mekong coast, the biophysical loop is largely broken because of mangrove deforestation, so that oceanic sedimentation is currently non-operational. But in the event of restoration of a healthy mangrove belt hundreds of meters or more in width (0.5 to 2.0 km), oceanic sedimentation could play a significant role [Besset *et al.*, 2019]. The upstream sediment flux from the Mekong River is subject to severe ongoing decrease, and even if this trend is hardly reversible, however, a large quantity of liquefied muddy sediment is in transit nearshore along the continental shelf in shallow waters. According to Marchesiello *et al.* (2019), the volume of sediment in transit is in the range of 10.5–12.4 MTons/year, which broadly corresponds to 25% of the 40±20 MTons/year fluvial sediment flux of the Mekong river at the present day [Ha *et al.*, 2018]. Once restored, mangrove forests could efficiently trap a significant proportion of this flux, and thus contribute to the preserving of the Delta. It is worth noting that the temporal and spatial variability of ocean forcing around the coastal Mekong Delta is important and probably underestimated. The Mekong Delta currently develops towards the southwest under the effect of the waves and currents. This implies erosion in some places and accretion in others, which is perfectly illustrated by the opposite evolution on the two sides of the Ca Mau Peninsula. Erosion is observed in the south-east coast while accretion or stabilisation is observed along the west coast [Marchesiello *et al.*, 2019; Lappe *et al.*, 2022]. The balance between fluvial input and subsidence is therefore only relevant at the scale of the entire Delta, and does not consider the spatial distribution – which may be in constant transition – into account. This is important, because it means that the protection measures are also necessarily heterogeneous along the coast.

2. Assessment of the different adaptation strategies

2.1 Efficiency in the face of the impact, up to 2050

The biophysical nexus between mangroves and the mud-bank fringe depicted in Figure 2/2.2 is vital to a dynamic mud-bank and

[Figure 2/2.3]
Accretion rates and costs for different techniques



Left: Mean sediment accretion rate (in mm/year) for grey, green and hybrid techniques of restoration in mangrove and marsh ecosystems. Right: Mean cost of techniques per linear meters [from Waryszak *et al.*, 2021].

mangrove system, which itself buffers natural phases of erosion during storms, typhoons, and tsunamis. Disruption of this connection can result in a system switching from a positive feedback loop, under which mangroves are regenerated, to a disruptive feedback loop, under which the system is no longer capable of fixing mud and favoring mangrove regeneration. During the second half of the 20th century, many of the engineered coastal sea defenses were conceptually based on the idea of physically separating the ocean from the land, and of humans being able to control Nature. In practical terms, impermeable dikes and seawalls were massively constructed all over the world and also along the Mekong shore. While such engineering gray structures may be valuable options in some critical situations, where it is essential to protect a house or some public infrastructure, they are very costly and cannot be considered as a technically and economically viable option on a large scale. They are even counter-productive, as illustrated by the situation along the coast of Guyana, where the construction of kilometers of hard seawall defenses have led to a geomorphological switch from a resilient mangrove ecosystem to a vulnerable sandy-silty shoreline unfavourable to mangrove colonization [Anthony and Gratiot, 2012].

In recent years, the concept of Building with Nature has replaced this concept of human domination: instead of trying to control or regulate natural systems, it is now a matter of understanding the bio-physical nexus and accompanying the restoration of natural balances by means of soft geo-engineering techniques.

Along the Mekong Delta shoreline, the idea consists in using the energy of swells, currents and tides to: (i) trap some of the sediments in transit on the continental shelf along the shore, (ii) ensure their deposition to restore mudflats with convex geomorphological profiles, and finally (iii) facilitate the natural restoration of a healthy mangrove belt, by afforestation, planting and incentive to develop mangrove-com-

[Figure 2/2.4]
Hybrid techniques in Ca Mau province

a) and b): in 2010-2011, Ca Mau province piloted a 300 m long of breakwater 50-80 m away from the sea dike in Tran Van Thoi district. After 1 year, the breakwater brought into effect in the short term, causing a mudflat of 40-50 cm. c) bamboo T-shaped fence to generate sedimentation basin and restore hydrosedimentary conditions for mangrove natural colonization. Storm can partially destroy such structure. The recovery of mangrove ecosystem requires patience and persistence. After Marchesiello and Dinh (2017).

patible aquaculture. This Building with Nature approach enables the positive feedback loop described in Figure 2/2.2 to be re-established, and makes the system resilient.

Many techniques including the concept of Building with Nature have been tested along the coast of the Mekong Delta and on many other vulnerable shores during recent years. These initiatives used permeable dams, porous breakwaters or bamboo T-fences techniques [Figure 2/2.4] to boost the trapping and sedimentation of mud as a prerequisite to mangrove restoration. According to the recent reviews provided by Luom *et al.* (2021), Winterwerp *et al.* (2020) and Waryszak *et al.* (2021), one may conclude that an ecological engineering approach that integrates gray-green techniques is a promising one, and may match the Mekong agenda, with implementation over a few years (a decade) and some effective mitigation results by 2050 or before.

According to Luom *et al.* (2021), rates of mean sediment accretion of 32 to 51 mm/year occurred along the coast of Ca Mau where this technique was deployed (monitoring from Feb 2014 to Nov 2020); while the extensive bibliography review conducted by Waryszak *et al.* (2021) reported rates of mean sediment accretion of 320 to 500 mm/year [Figure 2/2.3].

The adequate use of hybridization techniques to restore a healthy mangrove forest ecosystem could offer a pluri-decadal buffer to the ongoing drowning of the Mekong Delta [Kondolf *et al.*, 2022] and thus provide precious time to engage the required political and socio-economic changes at Delta system-scale. The combination of gray (porous dikes) and green (bamboo T-Fence, mangrove afforestation, etc.) techniques could rapidly neutralize coastal erosion and restore the biophysical conditions favorable to mangrove growth, with positive feedback loops enhancing sediment trapping [Figure 2/2.2]. These coastal hybrid infrastructures provide not only cost-effective approaches to flood and storm risks (Waryszak *et al.* (2021); [Figure 2/2.3]; they also deliver multiple co-benefits stemming from restoration of mangrove ecosystems as discussed in the introduction of this focus.

2.2 Technical constraints of grey-green techniques

Several conditions are important to restore a resilient coastal ecosystem.

(i) Restoration of a convex mudflat longitudinal profile through hybrid techniques

In areas where coastal erosion is critical with regard to the assets to be protected, the use of porous dams is recommended to rapidly dissipate wave energy and create sedimentation basins. This solution is probably too expensive to be feasible all along the Mekong Delta. In areas with little degradation and where a mangrove fringe of several hundred meters exists, various nature-based solutions have been implemented as an alternative to hard infrastructure sea defenses, including mangrove planting and erecting low-tech structures such as bamboo fences, permeable brushwood dams, etc. The review provided by Winterwerp *et al.* (2020, see p. 22-23) contains a list of recommendations that will help in choosing the best-adapted solution for each study site, bearing in mind that the involvement of a multiple set of local actors takes precedence over any technical proposal.

The effectiveness of coastal protections that are porous to tides but provide an effective barrier to incoming waves is somewhat surprising, but has been observed at many locations along the cost, regardless of structure type [Marchesiello and Dinh, 2017]. The measured vertical accretion of about 10 cm/year or more is found to be close to the expected upper limit of sedimentation, an estimate of which is proposed in Marchesiello and Dinh (2017). Assuming that sediment passing through a breakwater during tidal inflow has time to settle in the protected area before outflow, the sedimentation rate per year is approximately the product of the tidal range (m) multiplied by the sediment concentration (g/l). Note that the success of this formula depends on the ability of the mud to pass through a porous breakwater. In addition, limited impacts are observed on the area surrounding the breakwater, as wave-induced littoral drift is not an important process in the very shallow mud banks of the Mekong coastal delta [Marchesiello *et al.*, 2019]. Therefore, the paradigms of sandy shore protection, which has been the focus of most engineering work, are not likely to be applicable to mud coasts.

(ii) Restoration of a >500 to 2000 meters mangrove belt (seaward and/or landward)

Strategies of mangrove restoration could be planned all along the ~600 km long muddy Mekong shoreline in the seaward direction, if a convex mudflat longitudinal profile exists. But the restoration can also be done in the landward direction, into aquaculture ponds [van Bijsterveldt *et al.*, 2020]. According to these authors, landward mangrove expansion into aquaculture ponds (operating or abandoned) is positively related to both emergence time and sediment stability (*i.e.*, shear strength), which are in turn both associated with bed level elevation and pond drainage. Such expansion thus provides a good option to restore zone of mangrove afforestation/reforestation. Whatever the direction of mangrove restoration (seaward and/or landward), it is

important to restore a >500 m minimum to 2 000 m mangrove belt, with a good hydraulic connection to ensure that seeds produced by mature mangrove trees can propagate seaward and colonize the shorefront. Additionally, in most cases some earthen dykes have been constructed and disconnect the mature mangrove forest from the pioneer front of colonisation, so that seeds produced by trees landward never reach the shore front. Some hydraulic techniques should be designed to restore the seed paths, as this is a key element of mangrove ecosystem resiliency.

(iii) Monitoring the biophysical nexus

The restoration of oceanic sedimentation, via hybridization techniques, first requires a good understanding of the multi decadal dynamic of the ongoing bio-physical processes that link sediment supply, compaction, and mangrove afforestation. Carrying out scientific measurements of the hydro-sedimentary conditions, subsidence, and evolution of the mangrove facies (size, density, width of the mangrove belt) during the implementation phase and later on is a valuable approach to evaluate the opportunity of mangrove restoration and the best-adapted strategy, according to local morphological and biological conditions [Waryszak *et al.*, 2021; Luom *et al.*, 2021].

Ignoring these overarching conditions implies that high expectations from mangroves in protecting and/or stabilizing the Mekong delta shoreline, and eroding shorelines elsewhere, will meet with disappointment. Among these false expectations are: 1] a large and healthy mangrove fringe is sufficient to stabilize the (eroding) shoreline, 2] a reduction in the width of a large mangrove fringe to the benefit of other activities, such as shrimp-farming, is not deleterious to the shoreline position, and 3] the effects of human-induced long-term reductions in sediment supply to the coast can be offset by a large belt of fringing mangroves.

2.3 Economic and social costs/ opportunities

To date, direct benefits from lucrative shrimp and aquaculture farms has led to the regional retreat of the mangrove belt, which almost disappeared in many sections of the Mekong Delta. Wesenbeeck *et al.* (2015) evaluate the long-term negative trend of mangrove deforestation, but this dynamic could even be accentuated in the coming years, if the positive effect of mangroves on carbon storage is introduced within a global carbon market. Migration of populations, fostered by the lack of material perspectives where they live, could also have major financial and economic costs. A reversal situation encouraging some mixed shrimp/mangrove lots could offer a sustainable perspective for the endangered coast of the Mekong Delta.

(i) Mixed mangroves and shrimp ponds

In the recent years, there has been a very significant increase in aquaculture, which has profoundly altered and fragmented the coastal landscapes of the Mekong Delta. Shrimp aquaculture has thus become the biggest source of export income for aquaculture in Vietnam, with 85% of shrimp production in the Mekong delta. It is worth noting that according to the Vietnamese policy states, mangrove coverage in shrimp farming systems, created by mangrove deforestation, should be 60–80%. However, previous studies have found that the mangrove coverage of aquaculture ponds in the Mekong River Delta did not comply with the government's regulations due to illegal deforestation, which adversely affects shrimp yields [Tuan, 1992 reported in Thuy and Luat, 2017].

As a consequence of mangrove fragmentation, hydraulic connectivity is very poor and mangrove seeds are no longer connected between mature mangroves and the ocean front. Satellite images clearly show a mosaic of geometric basins and confirm this point of fragility. Much effort has been made recently to replant mangroves and reduce the impacts of shrimp farming on the environment, and according to Lai *et al.* (2022), maintaining mangrove coverage at 30–50% of total farm area has provided the highest benefits in the integrated mangrove shrimp model (from 786±200 for low or null coverage to 1638±200 $/ha/year for 30–50% mangrove coverage). The integrated mangrove-shrimp farms studied in Ngoc Hien district, Ca Mau province, provide a comparison of shrimp production and benefits between farms having different mangrove coverage ratios. Farms with higher mangrove coverage offer significantly higher yield, survival (nearly two fold), and Catch Per Unit of Efforts of tiger shrimps compared to other groups, given the high variability of data recorded. The production and profit statistical functions, previously proposed by Thuy and Luat (2017) to examine the impacts of mangrove coverage in shrimp production, did support the same conclusion and pointed out some best efficient practices for mangrove coverage of about 60% in shrimp ponds. Restoring a large mangrove coverage in aquaculture shrimps is a nature-based approach that should benefit to water resource and the environment, even if further research could be conducted to better assess the potential impacts.

(ii) Construct with local people and raise awareness

Rehabilitation of mangroves and their habitat is rarely successful without the involvement of local stakeholders. Socio-economic aspects should be included in restoration projects, so that local communities benefit from sustainable mangrove use. It is key to introduce sustainable economic activities alongside mangrove restoration, such as sustainable aquaculture and integrated mangrove-aquaculture schemes, fisheries, eco-tourism and non-timber forest products [Ahammad *et al.*, 2013]. Patience and persistence – including maintenance – are needed, as the natural time scales to rehabilitate mangrove green belts take years to decades, and require intensive stakeholder involvement.

In their exhaustive review on the management of mangrove-mud coasts to limit and mitigate risks of erosion, Winterwerp *et al.* (2020, see pages 22-23) suggested a list of eighteen qualitative criteria learnt from the lessons from the past. It could be beneficial to consider these criteria prior to any measure to rehabilitate coastal resiliency along the Mekong Delta, as part of Integrated Coastal Zone Management. Mangrove rehabilitation should involve local people, it requires patience and persistence, it also requires adaptive management and learning by doing. It can be considered a low-cost and no-regret measure that creates multiple benefits, compared to civil engineering gray solutions.

3. Recommendations/ options for different levels of policy-makers

As already stated in the introduction, a Business-As-Usual scenario in groundwater extractions will potentially lead to the drowning of over 90% of the Delta by 2100. According to Oanh *et al.* (2020), the total economic damage could reach more than US$ 22,000 billion (2010 real value) by 2100 with no discount rate. The political and economic choices made today will therefore have a profound impact on the resilience of the Delta. The human impact on the dynamics of the Mekong Delta has mainly occurred in recent decades through the construction and planning of a large number of dams along the Mekong river and tributaries, the exponential increase in sand mining for construction, the acceleration of water withdrawals for agriculture, industry, aquaculture, urban development, and finally the destruction of mangrove forests for fish farming. Over the last century, the Delta has been transformed into a huge human artifact, or "Delta Machine" [Molle *et al.*, 2012]. Saving the Mekong Delta from drowning requires thorough connectivity between science, policy-makers, decision-takers and society. Scientific know-how on the Mekong Delta has seen a meteoric rise over the last decade in particular, reflecting the growing concern for one of the last of the large Asian deltas (along with the Irrawaddy and the Ganges-Brahmaputra) to be rapidly impacted by development pressures. This scientific knowledge is important but needs to serve societal well-being. The connectivity can only be efficient if courageous decisions are taken by policy makers and stakeholders to radically change the way people inhabit the Mekong and use its resources, and to restore the fundamental natural balances discussed earlier. As a concluding remark, mangroves cannot accomplish their land-building and coastal protection roles under conditions of failing sediment supply, subsidence, and prevailing erosion, but the restoration of oceanic sedimentation could accompany measures to re-establish the fluvial sediment flow and nexus with the coast, in complement with organic sedimentation. These options/recommendations, offer a locally-driven alternative that could – if well-implemented – partially counterbalance the damaging effects of subsidence and dams.

Some policy recommendations:

1] Restore oceanic sedimentation, by using green and hybrid (gray/green) techniques to re-establish sediment dynamics and trapping in line with the 'Building with Nature' approach;

2] Where conditions are favorable, restore hundreds of meters of mangroves (500 m to 2 000 m in width), in both the seaward and landward (mangroves in aquaculture ponds) directions;

3] Monitor bio-physical processes (subsidence, sediment supply, mangrove distribution) to evaluate the opportunity of mangrove restoration and/or afforestation;

4] An integrated mangrove/shrimp model with about 50% of mangrove forest offers the highest societal benefits

5] Raise awareness and involvement of the local populations. Patience and persistence, including maintenance are important, as the natural time scales to rehabilitate mangrove green belts range from years to decades, and are better fostered by intensive stakeholder involvement.

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Focus 3

The role of retention basins against salt intrusion in the Mekong Delta

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Abstract

The Mekong Delta is under significant threat from a combination of climatic and local or regional anthropogenic stressors. The Delta has historically benefitted from two sources of freshwater during its dry season: the Mekong River and the Tonle Sap Lake. The lake is generally filled during the wet season and drained in the dry season. Over the past years, earlier drainage of this natural retention system has resulted in a longer period of exposure to salt intrusion. In response, it has often been suggested that lack of freshwater to combat increased salinity could be tackled by retention schemes. This could take place within the Delta by changing land use, or potentially upstream in the Tonle Sap Lake. These solutions could theoretically be effective in limiting salt intrusion, yet the technical aspects of such measures are complicated. For retention basins to be effective against increasing salinity in the Delta, the required retention volumes amount to ~8–12 billion m^3. Accommodating such retention volumes within the Delta would mean modifying land use of some 12–15% of the Delta's surface area. A more feasible retention basin is the Tonle Sap Lake, with additional potential benefits in restoring the endangered ecosystem of the lake. We have tested several solutions to control retention in the lake, indicating that slowing down the lake's drainage could be effective with reasonable investments. However, this needs in-depth environmental impact assessment to extensively examine the large-scale effects of such changes. This preliminary study aims to fuel the discussion for further assessment of these measures.

Tóm tắt

Đồng bằng sông Cửu Long đang bị đe dọa nghiêm trọng do sự kết hợp của các yếu tố gây căng thẳng do khí hậu và tác nhân con người ở địa phương hoặc khu vực. Trong quá khứ, khu vực Đồng bằng đã được hưởng lợi từ hai nguồn nước ngọt vào mùa khô: sông Mekong và hồ Tonle Sap. Hồ Tonle Sap thường chứa đầy nước trong mùa mưa và thoát nước vào mùa khô. Trong những năm qua, việc thoát nước sớm hơn của hệ thống giữ nước tự nhiên này đã dẫn đến việc phơi lộ với xâm nhập mặn trong thời gian dài hơn. Để ứng phó, người ta thường cho rằng việc thiếu nước ngọt để chống lại sự gia tăng độ mặn có thể được giải quyết bằng các kế hoạch giữ nước. Điều này có thể diễn ra trong vùng Đồng bằng bằng cách thay đổi mục đích sử dụng đất, hoặc có khả năng xảy ra ở thượng nguồn phía hồ Tonle Sap. Về mặt lý thuyết, các giải pháp này có thể có hiệu quả trong việc hạn chế xâm nhập mặn, tuy nhiên các khía cạnh kỹ thuật của các biện pháp này rất phức tạp. Để các lưu vực lưu giữ nước có hiệu quả chống lại sự gia tăng độ mặn trên khu vực Đồng bằng, thể tích lưu giữ cần lên đến ~ 8-12 tỷ m3. Việc dung nạp được thể tích lưu giữ như vậy trong khu vực Đồng bằng đòi hỏi phải điều chỉnh mục đích sử dụng đất cho khoảng 12–15% diện tích bề mặt của Đồng bằng. Một lưu vực lưu giữ nước khả thi hơn là hồ Tonle Sap, với những lợi ích tiềm năng bổ sung trong việc khôi phục hệ sinh thái đang bị đe dọa của hồ. Chúng tôi đã thử nghiệm một số giải pháp để kiểm soát lượng nước lưu giữ trong hồ, cho thấy rằng việc làm chậm quá trình thoát nước của hồ có thể hiệu quả với các khoản đầu tư hợp lý. Tuy nhiên, điều này cần được đánh giá tác động môi trường chuyên sâu để xem xét toàn diện các tác động quy mô lớn của những thay đổi đó. Nghiên cứu sơ bộ này nhằm mục đích thúc đẩy các thảo luận để đánh giá về các biện pháp này trong tương lai.

Résumé

Le delta du Mékong est fortement menacé par une combinaison de facteurs de stress climatiques et anthropiques locaux ou régionaux. Historiquement, le delta bénéficiait de deux sources d'eau douce pendant la saison sèche : le fleuve Mékong et le lac Tonle Sap. Le lac est généralement rempli pendant la saison humide et drainé pendant la saison sèche. Au cours des dernières années, le drainage précoce de ce système de rétention naturel a entraîné une plus longue période d'exposition aux intrusions salines. En réponse, il a souvent été suggéré que le manque d'eau douce pour combattre l'accroissement de la salinité pourrait être résolu par des systèmes de rétention. Cela pourrait se faire dans le delta en modifiant l'utilisation des terres, ou potentiellement en amont dans le lac Tonle Sap. Ces solutions pourraient théoriquement être efficaces pour limiter les intrusions salines, mais les aspects techniques de ces mesures sont complexes. Pour que les bassins de rétention soient efficaces contre l'augmentation de la salinité dans le delta, les volumes de rétention nécessaires s'élèvent à environ 8–12 milliards de m^3. La mise en place de tels volumes de rétention dans le delta impliquerait de modifier l'utilisation des terres sur environ 12 à 15% de la surface du delta. Le lac Tonle Sap constitue un bassin de rétention plus réalisable, avec des avantages potentiels supplémentaires pour la restauration de son écosystème menacé. Nous avons testé plusieurs solutions pour contrôler la rétention dans le lac, lesquelles indiquent que ralentir le drainage du lac pourrait être efficace avec des investissements raisonnables. Cependant, cela nécessite une évaluation approfondie de l'impact environnemental afin d'examiner en détail les effets à grande échelle de tels changements. Cette étude préliminaire vise à alimenter la discussion pour une évaluation plus approfondie de ces mesures.

1. Introduction

1.1 Context and Background

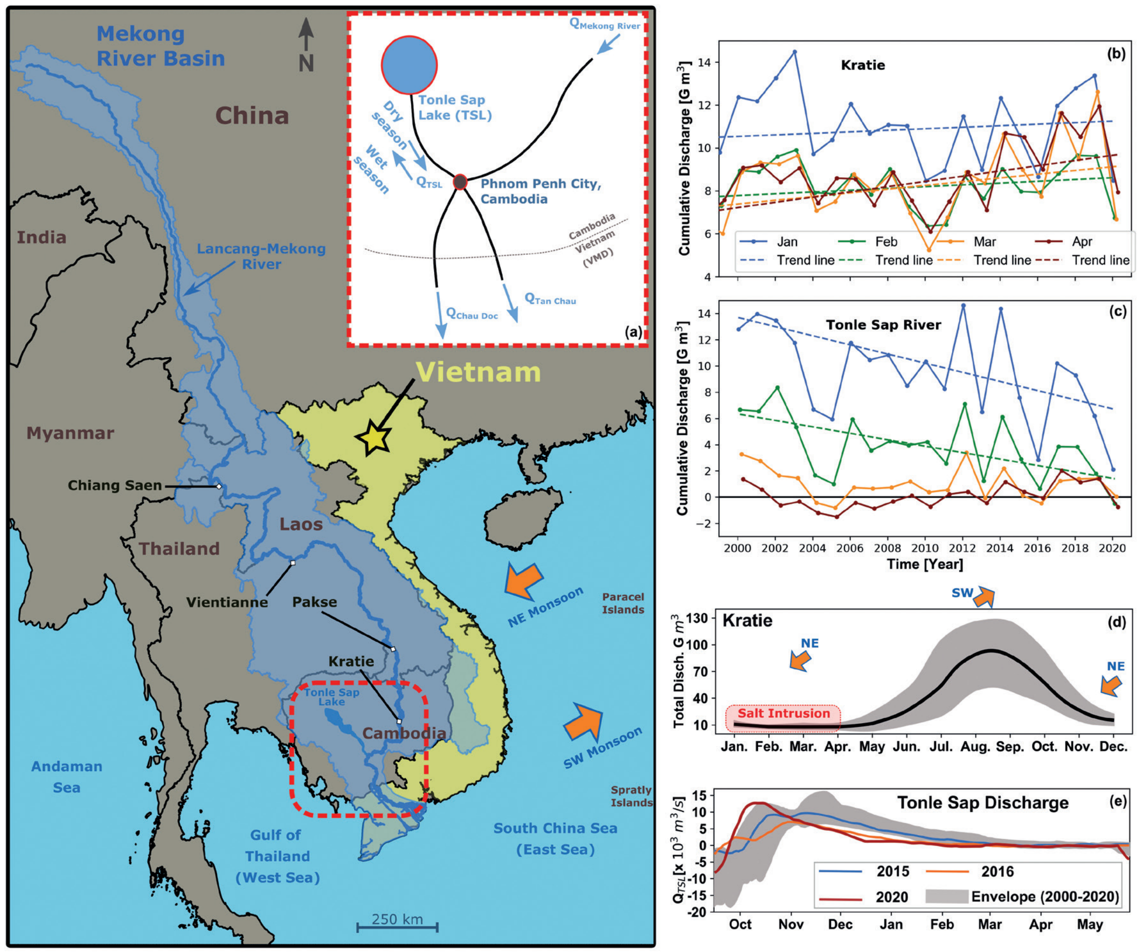
Natural resources of the Mekong Delta are under significant threat from a combination of climatic and anthropogenic stressors. The ever-urbanizing and low-lying Vietnamese Mekong Delta (VMD), elevated at an average of ~80 cm above mean sea level [Minderhoud *et al.*, 2019], is at risk from multiple processes. These include two major trends: a] relative sea level rise as a combination of local land subsidence and global sea level rise [Minderhoud *et al.*, 2017, 2020a], and b] dry season saline water intrusion [Eslami *et al.*, 2019, 2021d]. While sea levels are rising by ~3-4 mm/yr [MONRE, 2016], the land is subsiding by 1-6 cm/yr due to natural [Zoccarato *et al.*, 2018] and groundwater extraction-induced land subsidence [Minderhoud *et al.*, 2017]. Upstream impoundments [Kummu *et al.*, 2010] and downstream sand-mining [Bravard *et al.*, 2013; Jordan *et al.*, 2019; Eslami *et al.*, 2019] have led to significant sediment starvation, leading to river bed [Eslami *et al.*, 2019; Vasilopoulos *et al.*, 2020], bank [Hackney *et al.*, 2020] and coastal erosion [Anthony *et al.*, 2015]. The integrated effects are reflected in existing [Eslami *et al.*, 2021b] and future [Eslami *et al.*, 2021d] increasing trends of salt intrusion, with historic maximum intrusion lengths (~80 km) recorded twice in a span of only 5 recent years (2016 & 2020).

Chapters 7 and 9 of the GEMMES COP26 report [Espagne *et al.*, 2021] previously summarized the drivers of change in the VMD, and showed that, while relative sea level rise could impact salt intrusion by up to an additional 10% of the surface area of the Delta between now and 2050, the largest driver of salinity will remain riverbed incision. Indeed, depending on future levels of sand-mining, the resulting riverbed incision could increase the total area affected by salinity by an additional 5–25%. 2–3 m incision over the past two decades has already made the Delta far more vulnerable to even moderate low discharge events. Eslami *et al.* (2021b) showed that, had the riverbeds remained at their 2008 levels, the 2016 El Niño would have resulted in reduced salt intrusion by up to 20 km in places. In addition, the salty season starts earlier and lasts longer due to hydrological regime shift, besides the deeper channels. This is partly driven by upstream dams and their effect on offsetting the flood pulse, resulting in less water diverting to the Tonle Sap Lake (TSL), diminishing its role as a natural retention area for the Delta (see Section 4.2.1).

1.2 Hydrology of the Mekong Basin

The seasonal variability of the Mekong River Basin [Figure 2/3.1.d, grey line], driven by South Eastern (SE, dry) and North Western (NW, wet) monsoon seasons, has been the beating pulse of livelihood along the Mekong River [MRC, 2010]. The flood pulse of the wet season nourished the flood plains, filled the lakes, fed and bred the large diversity of fish that made the Mekong the world's largest inland fishery, producing nearly 18–25% of the world's inland catch [Orr *et al.*, 2012; Baran *et al.*, 2015]. Eslami (2022) showed that there is no clear declining trend in freshwater supply to the VMD during the dry season. Although cumulative and minimum dry season discharge upstream at Kratie has been on the rise over the past 35 years (also see Figure 2/3.1.b), the total dry season discharge from the Tonle Sap River (hereafter, TSR) has declined, and the total discharge to the Delta itself has remained nearly constant (with some years recorded as anomalies, see also the Online Supplementary Information). With salt fluxes reaching further upstream due to deeper channels, increasing trends of salinity are inevitable. When looking at a longer series of discharges through TSR, it can be observed that the pulsation of the lake shows large fluctuations [MRC, 2018]. Especially in the last part of this series, the an-

[Figure 2/3.1]
System layout and discharges in Mekong and Tonle Sap



An overview of the Mekong River Basin (MRB) within the Indochina Peninsula, and the predominant monsoon seasons, with a) a conceptual diagram of the Tonle Sap Lake's interaction with the Mekong River in Phnom Penh, Cambodia, b) timeseries of historical cumulative monthly discharge over time with trend lines at Kratie, c) timeseries of historical cumulative monthly discharge over time with trend lines from the Tonle Sap River, d) Average and envelope of Kratie discharge highlighting the dry season and the period identified by salt intrusion in the VMD, e) Envelope of Tonle Sap discharge (2000–2019) and examples of an average year in 2015 and the extreme years in 2016 and 2020. [Eslami *et al.*, 2019, 2021a & 2022].

nual flow to the lake has declined significantly. On the other hand, the outflow from the lake shows a smaller decline, meaning that tributaries of Tonle Sap partially compensate for this decline of inflow from the Mekong. It is important to realise that the retention effect of TSL is irregular, and difficult to predict with changes in the upstream developments.

The hydrological regime of the Mekong River Basin is subject to changes, reflected in reduced wet season flow caused by increased storage in reservoirs and changes in precipitation [MRC, 2022]. MRC (2022) also relates the droughts of the past 3 years to reduction and changes in timing of precipitation. It is speculated that Enso shifts and climate change also contribute to these impacts, resulting in a combination of anthropogenic and climatic hydrological regime shift (see also Online Supplementary Information). Therefore, in any adaptation planning, *e.g.* design of retention areas, it is important to account for these exceptional conditions, as they may indicate regime changes. The late arrival of floods in 2019, 2020 and 2021 at the VMD (instead of starting in June, they started in July or even August) caused peak accumulated reverse flows, and lake levels were lower than normal. It is not yet clear if these abnormalities are representative of a major regime shift, but they may indicate that past trends may not be fully representative for future planning.

Despite the above-mentioned possible recent changes in hydrological regime, the water level records associated with the TSL show earlier declining trends in higher water levels post 2003 [see Eslami, 2022 and Chap.9 in Espagne *et al.*, 2021]. As the lake is generally filled during the wet season by the flood pulse and drained to the VMD during the dry season, this translates into an even faster decline in water level at the lake. Note that water level is the key indicator of volumetric storage in the lake [Eslami, 2022]. The earlier drainage of this natural retention system has significant implications for freshwater supply to the VMD and fisheries in Cambodia. For the vulnerable VMD, this means that it is exposed to a longer period of salt intrusion. For the TSL, which alone provides 80% of Cambodia's protein through fisheries, this is an environmental catastrophe that strains regional job and food security [Hortle, 2007; Baran *et al.*, 2015; Sarkkula *et al.*, 2005].

1.3 Scope of study

The lack of freshwater during the dry season to combat saline water intrusion could be solved by various means, such as reducing water demand in the dry season or increasing river discharge during the dry season (February to March). This increased discharge could be created by enhancing the outflow from upstream dams or using retention basins.

The potential of retention schemes forms the focus of this research. Retention could be materialized within the Delta or upstream. In the Delta it could be achieved by changing land use. Upstream, it would be possible to increase retention by diverting the Mekong flood pulse to the Tonle Sap Lake, with significant benefits for the lake's ecosystem and economy as well as flood control for urban areas. Using a modelling exercise, we aim to explore a freshwater supply scheme that could effectively limit salt intrusion, and then assess the technical feasibility of such a scheme to be supplied by retention areas within the Delta, or in the Tonle Sap Lake.

This assessment is two-fold: **1]** in the timing of, and **2]** in the amount of the freshwater supply. In other words, how much water is needed and at what time to limit salt intrusion.

2. Methods

2.1 Modelling approach

The approach used for this analysis builds upon the work carried out by [Eslami *et al.*, 2021a, b, c], using a state-of-the-art 3D hydrodynamic model, starting from Kratie, Cambodia, and stretching 70 km offshore. This accounts for the effects of upstream discharge variations as well as tide and storm surges on salt intrusion. The model also included the network of irrigation/navigation primary and secondary channels, including 54 moveable dams (sluices) and temporal variation of dry season water demand. For more details on model set-up and its calibration, see Eslami *et al.*, (2021b).

2.2 Selection of future scenarios

The model set-up and scenarios are based on the climate change, land subsidence and riverbed incision scenarios presented in Eslami *et al.* (2021d). To show the potential impact of enhanced retention under current day conditions, the 2016 drought (resulting in nearly 80 km of salt intrusion) has been simulated and compared to a simulation in which the retention volume is enhanced. In addition, three scenarios are tested to study the impact of a retention basin on salt intrusion under future conditions (assuming an unchanged coastline):

a] the impact of climate change alone, reflected in discharge changes and global sea level rise (scenario RCP 8.5);

b] a combination of an extreme extraction-induced land subsidence scenario [B2 of Minderhoud *et al.*, 2020b] assuming "business as usual", *i.e.* an increase in annual groundwater extraction of 4% compared to the 2018 volume;

c] combining the abovementioned climate change and land subsidence scenarios with riverbed incision of 3 G m³ until 2040 (similar to the past two decades), accounting for extreme riverbed incision over the next two decades.

2.3 Set-up of retention basins in the model

To describe the effect of water retention basins on salt intrusion in the VMD, additional discharge has been implemented in the model, representing the controlled drainage of the stored water over time. This discharge was implemented on the model as a boundary condition at the TSR. We used the timeseries of TSR in 2015 as a moderate year, representative of a discharge rate that can be effective against salt intrusion (see also Figure 2/3.1.e). The assumption is that storage during the flood season as it occured within TSL during 2015 is similar to what could be effective as a retention volume during drought years. The corresponding retention volume calculated with the discharge from TSR between December 1st and May 1st is ~27 km³. Between January 1 to April 15 (period of highest of salinity), it amounts to 10.6 km³. We will further assess the required amount to control salt intrusion during the peak periods of the dry season in Section 3.1 and 4.2.4.

3. Model results

The objective of the modelling was to show a] the effect of additional discharge, b] the volumes required to make changes in salinity, c] the potential effectiveness of a certain volume of additional freshwater supply in dry years under future scenarios. The calculated volumes may be indicative of the conditions under which a retention basin could be effective. This could act as a guide in evaluating the later conceptual design of such mitigation/adaptation solutions; the actual numbers should not be treated as final.

3.1 Retention impact on salt intrusion

Impact on a drought year

To assess the potential impact of additional retention on salt intrusion under current conditions, the additional retention discharge was first implemented on the model simulation of a current-day dry year (2016). The modeled discharge rates [Figure 2/3.2.a] show a substantial contribution of the additional retention, especially during the onset of the dry season (January to March), compared to the actual discharge in 2016.

The additional discharge drives a pushback of the salinity contour lines downstream within the estuarine channels, and a considerable decrease in mean salinity over the entire area [Figure 2/3.2.b and c]. In total, the area influenced by salt intrusion is reduced by 5%, or 116 10³ ha.

Impact under future scenarios

In Figure 2/3.2 (d-i), the salinity increase and 2 psu contour line under different future scenarios for 2050 are presented, with (d-f) or without (g-i) additional discharge from retention. Differences are determined by comparing with the present-day normal situation (year 2015).

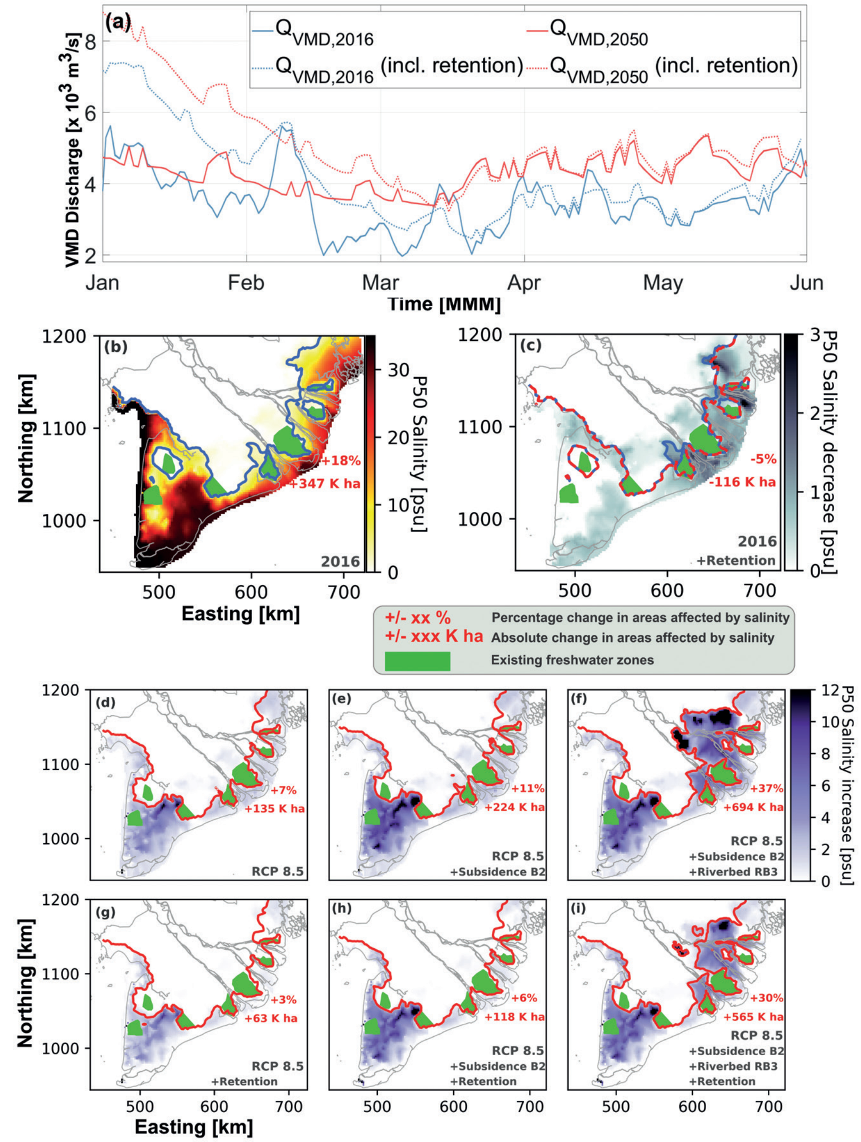
For the purely climate change-driven scenarios (panels d and g), the additional discharge can prevent an area of 72 10³ ha from being affected by salt intrusion. Where the situation without this discharge would cause an increase in affected area of 7%, this can be reduced to 3%.

When also including subsidence due to groundwater extraction (panels e and h), a reduction of 106 10³ ha of the area influenced by salt intrusion can be achieved by including the additional discharge. This represents an increase in affected area of 6% instead of 11%.

Finally, when also incorporating riverbed incision into the future scenario (panels f and i), the additional discharge can reduce the affected area by 129 10³ ha. This represents an increase in the affected area of 30% instead of 37%.

Thus, in the future scenarios, the simulated additional freshwater discharge could have significant impact on salt intrusion. Nevertheless, it would not be sufficient to avoid a large increase in salinity in a scenario of further deepening of the river channels.

[Figure 2/3.2]
Impact of additional retention volume on 2016 and 2050 salt intrusion



a) Discharge into the VMD during 2016 and during future climate change conditions (RCP8.5, for year 2050) with and without additional retention. b) Spatial distribution of P50 absolute salinity during extreme drought of 2016 (blue contour line: 2 PSU; red numbers: relative to 2015) and c) spatial distribution of resulting decline in salt intrusion with additional retention (blue contour line: 2 PSU absolute salinity without retention; red dashed contour line: 2 PSU absolute salinity with retention; red numbers: change relative to the 2016 drought). d-i) Spatial distribution of P50 "salinity increase" under only RCP 8.5 climate change scenario without (d) and with (g) additional retention area; combined effect of climate change and land subsidence without (e) and with (h) additional retention; combined effect of climate change, land subsidence and bed level incision without (f) and with (i) additional retention (red contour line: 2 PSU absolute salinity; red numbers: relative to present).Data source for upper panel: Mekong River Commission and Southern Regional Hydrometeorological Centre ; for lower panels: model results; the freshwater zones in the maps is from Southern Institute for Water Resources Planning.

4. Water retention solutions

In the previous section we showed the potential impact on salt intrusion of increased dry season discharge from additional retention. While this could be substantial, we still need to further assess the practicalities of such retention schemes. In this section, we expand on feasibility of land use change within the VMD for retention basins or enhancing the role of TSL. This is done through a desk study and using secondary information for the areas within the VMD, and through additional simulations when it comes to the practical aspects of employing the TSL as a retention basin.

4.1 Water retention within the Delta

To control salt intrusion, the initial estimate of the potential water retention areas within the upper VMD, considering 1] existing floodplains, 2] land use (agriculture/nature reserve), 3] available embankments and 4] avoiding transboundary disputes, leads to 21 potential retention sub-zones with a total storage volume estimated at ~8 km³ (see the Online Supplementary Information).

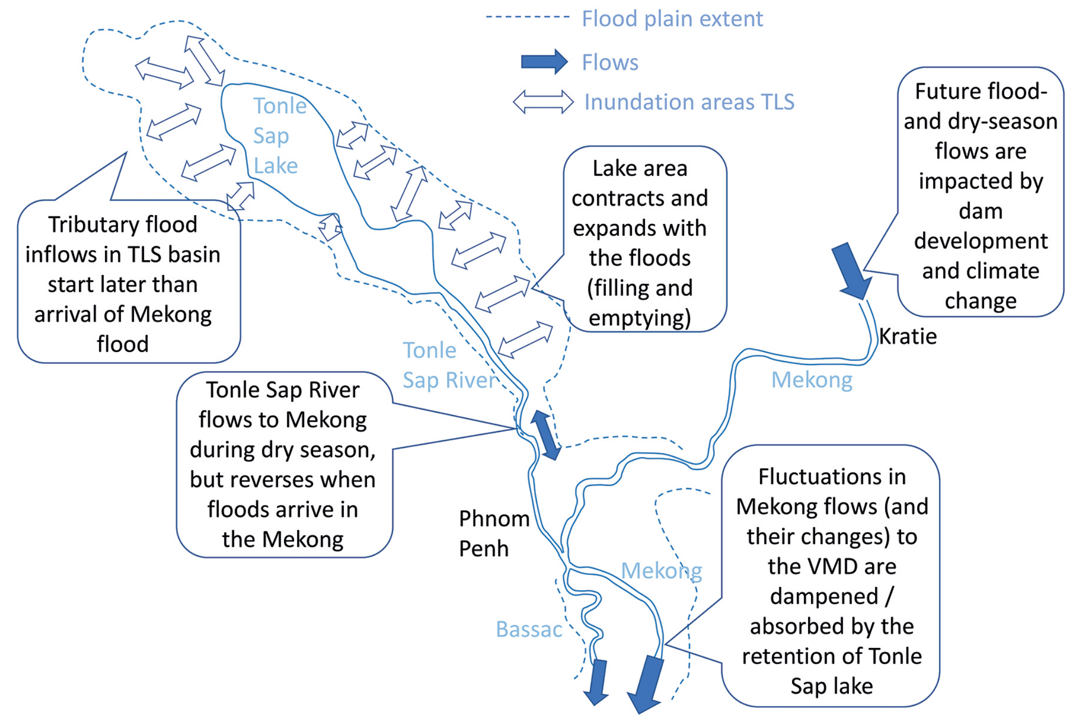
Based on the modelling study in Section 3, and the observed TSL discharge (see Table 2/3.1) over three different years (2015: average, 2016: dry, 2011: wet), the estimated required volume to control the 2016 dry season impact ranges from 27 to 30 km³ (cumulative discharge of December to April 2015 and 2011), of which ~60–70% was the December discharge. However, if the purpose is to limit salinity, even the low discharge of December 2016 was sufficient to keep salinity away. This means, the actual required volume can be considered 8–12 km³ (December 2016 or cumulative discharge of January to March 2015 and 2011), mainly to bridge the very saline period of January to March (as highlighted in Table 2/3.1). To store 10 km³, an area of 5,000 km² (2 m depth) is required, assuming nearly 2 km³ will be lost to evaporation (~4–7 mm/day). With that representing nearly 12–15% of the VMD surface area, it is an expensive option in the context of strategic land-use planning. Furthermore, these areas need to be flooded in the wet season, and will only drain during the low discharge period. In practice, this renders these areas nearly unusable for up to half the year.

[Table 2/3.1]
Comparison of cumulative discharges

	Cumulative discharge per month					Cumulative discharge	
Year	Dec.*	Jan.	Feb.	Mar.	Apr.	Dec.*–Apr.	Jan.–Mar.
2016	8.2	2.8	0.9	0.2	0.4	12.5	3.9
2015	15.5	7.6	2.9	0.6	0.6	27.2	11.1
2011	17.8	8.3	2.6	0.7	0.5	29.8	11.5

* Dec. (Prev. year). Cumulative discharge from Tonle Sap during 2016 (drought), an average year (2015) and a wet year (2011) [bil.m³]. Data source : Southern Institute for Water Resources Planning.

[Figure 2/3.3]
Tonle Sap and the Phnom Penh trifurcation



Schematic representation of the Tonle Sap - Mekong system, and its main characteristics, drivers and hydrological responses.

4.2 Tonle Sap Lake as a retention basin

The original additional natural retention basin of the VMD has been the TSL. However, as this role has been diminishing in the past decade, we expand further on the dynamics and potential solutions to utilize the lake reliably as a retention basin in this section.

The role of the Tonle Sap Lake

The TSL is a crucial element in the hydrological regime of the VMD. It acts as a large retention basin, capturing a major part of the Mekong flood pulse, and releasing the water gradually during the falling limb of the flood (after September/October). During the first months of the dry season (Dec. & Jan.), the outflow of the lake is a large contributor to the VMD freshwater supply. Generally, the lake serves as a giant expansion vessel for the flow fluctuations in the Mekong. With the arrival of the Monsoon-flood, the Mekong level rises and flows in TSR reverse (flowing towards the lake, the so-called "reverse flow"). During the dry season (November to May) the TSR initially discharges 8 000 m³/s from the lake towards the VMD, until it is fully drained with no discharge (see Figure 2/3.1.e).Therefore, the lake area expands and contracts significantly during the year, while sustaining ecologically valuable wetlands and agricultural areas with high nourishing values. From the dry to the flood seasons, the surface of the lake increases from 2,500 km^2 to 15,000 km^2, with water levels rising from about 2 m +MSL to about 10 m +MSL, and volumes ranging from 1 to 70 km^3 [MRC, 2009]. The total inflow volume to the lake is made up of about 50% from the Mekong river, whereas the other half consists of both direct precipitation and inflow from the 11 tributaries, covering a drainage basin of over 85,000 km^2. With this retention characteristic of the Mekong flows, it also to some extent dampens changes in the upstream hydrological regime (*e.g.* impacts of dams), but at the cost of changes in annual fluctuations in lake level and inundation area. The latter causes significant feedback on ecosystem services for the whole system. Figure 2/3.3 illustrates and explains the key elements of the present and future functioning of the system.

To enable retention characteristic of the TSL to counter salinity intrusion in the VMD, we hereby identify the relevant controls of this system:

- The TSR connects the lake to the Mekong River. Its conveyance capacity is mainly driven by water-level difference between the lake and the Mekong, hydraulic roughness and cross-sectional area.
- The filling and emptying of the lake at every flood pulse, depends on the volume of the lake.
- The timing of the reverse flow and outflow through TSR.

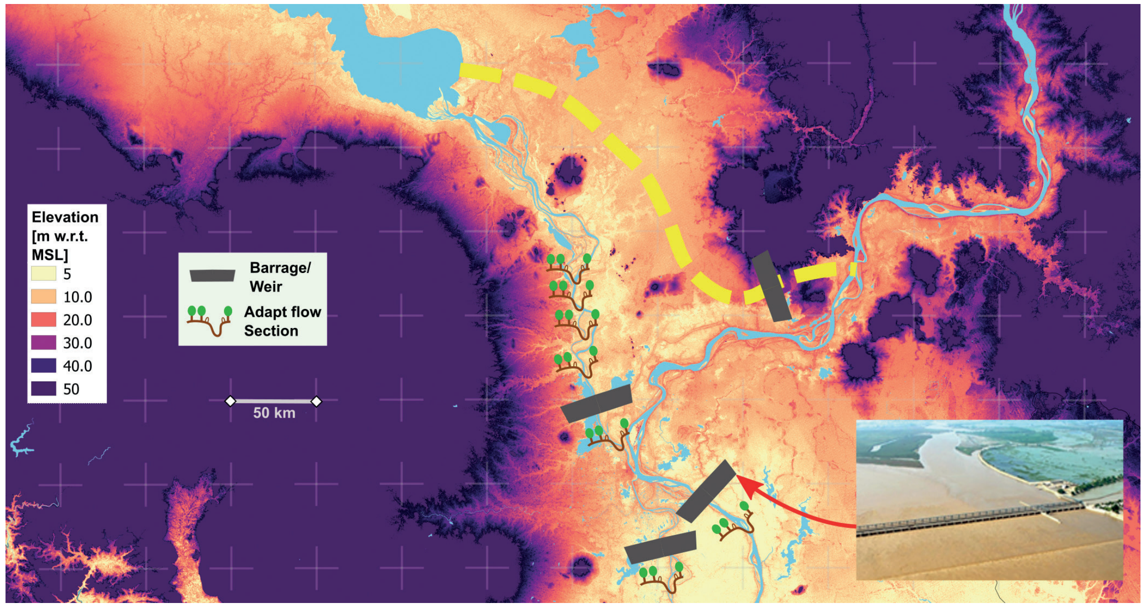
Modifying these controls enables the retention effect of the TSL to respond differently than it does at present. Considering this, possible solutions are explored further in Section 4.2.2.

Tonle Sap freshwater against salt intrusion: practical solutions

It has been shown that TSL already provides significant retention for the Mekong flood pulse, but outflows from the lake do not last long enough to extend to the very dry months of February, March, and April. An increase in the outflows from TSL during these months would be beneficial for reducing salt intrusion. Given the immense natural retention potential of TSL, manipulation of releases from the lake may require immense efforts. Generally, releasing the flood volume stored in the lake drains it by February at the latest. In this section, we qualitatively explore several solutions that could potentially sustain the release of outflow from the lake for a longer period during the dry season through February and March (until the rise of Mekong discharge towards late April). The following solutions could be considered:

- Increasing and extending the duration of the reverse flow (towards the lake) by raising the Mekong water levels at Phnom Penh (the mouth of the Tonle Sap River). This could be done by impeding the downstream flow (*e.g.*, at both Bassac and Mekong branches). Effectively, this means creating resistance for the downstream flows. Solutions could be large-scale and far-reaching. For example, constructing barrages or temporary narrowing the flood plains in these major rivers, as demonstrated in Figure 4 with small icons. To prevent an increase in flood-risk, these measures should operate in a controlled manner through gated structures. In the long term, such measures may have far-reaching impacts on river morphology (*e.g.* erosion in the narrowed sections), river ecology or other functions.

[Figure 2/3.4]
Practical solutions for Tonle Sap



Indication of locations of measures to influence retention in Tonle Sap system. Dashed arrow indicates location of a diversion channel to bring extra water to Tonle Sap Lake during the Mekong flood. The blue area is the permanently flooded area (from Floodmap.net) projected on a topographic map of the Tonle Sap system (OpenTopoMap), to indicate the extent of the low area that could contribute to retention. Photograph shows example of Taunsa Barrage in Indus River (Pakistan) for comparison. Source of elevation data : SRTM.

- Increasing the storage volume of the lake, for example by substantial removal of sediment deposits, or by adding storage in the tributary systems to delay the tributary inflow. This would allow lake levels to rise and fall more slowly. This would cause the reverse flow to last longer, and allow the lake to capture a larger part of the flood volume from the Mekong. In turn, during the dry season, it would cause the lake to release a higher discharge for a longer period.

- Increasing the amount of floodwater entering the lake by diverting Mekong flow through a new diversion channel from the Mekong (*e.g.*, as indicated in Figure 2/3.4). Such a diversion channel bypasses the TSR, but drainage would still be through the TSR towards the VMD. The channel off-take must be located on the Mekong right bank at a distance as far upstream of Phnom Penh as possible, to allow sufficient head difference. However, due to the hilly terrain, the off-take cannot be further than ~80–100 km upstream, which limits the effectiveness of the solution. Furthermore, the measure only effectively increases the outflow from TSR after the flood season if the diversion inflow is large enough to compensate for a reduction of the reverse flow in TSR (because of reduced water level at Phnom Penh).

- Increasing and extending the duration of both reverse flows and outflows, by impeding discharge through Tonle Sap. The solutions for reducing discharge through the river are, for example, gated controllable weirs/sluices/culverts [1], narrowing of the river channel (*e.g.*, embankments/levees), or adding hydraulic friction, *e.g.*, by afforestation of flood plains and banks or a sequence of sills, etc. (see Figure 2/3.4). Note that our assessment shows that increasing friction in the TSR impedes the outflow more than the reverse flow (also see the Online Supplementary Information).

A conceptual analysis of practical solutions

To understand the operation of TSL and evaluate the effectiveness of potential measures, a simple water-balance analytical model was developed to mimic its main hydraulic forcing and responses. The model is based on the model by Pronker (2017), see Online Supplementary Material. The objective was to establish an approximate relation between Mekong water-levels and discharges from Tonle Sap River, particularly during the dry season. The model can roughly estimate the magnitude of potential measures to enhance the retention effect. Some of the assumptions behind this exercise are:

- Water-level difference between the Mekong and the lake forces the flows through the TSR. Time series of water level at the Mekong node is generated from a rating of water-level time series at Chaktomuk hydrometric station (in Phnom Penh) and discharge series at Kratie (data from MRC), corrected for travel time and hysteresis effects (between rising and falling limb).
- Flow in TSR is assumed uniform, and channel is assumed prismatic with constant Chézy hydraulic roughness.
- From the dry to the flood season, the surface of the lake increases from 2400 km^2 to 13,200 km^2 [Pronker, 2017], with water levels rising from about 2 m + msl to about 10 m + msl. The variation of volume with water level is assumed not to be a linear but a convex function [*e.g.*, Xu *et al.*, 2020].
- Inflow from tributaries and precipitation were taken from Pronker (2017).
- A timestep of 1-day is used.

The model was calibrated and validated using the 2014, 2015 and 2016 data, representative of both regular, and substantially dry conditions. We replicated the abovementioned measures in Section 4.2.2 in the model and concluded that impeding flow through the Tonle Sap River would make the largest contribution to increasing dry-season river flows in the VMD during the months February and March (see Online Supplementary Information). A width reduction, or significant increase in roughness, or simply energy dissipation through a structure such as a barrage, could delay the outflow from TSL. The additional discharge from February to April was small (in the order of 400–800 m³/s, or 3–6 km³) but substantial in countering salt intrusion in the VMD. The impacts of the calculated solutions were found to be significant during the flood season and at the start of the dry season (July – December). This behaviour holds for all the solutions presented. Nevertheless, it shows that a large-scale intervention is required to sustain a larger outflow from TSL for a longer period.

1. A hydraulic structure that channels water past an obstacle, typically a pipe made of metal or reinforced concrete embedded in a dam.

[Table 2/3.2]
Changes in monthly discharge

	Avg. Q in Jan. [m³/s]	Avg. Q in Feb. [m³/s]	Avg. Q in Mar. [m³/s]	Avg. Q in Apr. [m³/s]
reference situation (year 2016) (Roughness = 0.035 m$^{1/3}$/s)	2,199	342	20	-410
Scenario	**ΔQ Jan.** [m³/s]	**ΔQ Feb.** [m³/s]	**ΔQ Mar.** [m³/s]	**ΔQ Apr.** [m³/s]
Roughness = 0.05 m$^{1/3}$/s (entire TSR)	227	273	96	43
Roughness = 0.05 m$^{1/3}$/s (entire TSR) + additional 6 km3 storage	449	485	187	45
Roughness = 0.50 m$^{1/3}$/s (locally)	332	1,031	613	329
Roughness = 1.00 m$^{1/3}$/s (locally)	-185	1,167	1,103	1,102
Roughness = 1.00 m$^{1/3}$/s (locally) + additional 6 km³ storage	-175	1,203	1,168	1,194

Relative increase in discharge from Tonle Sap River to the Mekong (relative to the normal average discharge to the river with no additional measures during these months), model results.

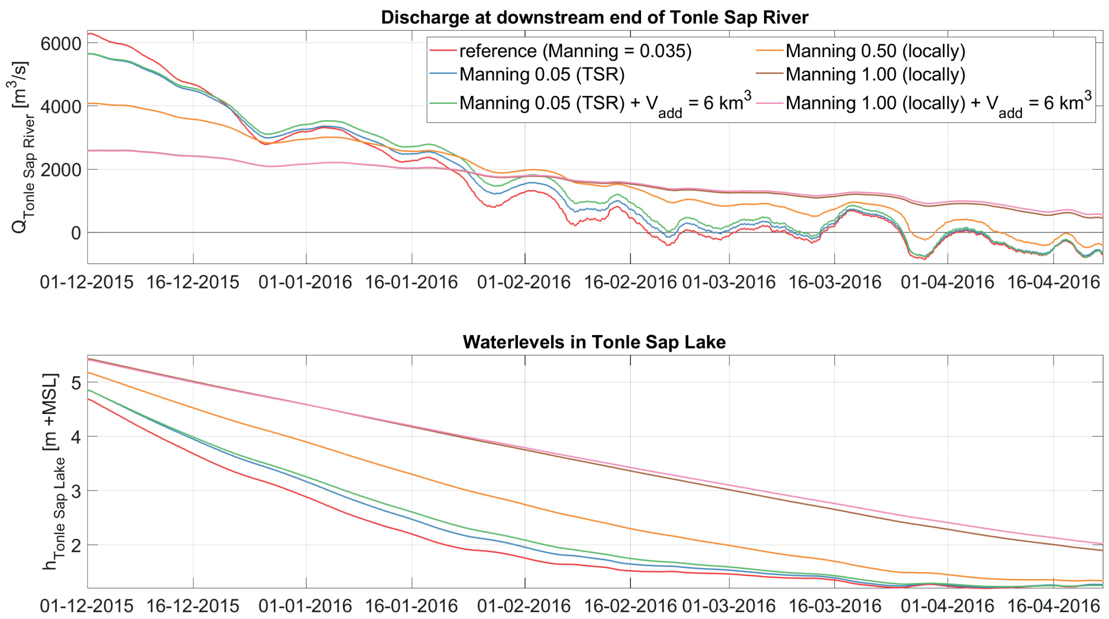
Numerical examination of practical solutions for the Tonle Sap Lake

In Section 4.2.3, we learned that reducing flow through the TSR is most effective in extending the TSL drainage later on in the dry season. Here, we assess this in more detail, using a 1D-2D hydrodynamic model [2] [Eslami, *et al.*, 2019], extending upstream to Kratie and downstream nearly 70 km offshore, including the network of primary and secondary navigation and irrigation channels. We examined two main hypotheses with this model: a] increasing roughness locally or over the entire TSR, replicating a soft or hard obstruction at a point within the TSR, b] increasing storage in the lake. The latter was a hypothetical attempt to show the effectiveness of even an unrealistic increase in TSL storage (~6 km³, by increasing depth in parts by ~90 cm] on discharge throughout the dry season.

Table 2/3.2 shows the average monthly discharge from the TSR to the Mekong simulated for the reference situation (2016) and for 5 different scenarios. Figure 2/3.5 shows the temporal variation of TSR discharge and TSL water level during the dry season in response to the measures. All scenarios result in an extension of TSR discharge further into the dry season, while even an unrealistic increase in TSL storage seems to have marginal impact. The most effective solution is drastic local increase in roughness. This could lead to an additional 500 m³/s in discharge by mid-April. In practice, this means significant intervention in the TSR flow by means of a structure such as a barrage.

2. The model is in 2D with ~2 km resolution over the TSL. TSR and other riverine channels are in 1D with a ~1 km. The Manning friction coefficient in the model is 0.035 m1/$^{3/s}$ in TSR and its surroundings, reducing gradually downstream to 0.018 m1/$^{3/s}$ towards the sea in the estuarine channels.

[Figure 2/3.5]
Impacts on discharge and water level



Discharge from Tonle Sap River to the Mekong (top) and water levels in Tonle Sap Lake (bottom) for the reference situation (red, year 2016) and different roughness scenarios, model results.

4.3 Discussion

There are more reasons to reconsider the measures that improve retention in TSL. The low water level of the TSR has been a grave threat to the livelihood of the population, and a grim prospect for freshwater supply to the VMD [MRC, 2022]. Since the idea of water retention has been considered for mitigation and adaptation to increasing salt intrusion in the Delta, we have aimed to explore the relevance and effectiveness of such measures today and in the future. The presented solutions focus on increasing dry-season discharge to push against flows. This can be done through storage of water within the Delta or in the TSL. The estimated level of required storage to be effective against salt intrusion (~10 km^3) would call for significant land-use reallocation of ~12–15% of the VMD to storage. On the other hand, enhancing the retention role of the TSL could only be effective if the outflow to the Mekong from the lake was impeded, extending the lake's drainage towards later in the dry season. However, these measures could also impact the hydrological conditions of the TSL, and potentially its productivity.

Due to the seasonal rhythm of contraction and expansion of TSL, a valuable flood-pulse ecosystem has developed, supporting current and future livelihoods and economies. The importance of fisheries and farming for food production in the region is significant.

However, the ecological balance is vulnerable, and threatened by increasing pressure from human activities. Both exploitation of natural resources (such as overfishing) and modification of the hydrological conditions are already impacting the productivity of TSL. At present, and in the future, the rhythm of the hydrological regime of the Mekong River is altering as a result of dam development and climate change. Projections [*e.g.*, Arias *et al.*, 2014] and recent observations confirm that these regime changes will lead to a reduction of water-level fluctuations in the lake, and thus to a reduction in the area and duration of inundation. Solutions to improve retention effects of the TSL, as shown in this report, are expected to amplify these impacts. Therefore, consideration of such measures requires detailed environmental impact assessment.

Arias *et al.*, (2014) found that climate change increases variability, whereas hydropower will dampen water level fluctuations of TSL. These combined changes lead to a decrease in maximum flood levels (October, −0.4 ± 0.5 m) and in the extent of areas that are inundated for more than about 5 months along the edges of the lake. This would enable these areas to be converted into rice paddies, removing their ecological value. On the other hand, the increase of minimum levels during the dry season (May–June, +0.87 ± 0.17 m) increases the area of permanent inundation (open water). Arias *et al.* calculated that gallery forest undergoes a net decrease of 261 ± 175 km^2 (40 ± 27%), flooded shrublands by 492 ± 212 km^2 (13 ± 5%), and flooded grasslands by 108 ± 28 km^2 (12 ± 3%). As a result, net primary production decreases by ~30%. However, this study did not cover all possible feedbacks between drivers, and therefore contain a high level of uncertainty. For instance, the change in vegetation type when inundation characteristics change, or the increase in fertilizer use by increasing rice production areas, can influence net primary productivity significantly as well.

For the proposed solutions in this focus, similar impacts can be expected, depending on the changes in maximum and minimum levels. Water levels, simulated with and without modifying the roughness of the Tonle Sap River, show a decrease of 0.1 to 0.5 m in maximum level after the wet season, and an increase of 0.5 to 1 m in minimum dry season levels. The release of the flows from the lake shows a delay, which implies that some areas remain inundated for longer periods. The changes shown in these figures are similar in magnitude to those presented by Arias *et al.* (2014). Therefore, their projections also apply to the simulation presented here, *i.e.* a loss of productive natural habitats caused by an increase in rice production areas and open water.

Note that soft solutions exist to reduce flows through the TSR, such as flood-plain afforestation (trees instead of crops), or more engineering solutions such as bottom sills and pile groynes. It is important that these measures should not obstruct the migration of fish, cause erosion of the river bed and banks, or hamper the reverse flow from the river to the lake in the wet season. One could argue that the design of a barrage (a combination of culverts) can still provide a fish migration corridor in the dry season, and provide suitable conditions for reverse flow in the flood season. But the overall environmental impacts on sediment, morphology, and aquatic ecology as a result of modifying flow field and energy levels need to be studied in detail, and cannot be estimated by simple rules of thumb.

5. Conclusions and Policy implications

– Salinity within the Delta is increasing, and an array of adaptation and mitigation measures to address the issue is required. Retention basins to store fresh water during the flood season and provide additional outflow during the dry season could be effective and considered as one of those measures. However, the technical aspects of such solutions may be complicated, and on their own they may not be sufficient to fully control salinity under extreme scenarios of salinity increase, *e.g.* if riverbed level erosion continues at existing rates.

– Water retention schemes can effectively reduce salt intrusion within the VMD. However, the volumes of such retentions should exceed 8 billion m^3 to have an impact, and the drainage scheme should extend until the end of March. This would need to result in a freshwater discharge increase of 500–1000 m^3/s during the dry months of February and March.

– To store water within the VMD, because of the low-lying and flat elevation of the Delta, some 10–15% of its surface area would need to be converted to storage for as long as some 6 months, making it a questionable choice when it comes to cost vs. benefit. However, water storage within the basin for emergency usage (*e.g.* agriculture) may be justified, and is not the subject of this study.

– Using TSL to store additional water instead of developing retention basins within the Delta would provide a more feasible solution, especially as the proposed retention volume is already stored in the TSL during wet years.

– In the context of rapid hydrological regime shift within the Mekong River Basin, enhancing the retention functionality of the TSL would require a managed inflow into the lake during the wet season, and controlled outflow during the dry season. We have investigated several solutions. The results indicate that only those measures that slow down the lake's drainage could be effective with reasonable investments. Other measures such as a diversion canal upstream or an [engineered] increase in water levels (during the flood pulse) near Phnom Penh are not sufficiently effective, or have far-reaching environmental consequences.

– According to this study, the only potential solution for TSL would be to impede the lake's outflow during the dry season, so that drainage is extended later into the dry season, possibly by use of a system of culverts (*e.g.* a barrage). Note that measures to enhance retention in TSL will have a similar impact on lake levels as the projected combined effect of climate change and upstream dams. The annual water level pulsation will decrease, possibly leading to an increase of open water area and rice fields, hence potentially causing a decrease in natural habitats and productivity.

– As this was a conceptual study, it is recommended that an extensive environmental impact assessment be carried out if such measures are to be considered. The impacts of modifications in the flow field could have significant effects on the sediment dynamics, morphology and aquatic habitats of the TSL and TSR. Socio-economic and political aspects should also be carefully considered and further investigated.

– We show that developing water retention would have a large impact on land-use or the characteristics of the TSR, with potentially far-reaching environmental consequences. However, our exercise also shows that an increase of 500–1000 m^3/s in VMD discharge in the dry season would be effective against increased salt intrusion. Therefore, before drastic measures are planned, a] transboundary agreements in releasing more water from upstream tributary and mainstream dams, and b] improvement of water usage and demand upstream and within the Delta should be considered as a priority. Note that the nearly 1000–2000 m^3/s of current extraction during the dry season in the VMD has a significant effect, and a large impact on salt intrusion.

– Several researchers have suggested considering joint releases from all the dams in the upstream catchment to create artificial flood waves, for instance to expedite the start of the (delayed) flood season [*e.g.*, Pronker, 2017]. In a coordinated transboundary agreement, this could also be used to increase the Mekong discharge during the months of February and March. Considering that 500–1000 m^3/s can make a significant difference in salt intrusion, negotiating more release of freshwater from upstream dams deserves to be on the table.

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Focus 4

Reduction of groundwater exploitation against land subsidence

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Abstract

The Mekong Delta is increasingly suffering from land subsidence, at rates of up to several cm per year, a magnitude larger than global warming-induced sea-level rise (*i.e.*, ~3.7 mm/year). As such, land subsidence has become the dominant force that determines if and when certain parts of the Delta will fall below sea level. Projections show that this may occur within the next decades for large parts of the Delta, if land subsidence is not slowed down. One of the factors driving land subsidence in the Mekong Delta is the overexploitation of groundwater in the Delta's various aquifers. Awareness of this connection between groundwater exploitation and land subsidence has been increasing in recent years, and several government-led initiatives and policies have been developed aiming to reduce groundwater extraction and slow down subsidence. Here we provide an overview of the status quo with regard to groundwater and land subsidence, along with current and future-planned initiatives, and evaluate their implementation for several cases in cities and provinces in the Mekong Delta. Furthermore, we identify bottlenecks that are currently hampering effective implementation, and provide policy recommendations to improve future efforts to limit groundwater overexploitation and land subsidence in the Mekong Delta.

Tóm tắt

Sụt lún mặt đất đang diễn ra ngày càng nghiêm trọng ở Vùng Đồng Bằng Sông Cửu Long, tốc độ lên đến vài cm/năm, cao hơn nhiều lần mực nước biển dâng do nóng lên toàn cầu (~3.7 mm/năm). Và do vậy, sụt lún mặt đất là nguyên nhân chính quyết định liệu và khi nào một phần diện tích của đồng bằng xuống thấp hơn mực nước biển. Các dự báo cho thấy rằng điều này có thể xuất hiện cho phần lớn diện tích của đồng bằng trong một vài thập kỷ tới, nếu không giảm tốc độ sụt lún. Một trong những nguyên nhân sụt lún mặt đất ở Đồng Bằng Sông Cửu Long là do khai thác nước ngầm quá mức ở các tầng chứa nước. Hiểu biết về mối liên hệ này cũng tăng lên trong những năm gần đây và một số chính sách của chính phủ cũng đã được phát triển nhằm mục đích giảm khai thác nước ngầm và làm chậm quá trình sụt lún. Sau đây, chúng tôi cung cấp một cái nhìn tổng thể về hiện trạng liên quan đến nước ngầm và sụt lún mặt đất, cùng với các chính sách quy hoạch hiện tại và tương lai, đồng thời đánh giá việc thực hiện chúng tại một số tỉnh và thành phố ở Đồng Bằng Sông Cửu Long. Hơn nữa, chúng tôi xác định các điểm nghẽn hiện đang cản trở việc triển khai hiệu quả các chính sách để đưa ra các khuyến nghị chính sách nhằm cải thiện các nỗ lực trong tương lai nhằm hạn chế khai thác quá mức nước ngầm và sụt lún mặt đất ở Đồng Bằng Sông Cửu Long.

Résumé

Le delta du Mékong est de plus en plus affecté par la subsidence, dont les taux peuvent atteindre plusieurs centimètres par an, soit une ampleur supérieure à la hausse du niveau marin global causée par le changement climatique (*i.e.*, ~3,7 mm/an). Ce phénomène est devenu la force dominante déterminant quelles parties du delta se retrouveront sous le niveau de la mer, et quand. D'après les projections, si la subsidence n'est pas ralentie, ce pourrait être le cas pour de grandes parties du delta dans les prochaines décennies. L'un des moteurs de la subsidence dans le delta du Mékong est la surexploitation des eaux souterraines dans les différents aquifères du delta. La prise de conscience de ce lien entre exploitation des eaux souterraines et subsidence s'est accrue ces dernières années, et plusieurs initiatives et politiques gouvernementales ont été développées pour réduire les extractions et ralentir la subsidence. Nous présentons ici une vue d'ensemble de la situation actuelle concernant les eaux souterraines et la subsidence, ainsi que des initiatives actuelles et futures dont nous évaluons la mise en œuvre pour plusieurs cas dans des villes et provinces du delta du Mékong. En outre, nous identifions les obstacles qui entravent actuellement une mise en œuvre efficace, et nous proposons des recommandations politiques pour améliorer les efforts futurs visant à limiter la surexploitation des eaux souterraines et la subsidence dans le delta du Mékong.

1. Introduction

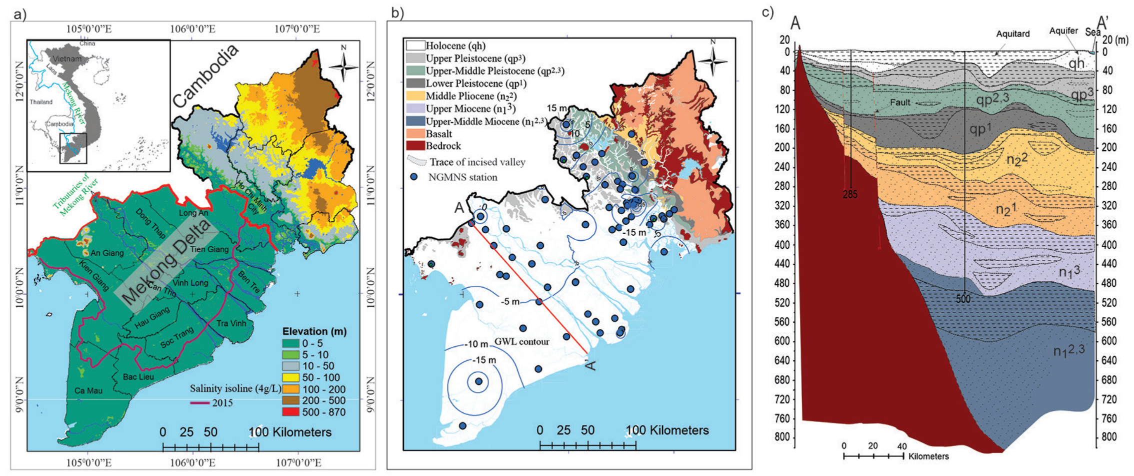
The Vietnamese Mekong Delta (VMD), a flat land area [Figure 2/4.1.a] inhabited by ~18 million people, is known to be among the most vulnerable areas to climate change and sea-level rise in the world. In addition, anthropogenic activities at the local and regional scale – such as hydropower dam operations, sand mining upstream and within the Delta [Dunn and Minderhoud, 2022], land-use changes, expansion of aquaculture and industrial areas – are also driving large environmental changes [GEMMES COP26 report, Espagne *et al.*, 2021]. In particular, the rapid economic development of the Delta over the last decades has put enormous pressure on freshwater resources, and has driven a large increase in groundwater extraction to provide cheap and good quality water [Wanger *et al.*, 2012]. As a result, groundwater pressure heads have been declining rapidly, with current rates up to 0.78 m/year [Erban *et al.*, 2014], and cone depressions are commonly observed in the area [Le Duy *et al.*, 2021]. This decrease in groundwater pressure head is driving compaction of sediments, causes salinization of groundwater [Ha *et al.*, 2019], and has been shown to be the main driver of high subsidence rates in the Delta [Erban *et al.*, 2014; Minderhoud *et al.*, 2017; 2020; GEMMES COP26 report], *i.e.*, the gradual lowering of the land surface.

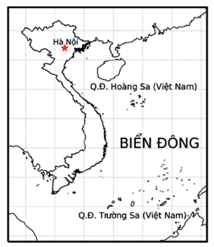
Indeed, the VMD geological setting – characterized by thick (>500 m) layers of unconsolidated sediments [Figure 3/4.1 b,c – SVG-MD,2004] – makes it particularly vulnerable to land subsidence. The top surface of the Mekong Delta is a clay-rich layer of Holocene formation, composed of soft soil such as mud and rich organic clay with high porosity, resulting in a high natural compaction rate [Zoccarato *et al.*, 2018]. At greater depths, the old alluvial sediments of the Pleistocene, Pliocene and Miocene formations have undergone long-term compaction and are more consolidated than the younger Holocene sediment.

Subsidence can cause serious problems in terms of damage to the foundations of infrastructure, increased flooding and possible inundation, and salinization of low-lying coastal areas. In the Delta, the foundations of large buildings are normally piled on the older sediments to minimize the impact of land subsidence caused by shallow compaction. But small buildings and roads normally only have shallow foundations installed on the Holocene sediment layer, and they generally experience higher subsidence rates than deep-founded constructions [de Wit *et al.*, 2021].

However, the largest threat associated with land subsidence in the Delta is the risk of submersion. Indeed, current land subsidence rates (up to ~60 mm/years; Minderhoud *et al.*, 2020) are up to twenty times larger than climate change-induced sea-level rise (~3-4 mm/year) in the area. As the VMD average land elevation is only about 0.8m above mean sea level [Minderhoud *et al.*, 2019], recent studies even suggest that continuing to increase groundwater extraction rates will cause large parts of the delta to fall below sea-level in the coming decades [Minderhoud *et al.*, 2020; GEMMES COP26 report]. Elevation loss caused by the combination of subsidence and global sea-level rise triggered by climate change (*i.e.* relative sea-level rise) could cause majority of the Delta to fall below sea-level by the end of the century [Minderhoud *et al.*, 2020; Kondolf *et al.*, 2022]. Therefore, reduction in groundwater extraction is highly recommended as the top prioritized solution for minimizing land subsidence in the VMD.

[Figure 2/4.1]
Location of provinces, elevation and geological setting





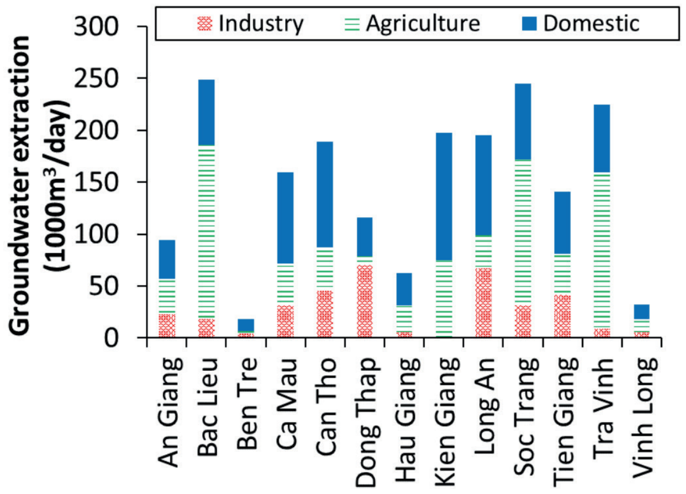
Location of provinces and salinity isoline of surface water during the dry season in 2015 (data from Eslami *et al.*, 2021) plotted on elevation map (a), geological map, location of National Groundwater Monitoring Network Stations (NGMNS) (blue points) and groundwater pressure head in 2015 from upper-middle Pleistocene aquifer (b) and geological cross-section A-A' in (b) of the VMD (modified from Ha *et al.*, 2019) (c).

2. Groundwater use for development of the VMD

Groundwater is a crucial natural resource both for drinking and for the socio-economic development of the VMD. Due to a lack of freshwater in the dry season and an insufficient piped-water supply system, groundwater is a major water supply source [Figure 2/4.2]. The relative share of industry, agriculture and domestic use in groundwater consumption depends on the province under consideration: agriculture is estimated to be the largest consumer in Bac Lieu, Soc Trang and Tra Vinh for instance, whereas domestic use has the greatest share in Ca Mau, Can Tho and Kien Giang. However, the extent of groundwater extraction for aquaculture is not adequately estimated in the data collection. In rural area and coastal areas (*i.e.*, Tra Vinh, Ca Mau, Bac Lieu), groundwater is the only source of fresh water for drinking and industrial activities.

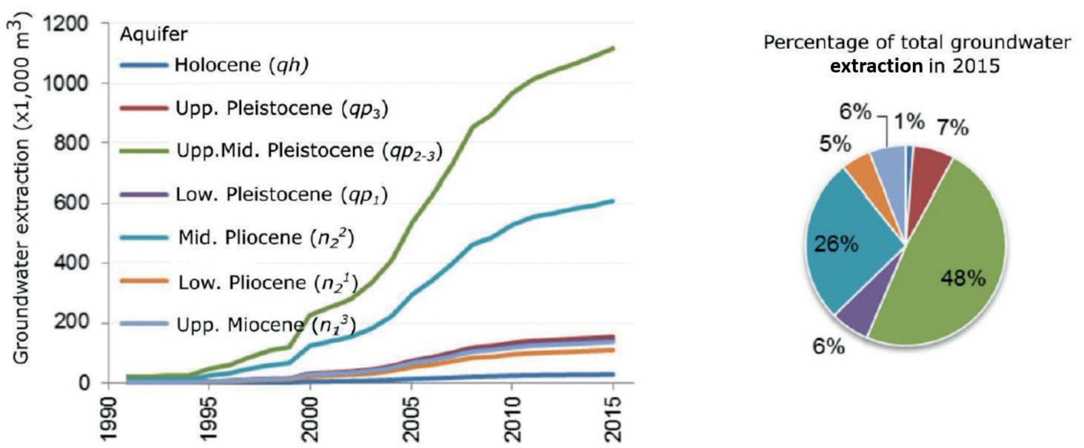
Groundwater extraction rates in the VMD have increased significantly from 140,000 m³/day in 2001 [Wanger *et al.*, 2012] to approximately 1.92 million m³/day in 2010 [Bui *et al.*, 2015], and as high as 2.8 million m³/day in 2020 [Minderhoud *et al.*, 2020]. According to data from the Division for Water Resources Planning and Investigation for the South of Viet Nam (DWRPIS), the groundwater extraction rate has clearly increased in recent years in coastal areas

[Figure 2/4.2]
Groundwater use by sector and province



Data from Bui *et al.*, 2015. N.B. groundwater used for aquaculture is not presented in this data.

[Figure 2/4.3]
Groundwater extraction in Mekong Delta in the different aquifers



Modified from DWRPIS data; Minderhoud *et al.*, (2017).

and dense cities. For instance, the withdrawal rates in Ca Mau and Tra Vinh provinces have increased 2.7 and 1.4-fold from 2010 to 2015; the annual groundwater extraction rate in Can Tho City increased by about 16% per year during 2010–2017. Demographic changes have been very small over this period, and extraction increases have been mostly driven by economic development and the increasing number of people using groundwater, as it is cheap and of good quality. In the An Giang province alone, the groundwater extraction rate dropped from 94,000 m³/day in 2010 to 30,000 m³/day in 2015. The increase in groundwater extraction has occurred in all aquifers, but the most important increases have taken place in the Upper Mid-Pleistocene and Mid-Pliocene groundwater aquifers, which now account for 46% and 28% respectively of total extractions in the Delta [Figure 2/4.3].

3. The improvement of groundwater and related land subsidence policies

3.1 Responsible actors

The water sector in Viet Nam in general and groundwater specifically have gone through a considerable shift in this new millennium in terms of responsible actors. Before 2002, water resource governance fell under the responsibility of the Ministry of Agriculture and Rural Development (MARD). Since 2002, responsibility for groundwater, which is considered a natural resource, rests primarily with the Ministry of Natural Resources and Environment (MONRE), which is responsible for the overall management and use of the resource. However, MARD continues to be an influential actor, since it is in charge of agriculture and rural water supply, to which extracted groundwater greatly contributes. Other ministries are responsible for specific water use in their sectors.

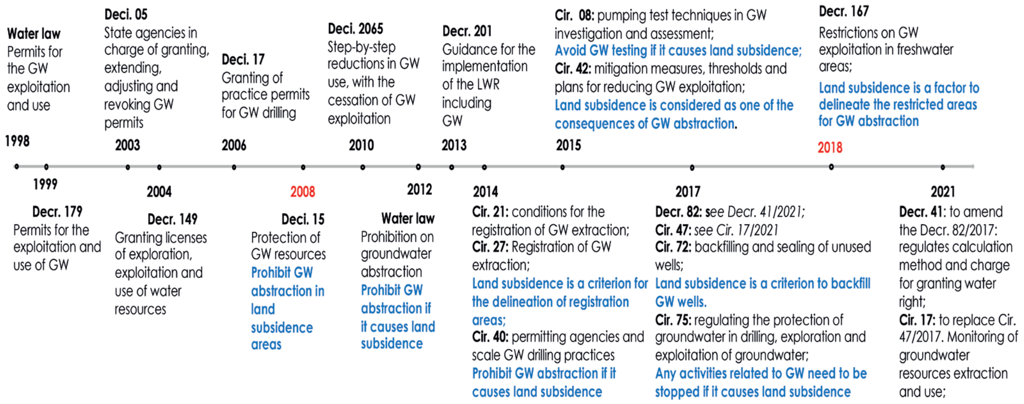
3.2 Policy development and implementation

The supreme institutional and governance framework for water resources including groundwater was first established in 1998, and then amended in 2012 in the Law on Water Resources (LWR) (No. 17/2012/QH13). A number of policies such as Decrees, Decisions, and Circulars further elaborate and instruct the management of groundwater and land subsidence [Figure 2/4.4].

According to the Law of Water Resources 1998, avoiding land subsidence is mandatory for groundwater extraction plans. Decision 15/MONRE, issued in 2008, provides guidelines at the provincial level to protect groundwater, and to identify zones in which groundwater extraction is prohibited and restricted, to minimize groundwater contamination, salinization and land subsidence. Groundwater extraction is prohibited in areas in which land subsidence has been induced by groundwater extraction. Following the decision, several provinces in the VMD such as Long An [Long_An_PPC, 2017], Ca Mau and Soc Trang implemented projects to delineate groundwater prohibition and restriction zones. The province also closed 326 wells during 2016-2020, due to availability of water supply systems [Thanh, 2022].

The most recent regulation was issued in 2018: decree 167 of the Vietnamese Government for

[Figure 2/4.4]
Policy development in groundwater management



Source: authors' compilation based on Neussner, (2019) and RVO (2020).
Deci.: Decision; Decr.: Decree; Cir.: Circular; Dark blue texts are related to land subsidence; The years in red color are milestones in groundwater governance.

groundwater restriction to protect groundwater by avoiding land subsidence, salinization and contamination. The decree 167 is quite similar to the decision 15/2008-MONRE, but it was issued by central government and does not use the term of groundwater prohibition. Based on the decree, local provinces need to delineate groundwater restriction zones for groundwater management. Following the decree, some provinces in VMD like Soc Trang, Ca Mau, Can Tho [Phuong, 2019], An Giang, and Tra Vinh have almost completed their projects to delineate groundwater restriction zones. But other provinces such as Kien Giang and Ben Tre are still completing their lists.

The link between groundwater extraction and land subsidence is thus well recognized, and several laws have tackled the issue over the last decades. However, groundwater management faces many challenges which often prevent efficient implementation of the legislation.

4. Current challenges and recommendations in groundwater management

4.1. Monitoring capacity and measurements

Monitoring groundwater level and land subsidence

To manage groundwater level and land subsidence, a monitoring network is crucial [RVO, 2021]. At the national level, the benchmark surveys conducted by MONRE provided the movement of over 300 unprotected benchmarks, between 2005 and 2017. But these point measurements only provide local information and are inadequate to be interpolated into an accurate map. Few wetland sites in the Delta are equipped with relative Surface Elevation Tables (SETs) measuring shallow subsidence in the top 20 meters [Lovelock *at al.*, 2015], and two subsidence stations are installed in Ca Mau (third station malfunctioned) [Karlsrud *et al.*, 2020]. For groundwater management, MONRE has installed a national groundwater monitoring network for the southern Viet Nam (NGMNS), to monitor both groundwater level (*i.e.* water pressure) and water quality in different aquifers, since 1991. However, the number of wells in this network is actually very limited. In 2020, the NGMNS included only about 58 stations, with some 245 monitoring wells for the whole VMD with an area of ~40 500 km^2.

Generally, a structural monitoring network for land subsidence is non-existent in the Delta. Even though satellite data can provide good information on land subsidence to compensate the lack of in-situ monitoring, the technique has some uncertainties and needs to be calibrated on the basis of onsite monitoring. Lack of monitoring data is the main factor inducing uncertainty into modeling and projections of land subsidence. As stated above, in managing a natural resource, it is above all important to understand its status and impacting/controlling factors. It is thus crucial to improve monitoring networks at the regional and provincial scales, conduct studies, and gather information from various sources on different aspects of monitoring, to collect high-quality data to fill current knowledge gaps.

It is important to keep in mind that policymakers are never fully informed, meaning that policy development requires flexibility and adaptability to cope with uncertainties. The availability of reliable data via an effective monitoring network could be useful for 3D hydro-geological modeling of the Delta (*e.g.*, groundwater flow, or aquifer recharge and storage). Improved groundwater and land subsidence modeling capacity at governing institutions would assist in resource management.

Monitoring groundwater usage information in the VMD

Groundwater extraction volume is difficult to estimate with precision in the VMD. According to circular 27/2014/TT-BTNMT, small wells with extraction capacity < 10 m^3/day can be installed without any license or permission. Small wells are also exempted from circular 17/2021 for monitoring water extraction/use. The total number of small wells in the VMD is currently huge, estimated at over 500,000 in 2010 [Bui *et al.*, 2015] and 779,000 in 2015 [Nguyen *et al.*, 2018]. The number of groundwater extraction wells for aquaculture is not included in the figure. The huge levels of groundwater extraction from these small wells are thus not monitored. For big wells, groundwater extraction rates and levels are monitored, in accordance with circulars 47/2017 and No. 17/2021. However, installation of auto-monitoring sensors is expensive, and up to now the information has mostly been based on reports by well owners. Not knowing the exact level of groundwater extraction generates great uncertainty in simulations, and predictions of groundwater flow, storage and associated land subsidence.

Therefore, the VMD needs to improve these techniques: *e.g.*, measurement meters on large extraction pumps, a jurisdiction system to report actual pumped volumes from registered wells, registration of currently unknown illegal wells, and finding alternative ways to estimate groundwater extraction from small wells realistically.

Understanding hydrogeological structure

Comprehensive understanding of the geological structure and aquifer systems is crucial to clearly identify the causes of land subsidence, and manage groundwater sustainably in the VMD. Even though many wells are installed in the area to analyze the geological and hydrogeological structure [DWRPIS, 2018], aquifer information – such as recharge sources, river-groundwater interaction, depths, hydraulic conductivities, storage, and groundwater levels – is still very limited or unknown, especially in the very deep aquifers and unused groundwater area. These unknown factors can cause difficulties in drawing groundwater restriction zones, and create uncertainties in predicting the land subsidence rate as well. The lack of geological and hydrogeological information can also induce uncertainty in identifying the cause of land subsidence, and cannot clearly demonstrate the relationship between groundwater extraction and land subsidence. Further study of groundwater systems is thus highly recommended for better management of groundwater resources.

4.2. Policy and resources

Spatial scales

The physical borders of aquifer systems seldom coincide with provincial, regional, and national administrative boundaries [RVO, 2021]. Currently, groundwater exploitation and land subsidence have happened at the scale of the entire Delta. However, this scale level is insufficiently covered in policies. This scale mismatch could lead to inequality and ineffectiveness in policy implementation. For example, article 6 of Decree 167 classifies certain subsiding areas as 'Restricted Area 1', which is required to terminate all existing groundwater extraction. However, these restrictions differ per province, thus causing investors to move to areas where they are still allowed to extract groundwater. Extraction in non-restricted areas in return impacts the groundwater resources in the nearby 'Restricted Area 1' zones. To solve this problem, spatial planning on an appropriate scale should be considered a holistic solution in dealing with challenges in fresh water use and availability. In the VMD, an inter-regional plan – not limited by provincial or sectorial borders on sustainable development – and a more detailed master plan including (ground) water availability for certain sectors are recommended.

Collaboration

The conventional top-down and non-participatory approach is still prevalent, with high expectations and requirements of absolute compliance with regard to the mainstream mechanisms [RVO, 2021]. Different responsibilities are assigned to different levels of government, yet these responsibilities are not clearly stated. Lower governmental levels are mostly excluded from the decision-making process [Tran and Rodela, 2019]. In addition, the management approach is mainly driven by the varying interests of local governments, which are constrained by their limited capacity, leading to lack of collaboration between the various jurisdictional areas [Tran *et al.*, 2019]. The traditional management framework results in heterogeneous approach by the different provinces, and fragmentation within the region. Each province has its own strategy and priorities in groundwater management, while the aquifers are shared by several provinces, leading to a free-ride problem in the common use of groundwater resources. Effective management would require local adaptation, which is not easily fostered by the vertical management approach.

Inadequate communication between MONRE (National) and Departments of Natural Resources and Environment (DONREs) (Provincial) results in mismatches between policy goals and actual implementation, as discussed above. Regional collaborations among and between the two levels are therefore needed to resolve these mismatches. MONRE, in the leadership role, is recommended to direct this process, and reach out to DONREs to identify and consider local issues in future central planning. DONREs and relevant provincial actors are encouraged to coordinate and share common requests to MONRE, to amplify their voices [Tran *et al.*, 2020] and reduce transaction procedures.

Additionally, there is currently no cross-border coordination or monitoring between the provinces and Cambodia. Different understanding of the trans-boundary aquifers and management policies between the two countries could potentially hinder bilateral agreements. Regular dialogue is suggested, to facilitate collaboration in trans-boundary aquifer management between the two countries.

Licensing and pricing

The licensing of groundwater has proved effective internationally in managing groundwater extraction, and in avoiding overexploitation and thereby mitigating extraction-induced subsidence [RVO, 2021]. However, for the VMD, implementation of effective licensing is complicated at several levels. MONRE is responsible for all licenses for wells > 3000 m^3/day, while provinces are responsible for licenses below that quantity. Within provinces, districts regulate groundwater licensing for extractions < 20 m^3/day. There is also no groundwater fee for small wells (< 20 m^3/day; Decree No 41/2021/NĐ-CP). Users usually only have to pay for the installation the energy costs of pumping. Replacing groundwater by surface water will increase the costs, which will be unaffordable for some domestic users and economically less attractive for business sectors which depend on water for production. Moreover, small wells < 10 m^3/day are not normally considered to be important in policy-making, although their influence in large numbers can be substantial. Installation of many wells in the VMD will negatively impact not only land subsidence, but also fresh groundwater quantity due to salinization and contamination [Ha *et al.*, 2019b; Ha *et al.*, 2022]. However, in the current situation the indirect negative environmental effects of groundwater extraction, such as damage by land subsidence and salinization, are not factored into the price of groundwater.

Improving the current administrative process to provide quick and simple registration will encourage the registration of new and unregistered wells. In parallel, a groundwater taxation scheme offsetting the imbalance of ground- and surface water pricing is suggested. In doing so, human water consumption for basic needs should be prioritized over industrial and agricultural uses during the licensing process.

Policy Enforcement and implementation

There is a lack of enforcement in groundwater and land subsidence governance [RVO, 2021]. Sanctions for misdemeanors in groundwater use are insufficient to ensure implementation. In addition, the governing system is considered to be insufficient in terms of financial and human resources [RVO, 2021]. Regarding financial resources, local officials stated that the central government issues regulations on groundwater management, but does not allocate a budget for implementation. Local governments have to mobilize the resources themselves. Since groundwater is not the most urgent issue, many local governments prioritize finance for other short-term issues or ones they perceive to be more important, such as irrigation infrastructure or transportation. Regarding human resources, the number of specialists who are trained in water management in general and groundwater in particular is insufficient. They are therefore allocated various responsibilities that sometimes do not match their specialization. It is therefore difficult for local authorities to monitor and manage groundwater. Increased management capacity and awareness among the population are both recommended for the proper implementation of groundwater policy, which is further discussed in section 5.2.

5. Long term management of groundwater

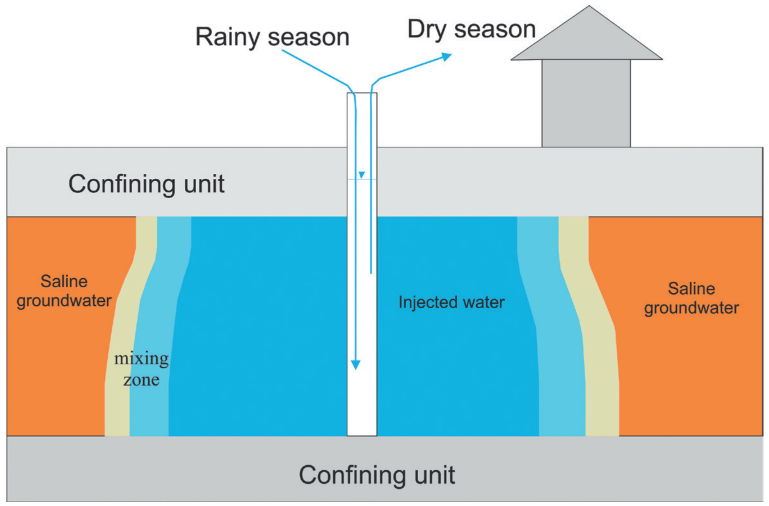
Further to the above recommendations, this section provides technical and educational tools for long-term management of groundwater and minimizing land subsidence in the Mekong Delta.

5.1. Technical tools

According to Poland *et al.* (1998), methods to control land subsidence include – among others – reduction of groundwater exploitation, artificial recharge of aquifers, or a combination of these techniques. In Thailand, the Chao Phraya River basin has a similar geological profile to the Mekong Delta, with thick sediment layers (> 500 m) and clay-rich organic matter on top of the geological strata [Lorphensri *et al.*, 2019]. Since 1977, the basin has dealt with serious land subsidence induced by groundwater extraction. The land subsidence rate was up to 10 cm/year during the period 1978–1981. The Thai government instituted a series of management actions, including not allowing new pumping wells, creating groundwater critical zones, and implementing a groundwater tariff and conservation work [Lorphensri *et al.*, 2019]. As a result, since 2000, groundwater extraction has been limited at a sustainable rate of 1.2 million m^3/day, while the land subsidence rate has been reduced from 10 to < 1.3 cm/year since 2000. Other examples of successfully reducing land subsidence can be found in the USA, where surface water has been transferred from other areas to minimizing groundwater extraction at the affected area [Poland *et al.*, 1998]. In Tokyo, Japan, infiltration rates of surface water have been increased in addition to restrictions of groundwater extraction. As a result, the land subsidence rate has been reduced from 20 cm/year during the 1970s to zero in recent decades [Sato *et al.*, 2007].

In the VMD, several studies also strongly recommend reducing groundwater extraction to minimize land subsidence and groundwater salinization [*i.e.*, Erban *et al.*, 2014; Minderhoud *et al.*, 2020]. In upstream provinces such as An Giang and Dong Thap, such re-

[Figure 2/4.5]
The concept of Managed Aquifer Recharge technique: Aquifer Storage and Recovery in the Mekong Delta



ductions in groundwater pumping could be implemented, since fresh surface water is available as an alternative resource. However, in rural and especially coastal provinces such as Ca Mau, Soc Trang, and Bac Lieu, the same approach could not be applied due to salinization of surface water [Figure 2/4.1.a].

Finding alternative or economizing freshwater sources may be the optimal approaches for this area to save groundwater. Alternative freshwater resources could be obtained from rainwater, imported water from other areas, groundwater in deep aquifers, or from offshore sources. Various strategies could be considered for water-saving and providing alternative freshwater sources:

– **Smart water use:** The coastal areas may need to divert groundwater from less important uses. Water savings through smarter irrigation techniques and reuse of wastewater, a cost-effective method [Haruvy, 1997], could reduce groundwater extractions. A reclamation water regulation strategy may also provide possible options for water-stressed areas.

– **Improve surface water quality:** Intensive agriculture is one of the main causes of water pollution. Transforming agriculture will require integrated solutions involving multiple actors and sectors. One of the goals is to reduce agricultural pollution by decreasing runoff, which would prevent surface water pollution and increase surface water usability for other users. Feasibility studies, to support actors who implement surface water projects for water supply and treatment, are needed.

– **Conjunctive use:** In the coastal zone, the reduction of groundwater extraction could also be achieved by conjunctive use of groundwater, surface water and rainwater. This may be the most effective approach to increase the efficiency of freshwater management. Indeed, the Mekong Delta has intensive rainfall and a large amount of fresh surface water in the rainy season. Annual precipitation is high (~ 2000 mm), of which 90% occurs in the rainy season. Meanwhile, the Mekong River brings an abundant flow of 4.5 km^3/year to the Mekong Delta.

– **Rainfall harvesting and Management of Aquifer Recharge (MAR):** Technical solutions like freshwater storage using excess water collected from treated wastewater, surface water or rain water to recharge wells or aquifers could be considered. The water can be stored in the aquifer system or even in saline aquifers during the rainy season for later use [Figure 2/4.5]. It closes the water gap between water supply and demand in space and time, and can prevent land subsidence and salinization. This technique is a cost-effective method for storing water because no big reservoir and storage sites are available.

In Southern Viet Nam, several pilots for MAR/ASR investigation have been conducted. Nguyen *et al.* (2011) have performed a rainwater injection test in the fresh groundwater aquifers in the Ho Chi Minh City area. MAR has been also implemented at a pilot scale in Tra Vinh province, exploring the potential for shallow infiltration in sandy dune deposits (FAME project). Ha *et al.* (2018) also conducted a rainwater injection test in a saline groundwater zone in the Ho Chi Minh City area. However, Ha *et al.* (2018) suggest that application of MAR in the Mekong Delta needs to be carefully implemented, because the techniques can induce mobilization of trace metals (*i.e.* As, Fe, Mn). Nevertheless, these hydrogeochemical problems can often be solved, and MAR projects have been successfully implemented over the last 60 years in many areas of the world [Dillon *et al.*, 2019]. However, it should be noted that MAR techniques could not provide freshwater in equivalent amounts to current levels of groundwater extraction.

5.2. Educational tools for sustainable groundwater management

Behavior change

Alongside institutional and technical solutions, changing the behavior of users is crucial to ensure the sustainability of groundwater governance. Raising the awareness of users to promote information sharing can change user behavior. Different topics and campaign strategies should be selected and designed according to different types of users. For household users in cities, for example, awareness-raising on the use of treated water and proof of good quality is needed, to encourage them to switch to water supply options other than groundwater. Meanwhile, rural users or industries might need a better understanding of regulations and sanctions on illegal groundwater exploitation.

Capacity-building

Strengthening public sector organizations is essential, because consistency in capacity to implement policies is important for each individual province, as well as to stimulate regional coordination of groundwater management and land subsidence. Technical assistance and training are essential factors for capacity-building. Practitioners need to provide themselves with knowledge about the existing aquifers and relevant mechanisms, such as the replenishment and compacting processes. Along with this, obtaining technical skills in applying relevant software – such as Geographic Information System (groundwater and land subsidence modeling software) – will support the officials responsible for managing the activities. Encouraging further education and training for officials to address knowledge gaps, and strengthening their skills through workshops, short courses, and collaboration with academic institutions, is recommended. In addition, preparing high quality human resources by encouraging more students to obtain qualifications and providing them with an excellent education portfolio in this field of expertise are considered to be more sustainable long-term solutions. Once again, to achieve this, awareness-raising on the importance of 'invisible' groundwater, its related impacts and relevant aspects needs to be carried among Vietnamese society as a whole.

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Focus 5

A resilient and low-carbon rice farming strategy

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Abstract

Over the past decades, rice cultivation in Viet Nam's Mekong Delta has steadily intensified. The negative impacts on ecosystems and the environment of this high-intensity economic growth have been accentuated by the effects of climate change (increased drought, flooding and saltwater intrusion). In 2017, the government released Resolution 120: a response to current problems, and also a potential roadmap for natural solutions. The objective of this Focus is to provide information that can contribute to evaluating and updating adaptation and mitigation measures for rice cultivation. It focuses on biophysical aspects related to nature-based solutions for the sustainability of rice cultivation. We provide maps of climate and environmental risks affecting rice fields, using observations and model-based projections, and discuss possible adaptation and mitigation options. For the short term, a number of measures proposed in the Resolution seem to be in line with our observations and proposed options (reduction of the intensity of rice cultivation in climate change-affected areas, modification of planting seasons, modification of production by alternating rice with other land uses). However, for long-term plans, the spatial planning approach will need to be based on projections for time horizons beyond 2030. Work is needed to assess adaptation measures in an integrated way – combining projections for the cropping calendar, crop yield and irrigation practices, and taking climate projections and the constraints of flooding and saline intrusion into account – for the whole of the Mekong Delta.

Tóm tắt

Trong những thập kỷ qua, việc trồng lúa ở Đồng bằng sông Cửu Long của Việt Nam đã liên tục được thâm canh. Tác động tiêu cực đến hệ sinh thái và môi trường của quá trình tăng trưởng kinh tế cường độ cao này bị gia tăng bởi ảnh hưởng của khí hậu (gia tăng hạn hán, lũ lụt và xâm nhập mặn). Vào năm 2017, chính phủ đã ban hành Nghị quyết 120, một giải pháp cho các vấn đề hiện tại và cũng là một lộ trình tiềm năng cho các giải pháp tự nhiên. Mục tiêu của bài này là cung cấp thông tin có thể góp phần đánh giá và cập nhật các biện pháp thích ứng và giảm nhẹ đối với canh tác lúa. Thông tin tập trung vào các khía cạnh lý sinh liên quan đến các giải pháp tự nhiên cho sự bền vững của canh tác lúa. Chúng tôi cung cấp bản đồ về các rủi ro khí hậu và môi trường ảnh hưởng đến ruộng lúa, sử dụng các quan sát và dự báo dựa trên mô hình, đồng thời thảo luận về các phương án thích ứng và giảm thiểu.

Trong ngắn hạn, một số biện pháp được đề xuất trong nghị quyết phù hợp với quan sát trong những năm gần đây của chúng tôi (giảm cường độ canh tác lúa ở các vùng bị ảnh hưởng bởi khí hậu, điều chỉnh thời vụ gieo trồng, điều chỉnh sản xuất bằng cách xen canh lúa với các sử dụng đất khác). Tuy nhiên, đối với các kế hoạch dài hạn, cách tiếp cận quy hoạch không gian sẽ cần phải dựa trên các dự báo cho các tầm nhìn xa hơn năm 2030. Cần nghiên cứu để đánh giá các biện pháp thích ứng một cách tổng hợp, kết hợp các dự báo về lịch trồng trọt, năng suất cây trồng, thực hành tưới tiêu, sử dụng dự báo khí hậu và các hạn chế của lũ lụt và xâm nhập mặn đối với toàn bộ Đồng bằng sông Cửu Long.

Résumé

Au cours des dernières décennies, la riziculture dans le delta du Mékong au Vietnam n'a cessé de s'intensifier. Les impacts négatifs sur les écosystèmes et l'environnement de cette croissance économique à haute intensité sont accentués par les effets du changement climatique (augmentation des sécheresses, des inondations et des intrusion salines). En 2017, le gouvernement a publié la Résolution 120 : une réponse aux problèmes actuels et également une potentielle feuille de route pour des solutions naturelles. L'objectif du présent focus est de fournir des informations pouvant contribuer à l'évaluation et à la mise à jour des mesures d'adaptation et d'atténuation pour la riziculture. Il se concentre sur les aspects biophysiques liés aux solutions fondées sur la nature pour la durabilité de la riziculture. Nous fournissons des cartes des risques liés au climat et à l'environnement affectant les rizières, en utilisant des observations et des projections basées sur des modèles, et nous discutons des options possibles d'adaptation et d'atténuation. Certaines mesures proposées dans la Résolution pour le court terme semblent conformes à nos observations et aux options proposées au cours des dernières années (réduction de l'intensité de la riziculture dans les zones affectées par le changement climatique, modification des saisons de plantation, modification de la production en alternant le riz avec d'autres utilisations des terres). Cependant, pour les plans à long terme, l'approche par planification spatiale devra être basée sur des projections pour des horizons de temps au-delà de 2030. Des travaux sont nécessaires pour évaluer les mesures d'adaptation de manière intégrée – en combinant des projections pour le calendrier cultural, le rendement des cultures, les pratiques d'irrigation, et en tenant compte des projections climatiques et des contraintes liées aux inondations et intrusions salines – pour l'ensemble du delta du Mékong.

1. General context

Rice production plays an essential role in Viet Nam's agricultural and rural development, contributing to national food security, affecting the livelihoods of the majority of farmers, and impacting on social security and social stability. Rice farming also embodies ecological and cultural values in Vietnamese society.

Around 82% of Viet Nam's arable land is used to cultivate rice, with the Mekong Delta being the key rice production region, contributing more than 50% to national rice production, and accounting for 90% of exported rice. In 2021–2022, the country is expected to export 6.5 million tons of rice, and is ranked the world's second rice exporter [Statista, 2022].

The area of the Vietnamese Mekong Delta (VMD) is 40,921.70 km^2 and the region is home to 17.4 million people, of whom approximately 80% are engaged in rice production, farming a total of about 3,898 million hectares [GSO, 2021]. However, the Mekong Delta is also a hotspot for climate change, facing rising sea level, higher temperatures, changes in rainfall and flood patterns, and increases in the frequency of extreme weather events. The Delta is also facing strong local human pressures, especially groundwater extraction – driving high rates of subsidence – and sediment starvation from upstream dams and excessive sand mining, which drives riverbed level incision and leads to increased saline water intrusions during the dry season (see introduction of Part 2, this report).

1.1 Evolution in rice farming in the Vietnamese Mekong Delta

Over the last three decades, rice-based farming systems in the VMD have been profoundly transformed. Facing an urgent need to boost rice production after 1975, the government increased investment in water control and irrigation, and promoted the intensification of rice farming, leading to the widespread adoption of double- and triple-cropping systems. Drainage and canal construction for agriculture in the upper Delta has accelerated since then, and the Delta now has over 10,000 km of major canals that have modified the hydrology and agroecosystems of the region. About 90% of the cropland is now irrigated [White, 2002].

With the expansion of irrigation and increased cropping intensity, the rice-planted area in the Delta increased from around 2 million ha in the post-war decade to 3.2 million ha in 1995, and 4.3 million ha in 2015. Since 2016, a decrease of the rice-planted area has been observed, with 3.9 million ha in 2020. Likewise, rice production decreased from 25.58 million tons in 2015 to 23.82 million tons in 2020 [GSO, 2022].

This current decreasing trend in rice production may be explained by recent national concern about the impacts of rice intensification on farmer livelihoods and the environment. Intensive production, in many cases of low-quality rice, has not provided farmers with adequate returns, especially as both domestic and global demand have shifted in favour of higher-quality rice and more diverse diets. Continuous rice production required massive use of fertilisers and pesticides, leading to soil and water pollution and reduction of biodiversity. Moreover, increased drought, flooding, and saline intrusion have become more and more of an obstacle for continuous rice production in impacted areas.

Furthermore, while agriculture in Viet Nam produces 14.6% of its Gross Domestic Product (GDP), it is also the second contributor to its greenhouse gas (GHG) emissions (~70 Megatons of CO_2 equivalents, or 15.8% of total GHG emissions in 2019)[1], with rice cultivation being a major source and methane the first contributor (~48 Megatons of CO_2 equivalents). Reduction of the area planted with rice, together with implementation of low-carbon[2] agricultural practices, could contribute significantly to reducing the GHG emissions of Viet Nam. Therefore, rice agriculture challenges in Viet Nam cover both adaptation to, and mitigation of climate change.

1.2 Policies concerning paddy fields in the VMD

Having recognised the impacts of rice intensification, in 2017 the government released Resolution 120, a response to current problems and also a potential roadmap for natural solutions. The Resolution[3] noted that *"the negative impacts of high-intensity economic growth of the region have become more acute"* and calls for *"a new vision, strategic orientation, comprehensive, radical and synchronous solutions"*. Targets have been set to increase the quality rather than the volume of rice, and to diversify rice-based farming systems to make the best use of each agro-ecological zone in the Delta. Reduction in the area planted with rice is intended to help reduce the overuse of chemicals in the ecosystems, while opening further opportunities for the diverse range of crops, livestock, and aquatic products that are increasingly in demand among the Vietnamese population.

In 2021, Decision-No-555-QD-BNN-TT-2021 approved and updated the scheme for restructuring Viet Nam's rice industry, following other governmental decisions[4] for paddy rice conversion. In this document, the adaptation measures to climate change for rice agriculture are as follows:

– Use rice varieties highly resistant to adverse conditions (saltwater intrusions, drought, heat and flooding) as well as pests and diseases, and with a short growth period to avoid saltwater intrusions, drought and flooding;

– Adjust planting seasons in line with early warnings about hydrologic conditions;

– Change production structure on paddy fields, such as by rotating rice with shrimp in areas affected by saltwater intrusion, and with fast-growing terrestrial plants in drought-stricken areas;

– Build and reinforce infrastructure, especially irrigation systems, river dikes and sea dikes;

– Complete saltwater intrusion, drought and flooding warning maps for key rice production regions, which will provide the basis for flexible changes to planting seasons and technical solutions for sustainable rice cultivation.

1. https://ourworldindata.org/co2/country/vietnam

2. "Low-carbon" means practices to reduce GHG emissions, including not only CO_2 but also methane and nitrous oxide emissions.

3. Resolution No.120/NQ-CP dated November 17, 2017 of the Government on sustainable and climate-resilient development of the Mekong River delta.

4. Government's Decree No. 35/2015/ND-CP (dated 13/4/2015) on management and use of paddy land, and the Government's Decree No. 62/2019/ND-CP (dated 11/7/2019) on amendments to Decree No. 35/2015/ND-CP.

Reducing GHG emissions in rice production is also mentioned in the updated 2020 Nationally Determined Contribution (NDC) as the national strategy for achieving emission reduction. At the COP26 in 2021, Viet Nam joined 102 countries in signing a methane emission reduction pledge to reduce global methane emissions by 30% by 2030 (from 2020 levels). According to the Global Methane Pledge,[5] such a reduction would reduce global warming by 0.2°C by 2050, contributing to the overall commitment to keep global temperature rise within 1.5°C above the pre-industrial level.

1.3 Objectives of the chapter

In this general context, the objective of the present focus is to provide information that can contribute to assessing and updating the adaptation and mitigation measures for rice cultivation, as specified in Decision-No-555-QD-BNN-TT-2021 and Resolution 120. It focuses on the biophysical aspects linked to nature-based solutions for sustainability of rice agriculture. We provide maps of climate and other environmental-related risks impacting rice land, using observations and model-based projections, and we discuss possible options for adaptation and mitigation measures, with respect to the measures proposed in the above-mentioned Decisions and Resolution. The focus builds on the previous study [Le Toan *et al.*, 2021] on agriculture in Viet Nam under the impact of climate change, in chapter 4 of the GEMMES COP26 report [Espagne *et al.*, 2021].

5. https://www.globalmethanepledge.org/

2. Risk areas for Rice agriculture in the Mekong Delta

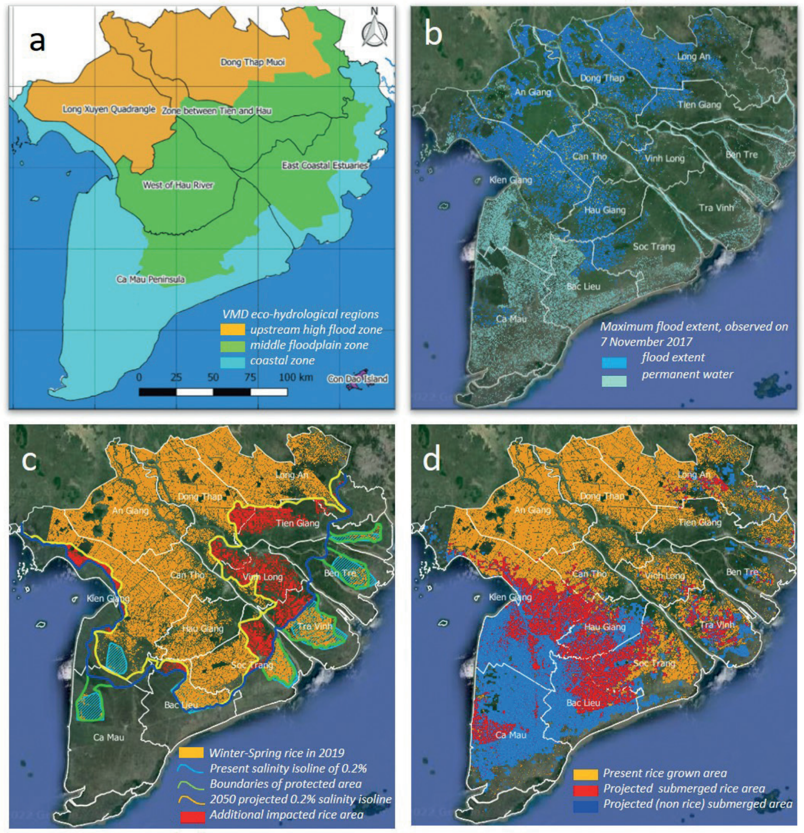
2.1 Rice cropping systems in different hydro-ecological regions

The climate of the Mekong Delta is well suited to developing almost all types of tropical agriculture. The climate is classified as tropical monsoon and is dominated by the Southwest monsoon, which gives rise to wet and dry seasons of approximately equal length. The dry season is from December to April–May with low rainfall over most areas. The monsoon season lasts from May–June to November–December, with heavy rainfall over most of the Mekong River basin, leading to high water flows and floods of various depths in the Delta. River water reaching the Viet Nam part of the Mekong Delta is distributed through the Mekong and Bassac rivers, their branches, and man-made navigation canals. In a normal year, the water level starts rising in June, peaks in September, then begins to recede. Floods start in upstream regions in August, expand laterally to the rivers and downstream, and peak in November, before receding in December.

In terms of temperature, water availability and length of the rice cycle (85–100 days and 100–120 days for respectively short-cycle and long-cycle rice varieties), it is possible to have three rice-cropping seasons in the Mekong Delta: 1] a wet season from July to November (the main crop, traditionally referred to as "Autumn-Winter crop"); 2] a late wet/early dry season from November to February (the "Winter-Spring crop"); and 3] a late dry/early wet season from March to June (the "Summer-Autumn crop"). However, depending to the hydro-ecological conditions, rice cultivation can encounter different constraints across the Delta, limiting the number of rice crops per year

Regarding rice cultivation, the MRD can be divided into 3 hydro-ecological regions [Bong *et al.*, 2018]: the upstream zone, the middle zone and the coastal zone [Figure 2/5.1.a].

[Figure 2/5.1]
The Mekong Delta and the risk areas



(a)The three eco-hydrological regions of the Vietnam Mekong Delta (in Bong *et al.*, 2018). (b) Map of the maximum flood extent observed on 7 November 2017 (Sentinel-1 data); rice field inundated by irrigation are excluded. c) Projections of salinity intrusions in 2050 in a worst-case scenario (RCP8.5 climate scenario, high subsidence and riverbed erosion rates (Eslami *et al.*, 2021)) and rice area impacted. (d) Map of the areas falling below sea level by 2050 under RCP4.5 global sea-level rise scenario (+25 cm) and land subsidence triggered by a steady 2%/year increase in groundwater extraction.

In the Upstream high flood zone (upper Kien Giang, An Giang, Dong Thap, East of Long An, see Figure 2/5.1.b for the location of the provinces), the dominant constraint is wet season flooding, with flood depths up to more than 4 m. Since 2000, ring dikes have been introduced for flood protection, enabling intensive rice cultivation. Triple-rice crop is found within full dike systems, with variation in elevation from 4 to 6 m above sea level, where floodwater is kept out entirely and water is supplied to rice crops only via irrigation. Double-rice crop is often found within the semi-dike system, with an elevation ranging from 2 to 3 m above sea-level, where the fields receive pumped water only during the first two rice crops and are inundated during the wet season [Park *et al.*, 2020].

The Coastal zone includes coastal flats and sand ridges on the East, and the Ca Mau Peninsula at the southernmost part of the Delta. These zones are subject to dry-season saltwater intrusion, drought, and land subsidence (GEMMES COP26 report, chapter 9). In coastal zones, dikes and large hydraulic structures to prevent saline water intrusion have been built (*e.g.* in Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, Kien Giang) to allow farming during the dry season. In the Ca Mau Peninsula, rice production is limited to a single wet-season crop, and large areas have been developed for brackish-water shrimp farming.

The Middle Alluvial Floodplain zone can experience, from upper to lower regions, a large shift from deep- and long-term inundation to no inundation during the wet season, and from non-saline to saline water during the dry season. Double and triple crop can be found. In the upper part, as for the high flood zone, semi-dike systems protect the end of the Summer-Autumn rice crop from early flooding. In the lower part, dike protection from saline water enables the dry season Winter-Spring crop.

2.2 Impacts of annual flooding on rice agriculture

Observations

Inundation in the Mekong Delta during the flood season is caused by 4 factors: 1] natural floods of the Mekong river and overland flow, 2] artificial floodwater distributed by canals and controlled by dikes and sluice gates, 3] extreme local precipitation events, and 4] floods related to high tides [Kuenzer *et al.*, 2013].

In general, inundation in the upper and middle part of the Mekong Delta is predominantly caused by river-induced floods, overland flow, and human floodwater control and retention; whereas in the low-lying southwestern part of the Delta, flooding is induced by both high tides and human actions. Climate change and local or regional human activities (upstream dam operations, dykes, riverbed level incisions) are both expected to drive changes in flood patterns and dynamics. Therefore, information and projections on the flood patterns and dynamics are needed to assess the current and future impacts of flooding on rice cultivation.

In most previous works, water level is used as an indicator for flood extent, but in the Mekong Delta it is difficult to convert water level into flooded area, due to lack of accuracy in Digital Elevation Models [Minderhoud *et al.*, 2019], and the presence of dense networks of dikes and ridges. Here, we provide observations of flood timing and extent by remote sensing. The flooding season (from August to December) has been monitored every 6 days (or 12 days) since 2015, using Sentinel-1 data. The resulting flood maps exclude rice field inundation by irrigation [Trang *et al.*, 2022]. Figure 2/5.1.b shows the maximum flood extent monitored in 2017. It can be observed that the ring dikes in the upper Delta protect most of An Giang and part of Dong Thap rice fields from floodwater. Flood dynamics show an important interannual variability, with for instance a reduction of ~20% in flood extent in 2020 compared to 2017. The timing of flood onset and flood peak may also change by up to 2 weeks, the latter occurring for instance on 27 October in 2018 and 9 november in 2020. Results also show that in 2017 and 2018, the early flooding impacted the Summer-Autumn rice crop in downstream semi-dike regions, mainly in Can Tho, Kien Giang and Long An. Traditionally, the Summer-Autumn crop here is harvested towards the end of August.

Possible adaptation and mitigation options:[6] Reduce risks from flooding or changes in flood timing and extent

Measure 1: Adjust planting seasons

An adaptation measure to counter early flooding or larger flood extent would be to advance the crop calendar of the Summer-Autumn rice season in potentially impacted areas, *e.g.* in semi-dike middle VMD. The measure is in line with Decision No-555-QD-BNN-TT-2021, with 'flexible changes of planting seasons', and also with the need to have available flood warning maps. However, longer term adaptation measures will need to take account of future changes in flood extent and duration under the combined effect of climate change, upstream dam operation, dikes and sluice gates [*e.g.* Triet *et al.*, 2020].

Measure 2: Reduce upstream wet season rice production

According to Triet *et al.*, (2017), the upstream high-dike system impacts downstream hydrodynamics by changing inundated floodplain areas. The flood maps have shown that in the high dike areas of Dong Thap province, there is an inter-annual rotation between wet season rice and flooding. This could be a trade-off solution to benefit from the fluvial sediment deposition on floodplains, and to preserve the rice prodution. Finally, if the paddy fields in high dike regions store flood water during the flood season, and release the waters at the beginning of the dry season, before the Winter-Spring crop, it could be beneficial for the reduction of saline water intrusion in the downstream regions, though very large water volumes would actually be required to have a significant effect (see Focus 3).

However, the impacts of reducing the wet season crop need to be assessed not only in terms of environmental benefit, but also regarding economical returns for farmers. The rice crop during the flood season has the lowest yield, due to limited solar irradiation, and is the most vulnerable to pest and disease. Therefore, reducing the wet season rice crop would also help to reduce the amount and the cost of chemical (fertilisers, pesticides) use. Practicing double crop instead of triple crop would enable planting higher-value rice varieties with long growth cycles for the other two crop seasons. This would be in line with the target of Resolution 120 on 'better quality than more volume' in rice production. For these reasons,

6. **Adaptation** involves adjusting to actual or expected future climate. The goal is to reduce our risks from the harmful effects of climate change. It also includes making the most of any potential beneficial opportunities associated with climate change (for example, longer growing seasons or increased yields in some regions). **Mitigation** involves reducing the flow of greenhouse gases into the atmosphere, either by reducing sources of these gases or enhancing the "sinks" that accumulate and store these gases.

the reduction of flood season rice in the upper Delta as a measure of adaptation – although not envisaged in Decision-No-555-QD-BNN-TT-2021 – is a potential solution to be assessed for future updated decisions.

2.3 Effect of saline water intrusion on rice agriculture

During the dry season, coastal areas of the Mekong River Delta face saline intrusion in surface waters. This natural process arises from competition between the river and ocean forces, but is enhanced by global sea-level rise, land subsidence and most of all sediment starvation. Indeed, the main driver of the increase in salt intrusion observed over the past 20 years is riverbed level erosion (10–15 cm/year), caused by sediment starvation from upstream dams and excessive sand mining [Eslami *et al.*, 2019].

In chapter 4 in GEMMES COP26 report, it was found that 95% of the current rice area is within a region with 0.2% of surface water salinity or less during the dry season. By 2050, without riverbed incision, the impact of increased saline water intrusions on rice area would be marginal (+3%). But if excessive sand mining continues and riverbed erosion rates remain at present-day level, it would drive large increases in saline water intrusions, which would increase the impacted rice cropping area by 13% (200,000 ha), in the provinces of Tien Giang, Vinh Long, Tra Vinh and Soc Trang [Figure 2/5.1.c].

Possible adaptation and mitigation options: Reduce risk from saline water intrusion

Measure 1: Reduce sand extraction from the rivers

Reducing sand extraction from the rivers, which worsens saline water intrusion, appears to be a relevant and urgent mitigation measure (see Focus 1, this report).

Measure 2: Change the rice crop calendar

An adaptation measure would be to change the crop calendar, in line with the short- to long-term projections of impacted areas. This is in line with Decision No-555-QD-BNN-TT-2021, for 'flexible changes of planting seasons', and also with the need for available salinity intrusion warning maps. In addition to salinity projections, changing the crop calendar would also require simulation of crop yield, with different planting dates under different climate scenarios [cf section 2.5].

Measure 3: Convert the Winter-Spring rice crop to other land use

A more drastic adaptation measure would be to convert the Winter-Spring rice crop in potentially impacted areas to other land use. After the recent drought and salinity intrusion events in 2016 and 2020, the conversion of rice land to other crops or land use is already being observed in coastal provinces. In Ben Tre, for example, where rice has been replaced by other crops (*e.g.* vegetables, corn, banana, mulberry, etc.).

2.4 Loss of rice area in shrinking Delta

The combined effect of global sea-level rise, land subsidence, and reduced sediment degradation will cause the Mekong Delta to lose elevation relative to sea level [Minderhoud *et al.* 2019]. Without adaptation, land that will be below sea level may be permanently inundated and no longer suitable for agriculture. In chapter 4 of the GEMMES COP26 report [Le Toan *et al.*, 2021], we assessed the extent of current rice area which could fall below sea-level by 2050, using relative sea-level rise projections for different groundwater extraction-induced subsidence scenarios [Minderhoud *et al.*, 2019, 2020]. As a first order assessment, we assume that there is no adaptation and that these areas would be inundated.

Assuming a global sea-level rise of 25 cm and drastic reduction in groundwater extraction allowing a recovery of groundwater level, 22% of current rice area could be lost. In the case of a steady increase in groundwater extraction of 2%/year, the proportion would increase to 34% [Figure 2/5.1.d]. The impacted provinces would be Kien Giang, Hau Giang, Soc Trang, Bac Lieu, Ca Mau and Tra Vinh.

Possible adaptation and mitigation options: Reduce risk from decreased elevation in the Delta

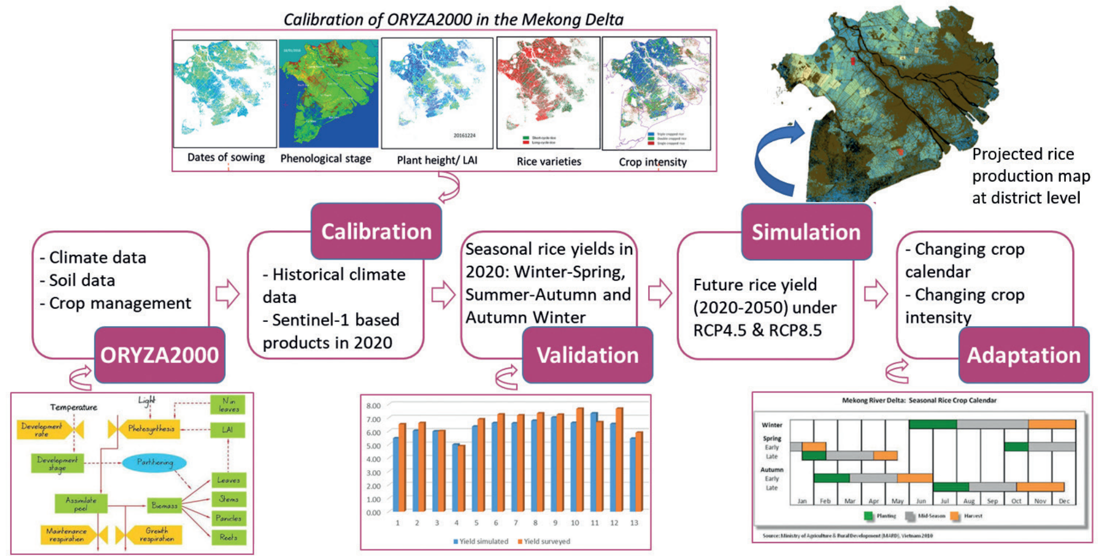
Measure 1: Reduce ground water extraction to restrict the impacted area

(see Focus 4, this report).

Measure 2: Conversion of rice to other land use

The adaptation measure would be to gradually convert rice land to other land use: mangrove forest and/or aquaculture. For aquaculture, it is important to avoid the use of groundwater for fresh water (fish) species, which would worsen the loss of elevation through land subsidence.

[Figure 2/5.2]
The methodology framework for rice yield simulation



2.5 Effect of changing temperature and precipitation on rice yield

Global climate change will drive further temperature increase and precipitation changes over the VMD (see introduction of part 2). In this section, we investigate the impacts on rice yield with the process-based rice model ORYZA 2000.

Input data for the model consist of climate data, soil data and data on crop management practices [Figure 2/5.2]. In past studies, crop management, rice varieties and crop calendar have often been taken as general information relevant to the Mekong Delta [*e.g.* Bui *et al.*, 2018]. However, these parameters depend on the hydro-ecological conditions and could vary greatly due to farmers' cultivation practices. For adaptation and mitigation measures, it is important to have the projection results not only at Delta and provincial level, but also at local scale.

For this purpose, we used the Sentinel-1 satellite mapping products to derive relevant inputs for the model. These include 10 m pixel-based information on the presence of growing rice, its sowing date and harvest date, phenological stage, plant height, long/short rice cycle varieties [Phan H. *et al.*, 2021; Phan H., 2018; Phung *et al.*, 2022]. The model parameters were refined by a comparison of model outputs with yield data from the National Statistics Office for 3 rice crops per year in 2019 and 2020. The validated model[7] was subsequently used for projections of future rice productivity in 2030 and 2050, under RCP 4.5 and RCP 8.5 climate scenarios, using the downscaled climate projections presented in chapter 1 of the GEMMES COP26 report.

The methodological framework is summarized in Figure 2/5.2.

The impacts of changing temperature and precipitation are quantified by a comparison between the average yields simulated for Winter-Spring, Summer-Autumn and Autumn-Winter crops for the last five years (2015–2020) and for 2025–2030 and 2045–2050. By 2050 and under RCP4.5 climate scenario, average rice yields over the whole Delta could decrease by 4.10% for the Winter-Spring crop, 6.8% for the Summer-Autumn crop, and 6.7% for the Autumn-Winter crop (see chapter 4 of the GEMMES COP26 report). However, our model simulations show very large variations across the Delta, not only at provincial level but also within provinces. In order to take adaptation measures, further work is needed to compare the simulated yields at experimental fields, and at district and village levels, in order to take the local conditions of the rice areas into account.

The ORYZA 2000 model was then used to assess the impact of the two adaptation measures considered in the previous sections: changes in crop calendar, and in rice varieties.

Possible adaptation and mitigation options: Reduce risk on rice yield in future climate

Measure 1: Change in crop calendar

Changing the crop calendar would avoid impacts from early flooding in semi-dike middle regions, and from drought and salinity in coastal regions. For this purpose, the ORYZA 2000 model is first run with the pixel-based current sowing date (for 2020), and we then test shifting the sowing date within the range of -25 days to +25 days, using the projected climate data for 2050 horizon.

As expected, the results differ among provinces and rice seasons. Mostly because of changes in precipitation patterns (seasonal distribution and intensity) in climate projections for 2040 and 2050 horizons, the dependency of simulated yields on the sowing date can be important on Winter-Spring and Summer-Autumn crops. For example, for the Tra Vinh Winter-Spring crop, a delay of 5–15 days in sowing date would increase rice productivity by up to 24%, because of more precipitation during the rice maturation period.

Measure 2: Change in rice varieties

As stated previously, the Vietnamese government has recently established a strategy for rice production in the period 2021–2030, by reducing the export volume and focusing on product quality. In this agricultural restructuring policy, by 2030, the proportion of Aromatic Rice (AR), High quality Rice (HR), and Medium quality rice (MR) will account for approximately 25%, 40%, and 10% of the total farming area, respectively (Decision 942/QD-Ttg, 2017)[8]. The important varieties for export[9] should account for 50–60% of the total cultivated area. Many of these rice varieties are long cycle varieties, with a growth cycle spreading up to 120 days, as compared to the shorter cycle of MR (85–100 days). Using ORYZA 2000, a simulation is performed to assess the rice yield, when short cycle rice is replaced by long cycle varieties. For the Autumn Winter rice crop, an increase of yield, by up to 11.3% (in Dong Thap, Tra Vinh) is observed in 11 out of 13 provinces (no change in Ca Mau and Vinh Long). A detailed analysis should be conducted to interpret the observed trend, as a result of changing temperature and precipitation during the vegetative phase of the rice cycle (the length of the reproductive cycle is similar for all varieties).

Finally, for adaptation measures, the simulations of changing rice crop calendar, changing crop varieties, and reduction of triple rice cropping in favor of double rice should be conducted in an intergrated manner, and for each of the local conditions within the hydro-ecosystems of the Mekong Delta. Further work is also required to take the timing of salinity intrusion or flood onset in middle regions into account.

3. Low GHG emissions strategy

Rice production is a major contributor to anthropogenic methane and Viet Nam is one of the few top rice-producing countries to sign the global methane pledge mentioned in section 1.2. Improving rice production practices is therefore key to reducing the country's emissions.

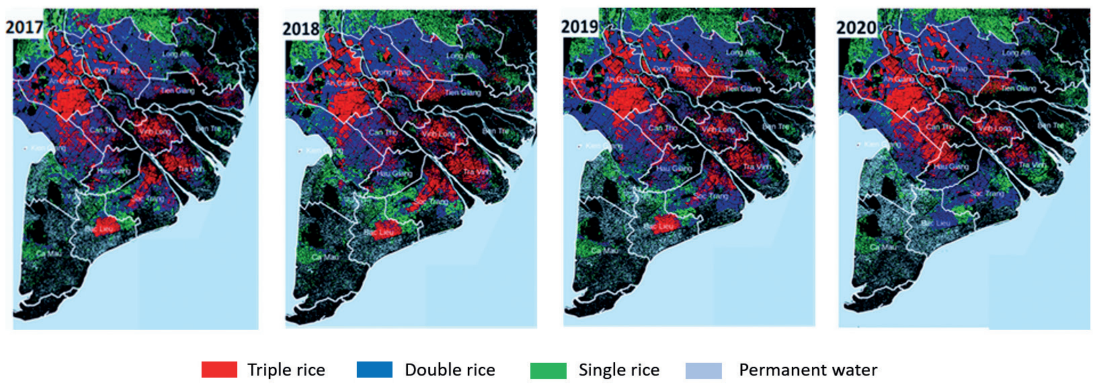
In the updated 2020 Nationally Determined Contribution, the national strategy for achieving emission reduction in rice outlines prag-

7. Averaging the provinces, the results are in broad agreement with province statistics from GSO, for example the Winter–Spring rice yield in 2020 varies from lowest yield 4–5 tons/ha in coastal regions (in Tra Vinh, Camau, Ben Tre) to highest yield 6–7 tons/ha in the upper and middle Delta (in Vinh Long, Dong Thap, An Giang, Kien Giang, Can-tho, Hau Giang).

8. Decision No. 942/QD-TTg dated July 03, 2017 approval for rice export market development Strategy of Viet Nam for the period of 2017-2020 with vision toward 2030.

9. such as Dai Thom 8, Nang Hoa 9, Jasmine 85, ST21, ST24, ST25 (AR group) and some of the HR group.

[Figure 2/5.3]
Observation of rice cropping density in the Viet Nam Mekong Delta



Maps of rice areas with triple, double, and single crop in 2017, 2018, 2019 and 2020.

matic and economical methods, mainly by controlling water management, and conversion of inefficient rice land to other uses. Mitigation practices such as alternate wetting and drying (AWD), and mid-season drainage are recommended to farmers. Rotating the use of land by introducing alternative activites like shrimp or fish farming to reduce emissions from rice paddies was also identified as a mitigation measure. For example, instead of having three rice crops a year, a farmer could produce two rice crops and one shrimp harvest in the same paddy (see chapter 4 in GEMMES COP26 report).

Possible adaptation and mitigation options: Low-carbon agricultural practices

Measure 1: Expand AWD irrigation practices

The challenge now lies in how to introduce mitigation options to all farmers across Vie Nam. At present, low methane emissions practices are not widely adopted in Viet Nam, although they have been implemented in some provinces [*e.g.* in An Giang province, Lampayan *et al.*, 2015]. In practice, the adoption of AWD by farmers is constrained by several factors. These include distance from the irrigation canal/drainage, density of subcanals inside the dikes, location of owned pumps. Heterogeneous water management practices are caused by non-synchronized drainage in adjacent rice paddies, with different cropping calendars and types of dike system. This causes difficulties in monitoring the operations required for mitigation measures, such as allocation of irrigation/drainage canals and pumping apparatus, opening/closing schedules of the sluice gates attached to each dike surrounding rice paddies, etc [Arai *et al.*, 2022a].

This highlights the fact that investments are needed to improve existing canals and pumping facilities to enable controlled water management. Viet Nam's participation in the methane reduction pledge represents an opportunity to obtain climate financing. Additionally, the country can improve the transparency, accuracy and comparability of national GHG inventory reporting. These efforts must be backed up by enhanced training, and an awareness campaign to encourage better water management behaviour [Nelson *et al.*, 2022].

Measure 2: Reduction of rice cropping density

The reduction of cropping density – like the adaptation measures mentioned in the previous sections – should also be assessed as mitigation measure for reducing GHG emissions. This concerns calculating the reduction of methane emissions obtained by the suppression or reduction of the Winter-Spring crops in salinity-impacted regions, the reduction of the Autumn-Winter crop in flood-prone regions, and the conversion of rice into other land use in submergence-risk regions. The calculation can make use of experimental data, collected across the Mekong Delta.[10]

4. Observation of changes in rice-cropping density after Resolution 120

To observe changes that occurred during the years after Resolution 120, multi-annual observations by satellites can provide information on adaptation measures adopted by farmers or by policy regulations, such as for example changes in crop calendar and in cropping density, and changes in crop types or conversion to other land use.

10. In Chapter 4 of GEMMES COP 26 report, methane emissions are shown to be highest in the wet season crop, and AWD practices reduce 40 to 60% of the methane (and N_2O) emissions [Arai *et al.*, 2022b].

Here we analyse the maps of annual cropping density (number of rice crops per year) as an indicator of changes in rice farming that occurred between 2017 and 2020 [Figure 2/5.3].

According to satellite monitoring, the areas of single crop and double crop have increased by 5.9% and 9% between 2017 and 2020; conversely, the area of triple crop decreases by 9.6%. Finally about 5% of rice area in 2017 was converted into other land use.

Coastal provinces and Ca Mau peninsula: there was a clear reduction of the rice-harvested area from 3 crops to 2 or 1 crop par year in 2020 vs previous years. For Ben Tre, Tra Vinh, Soc Trang, Bac Lieu and Ca Mau, the total triple crop area decreased by 78% between 2019 and 2020 (76.3 vs 16.7 10^3 ha), whereas the total double crop area increased by 12.5% (126 vs 158 10^3 ha), and the total single crop area increased by 11.8% (88.7 vs 105 10^3 ha). In Bac Lieu, the triple crop area – some 25 10^3 ha in 2017–2019 – was no longer observed in 2020. Instead, the double crop area increased from 12–15 10^3 ha to 39 10^3 ha. The same trend is observed in Soc Trang, with a drastic reduction of triple crop and a large increase in double crop. In Tra Vinh, the reduction of triple crop was accompanied by the increase of single crop area.

In these provinces, the question is whether farmers followed the Government Decision to reduce the triple rice crop in the area affected by salinity intrusion, or if the evolution actually reflects a loss of the dry season Winter-Spring crop because of the severe drought and salinity intrusions in 2020. Further analysis of data for 2021 and beyond will be needed to address this question.

Upper flood-prone zone: In An Giang, triple crop area has been maintained with a slight increase (of 3%) in 2020, as compared to 2017 (144 and 140 10^3 ha). The observation is in line with Decision No 1915 which recommended to maintain (or increase) triple crop in areas with complete embankment dikes. In Dong Thap, double crop decreased by 9.4% from 2017 to 2020 (138 and 125 10^3 ha), but predominates compared with triple crop (49 10^3 ha, no change from 2017). It is interesting to observe that the location of triple crop fields (or groups of fields) changes annually in Dong Thap, meaning that farmers are observing the annual rotation between triple crop and double crop, with fields being inundated during the flood season every other year.

Middle Areas: In Long An, Hau Giang, Vinh Long, Can Tho, no notable change in cropping density has been observed, except in Can Tho, where double crop decreased by 63% (from 52 to 18.8 thousand ha) in 2020 as compared to 2017, to the advantage of triple crop (from 19.9 to 48.5 thousand ha).

To sum up, 3 years after Resolution 120, changes in cropping density are observed in the Mekong Delta, most of which are in line with the Government target. A decrease in rice cropping density is observed in areas affected by drought and salinity intrusion, whereas an increase in triple cropping is found in areas fully protected from flooding during the wet season (*e.g.* An Giang) and areas with complete irrigation systems during the dry season (*e.g.* Can Tho). It is interesting to note that the recommended rotation of flood season rice with fallow fields, in order for flood waters to replenish agricultural land with fluvial sediments, is mainly observed in Dong Thap (and Can Tho) provinces.

5. Concluding remarks

The objective of this focus is to provide information that can contribute to the evaluation and updating of adaptation and mitigation measures for rice cultivation. It focuses on biophysical aspects related to nature-based solutions for the sustainability of rice cultivation. We provide maps of climate and environmental risks affecting rice fields, using observations and model-based projections, and discuss possible adaptation and mitigation options.

For the short term, a number of measures proposed in the resolution appear in line with our observations and proposed options (*e.g.* reduction of the intensity of rice cultivation in drought and saline intrusion -affected areas, modification of planting seasons to avoid early flooding, modification of the production by alternating rice with other land use-aquaculture, vegetable, etc.).

The action program for realizing the Resolution 120/ND-CP on sustainable development and climate change response in Mekong Deltaappears to be based on the key maps: land use map, infrastructure map, flood map and water salinity map. This is in line with traditional spatial planning approaches combining agro-ecosystems and development. However, the observed rapid change of land use, cropping density, salinity, flooded areas, subsidence, etc. implies the use of dynamic updating for these relevant maps that will need to be done.

However, for long-term plans, the spatial planning approach will need to be based on projections for horizons beyond 2030. Work is needed to assess adaptation measures in an integrated way, taking into account the projected climate and the constraints of flooding and saline intrusion, for the whole of the Mekong Delta. Specifically, the following should be considered:

- The adaptation measures for rice crop should be assessed in an integrated manner: *e.g.* the shift in crop calendar needs to be evaluated together with the impacts on the previous and the following crops, along with the projected rice yield, taking the projected climate and the constraints of flooding and salinity intrusion into account.

- Adaptation measures need be considered for the Mekong Delta as a whole, based on its hydro-ecological, environmental (and social) characterisics. Administrative units (provinces, districts, etc.) do not always coincide with the 'biophysical' specifications of the land. For example, cultivating rice crops during flood season in an upstream province can provoke damage by premature flooding of the previous rice crop in downstream provinces.

- Adaptation measures need to be assessed with respect to multiple factors. For example, the suppression of one rice crop per year (in flood-prone, salinity and drought-impacted, and submergence-risk areas) should be evaluated in conjunction with the reduction of GHG, and the opportunity to cultivate high-value rice varieties.

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Focus 6

Impacts of the Ba-Lai dam on production system and ecosystem

Bình-Đại district, Bến-Tre province

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Abstract

This focus presents some research results from three qualitative field survey missions carried out in Bình-Đại district (Bến-Tre province) within the framework of the GEMMES Viet Nam project. It considers social and economic impacts of infrastructure deployed to manage the effects of climate change, which appear to include the recent severe episodes of salinization-drought.

For this, we have chosen to focus on a technical device intended to counter saline intrusions while allowing storage of freshwater upstream: Ba-Lai dam, built in the early 2000s on the eponymous river. We study the local transformations of agrarian systems and modes of production that it has generated since it was commissioned 20 years ago. Alongside presenting key figures, our aim is to focus on the impacts that this development has had and is still having, as experienced and described by farmers and local authorities. In other words, the intention is not to establish a set of objective facts that would be the prerogative of specialists alone, but to question the perceptions of the inhabitants and users.

Tóm tắt

Tiêu điểm này trình bày một vài kết quả của nghiên cứu từ ba chuyến đi khảo sát thực địa bằng phương pháp định tính thực hiện ở huyện Bình Đại (Bến Tre) trong khuôn khổ dự án GEMMES. Tiêu điểm ước tính tác hại xã hội và kinh tế của cơ sở hạ tầng được triển khai nhằm chống chọi và/hoặc thích ứng với biến đổi khí hậu, trong đó có các đợt xâm nhập mặn và hạn hán gần đây để lại dấu ấn.

Nhằm đạt được mục đích này, chúng tôi đã chọn mục tiêu nghiên cứu là một thiết bị kỹ thuật dùng để chống lại xâm nhập mặn đồng thời cho phép dự trữ nước ngọt ở thượng nguồn – đập Ba Lai được xây dựng vào đầu những năm 2000 trên con sông cùng tên, nhằm nghiên cứu quá trình chuyển đổi hệ thống ruộng đất và phương thức sản xuất ở địa phương do con đập tạo ra kể từ khi đi vào hoạt động 20 năm trước. Song song với việc huy động một vài số liệu ước định, quan điểm ban đầu của chúng tôi là tập trung vào tác động mà quy hoạch này đã và đang gây ra như nông dân và chính quyền địa phương trải nghiệm và mô tả chúng. Nói cách khác, tiêu điểm này không đặt ra một chùm dữ kiện không thể chối cãi, vốn là đặc quyền của riêng chuyên gia, mà đặt câu hỏi về nhận thức của người dân, tức người sử dụng.

Résumé

Ce focus présente quelques résultats de recherche provenant de trois missions d'enquête de terrain qualitatives menées dans le district de Bình-Đại (Bến-Tre) dans le cadre du projet GEMMES. Il envisage l'impact social et économique des infrastructures déployées pour lutter et/ou s'adapter aux dérèglements climatiques dont les sévères épisodes de salinisation-sécheresse récentes portent la marque.

Pour cela, nous avons choisi comme objet d'étude un dispositif technique destiné à s'opposer aux intrusions salines tout en permettant un stockage d'eau douce en amont, le barrage Ba-Lai construit au début des années 2000 sur le fleuve éponyme, afin d'étudier les transformations locales des systèmes agraires et des modes de production qu'il a généré depuis sa mise en service, il y a 20 ans. Parallèlement à la mobilisation de quelques données chiffrées, notre parti pris est de nous intéresser aux impacts qu'a eu et a toujours cet aménagement tels qu'ils sont vécus et décris par les agriculteurs et les autorités locales. En d'autres termes, il ne s'agit pas d'établir un faisceau de faits incontestables qui seraient l'apanage des seuls spécialistes mais de s'interroger sur les perceptions qu'en ont les habitants, c'est-à-dire les usagers.

1. Ba-Lai dam: a structure integrated within a complex system

In the Mekong Delta, dams have three main purposes: fighting against saline intrusions, flood control, and storing freshwater for domestic and agricultural uses.[1]

At the level of the province, Ba-Lai dam (the largest hydraulic structure in Bến-Tre province) is one of the nine components[2] of a global development project whose objectives are similar to those of entire delta, *i.e.* adapting to climate change, and in particular to the rise of sea level and the declining trend of river flows (see Figure 2/6.1).[3]

1.1. Objectives and technical characteristics of Ba-Lai dam

To cope with drought and salinity, the main measures adopted at present in Bến-Tre province are the construction of dams/sluices and dyking rivers. It is in the context of this compartmentalization policy that Ba-Lai dam was built. Ba-Lai River, about 55 km long, is entirely located in Bến-Tre province and crosses Châu-Thành and Giồng-Trôm districts followed by the districts of Bình-Đại and Ba-Tri, to emerge into the East Sea by forming the Ba-Lai estuary, one of the eight estuaries of the Mekong Delta.

It is a dam 544 meters in total length, whose 84-meters active part is divided into ten sluicegates. Inaugurated in 2002 (April 30) after more than two years of work (which began on January 27, 2000), the structure – whose total cost was 67 billion VND – has five objectives:
– Countering saltwater intrusion while allowing upstream freshwater storage of approximately 90 million cubic meters (m³).
– Contributing to improving the development of 80,000 ha of cultivated land via freshwater (upstream of the dam), and 20,000 ha of aquaculture through better control of salinity (downstream of the dam).
– Supplying domestic water to Bình-Đại, Ba-Tri, Châu-Thành and Giồng-Trôm districts and to Bến-Tre city, via five water treatment plants drawing water from the Ba-Lai River.
– Increasing and regulating river traffic.
– Creating a road link between the Ba-Tri and Bình-Đại districts (traffic on the dam).

1. 2 Management and opening / closing of sluicegate

The Dam Management Committee (BQL) reports to Bến-Tre Irrigation Company (Công Ty Thủy Lợi Bến-Tre: CTy-TL-BT) which in turn reports directly to the province's Department of Agriculture and Rural Development (DARD). The head of this committee describes the tasks of his team as follows: 1] measuring the lake-reservoir's water level every hour; 2] measuring salinity upstream and downstream of the dam once a day;

1. Due to the geomorphological characteristics of the Delta, there are no hydroelectric dams.

2. The 8 other components are divided into 2 sections (Bến-Tre North and Bến-Tre South): bridge-lock of Bến-Tre; bridge-lock of Giao-Hòa; Bến-Rớ and Tân Phú locks; dredging of Ba-Lai riverbed upstream of the dam; Hàm-Luong River embankment system; embankment along the Mỹ-Tho River; level 1 canal system and irrigation networks; rural freshwater; River transport.

3. "Quy hoạch tổng thể thủy lợi đồng bằng sông Cửu Long trong điều kiện biến đổi khí hậu, nước biển dâng" ["Mekong Delta development plan in the context of climate change and sea level rise" approved by the Prime Minister on September 25, 2012].

[Figure 2/6.1]
Bai-Lai dam localisation

3] dam maintenance; 4] managing the opening and closing of sluicegates.

The calendar which establishes the days and durations for the opening/closing of all the hydraulic structures (dam, locks, cofferdams) of Bình-Đại district, specifies for Ba-Lai dam:
– From the beginning of January to the end of May (solar calendar): open for 2 days, on 15 and 29 of lunar calendar.
– From the beginning of June to the end of October (solar calendar): open for 6 days, on 7, 15, 16, 22, 29, 30 of lunar calendar.
– From the beginning of November to the end of December (solar calendar): open for 4 days, on 15, 16, 29, 30 of lunar calendar.

While the person in charge of the BQL states that the calendar can be modified to take critical situations into account – especially in periods of salinity-drought – the company management board affirms, on the contrary, that the fixed calendar cannot be modified to open sluicegates outside the fixed days. This point is important for analyzing the salinization-drought period of 2019–2020, during which dam sluicegates remained closed (see below).

2. Overall impacts

2.1 Positive impact and limitations

For the CTy-TL-BT management board, the fight against saltwater intrusions combined with the creation of a freshwater reservoir upstream (see Figure 2/6.2) have made it possible to greatly reduce the salinization period, which was previously four to six months per year (dry season) and which only lasts one to two months since the dam was commissioned. This reduction has made it possible to achieve the target of securing 3 rice seasons/year while developing plantations of coconut palms and fruit trees in Bình-Đại, Ba-Tri and Giồng-Trôm districts. Still according to the management, water releases have reduced salinization downstream from between 20‰ (1 milligram/litre) and 10‰.

According to the designers of the dam project (*Dự án Vận hành đập*), agricultural areas have increased, and land has improved. It has contributed to restructuring cropping systems (conversion of rice fields into perennial crops: coconut trees, longan trees, banana trees, grapefruit trees, jackfruit trees) and to the development of water-intensive market gardening (watermelons, peppers, cucumbers, etc.), while generating new models such as intercropping coconut-fruit trees. Thus, between 2002 and 2014, the total plantation area in Ba-Tri, Bình-Đại and Giồng-Trôm districts expanded by 5,600 hectares (reconversion of paddy fields) and was accompanied by an increase in average yields. Farmers who cultivate land upstream actually highlight the beneficial effects of this development.

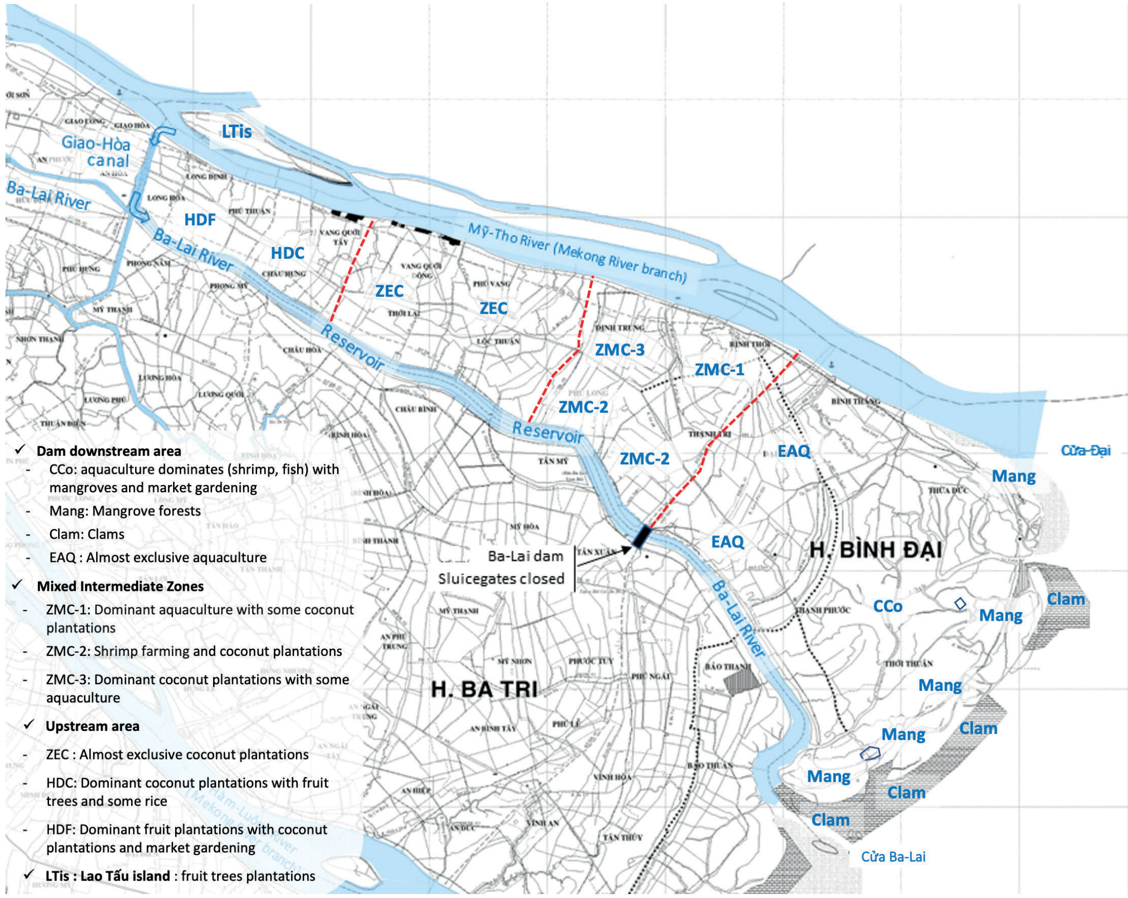
The creation of this lake-reservoir was also accompanied by construction of five water treatment plants, which draw water from Ba-Lai River (Thoi Lai, Long Dinh, Tan My, Ba-Lai and Trung Thanh) and supply domestic water to Bình-Đại, Châu-Thành and Giồng-Trôm districts and Bến-Tre city. However, it is only domestic water and not freshwater. Indeed, the salt content never drops below 2‰, whereas the standard is set at 0.5‰ for human consumption, while the water is also more or less aluminized (CTy-TL-BT). As a result, all the people interviewed, regardless of their place of residence, use this water for domestic tasks and – if the salt concentration is «acceptable» – for body care and watering their garden, but never for cooking or drinking: only rainwater is used for these (all homes are equipped with reservoirs). In addition, the plants do not supply all hamlets, or even all households within the same hamlet (in Vinh-Xương hamlet – Vang-Quới-Đông commune- 22% of households are not connected). This is because on top of the price per m^3 of water invoiced monthly, the costs of connection to main network (material and labor) are charged to each user. Those who are not connected – either because their residence area is off-network, or because they cannot or do not want to invest in the facility – draw water directly from the river or inland canals, a practice that raises the issue of water pollution (see below).

Finally, the dam's embankment effectively constitutes a new direct traffic axis between Bình-Đại and Ba-Tri districts and contributes to their accessibility.

2.2 Upstream: accretion of the riverbed and erosion of the banks

The Bai-Lai riverbed and the reservoir are undergoing a strong and rapid accretion, since the few days each month when the sluicegate is open are insufficient to evacuate the sediments contained in the stagnant water of the reservoir, which are deposited on the riverbed. This phenomenon is further amplified by the downward trend in the flow of Ba-Lai River. (CTy-TL-BT)

[Figure 2/6.2]
Distribution of dominant productions in territory of Bình-Đại district



A series of measurements carried out in 2010 shows that after nine years of operation, elevation of the riverbed has reached between 1.5 m and 2 m, which represents an impressive volume of 18.4 million m^3 over the 29 km section which extends from the mouth of the Giao-Hòa canal in Ba-Lai River and the foot of the dam [Nguyễn Thế Biên, 2014].

To reabsorb this layer of sediment, the dredging project "Restoration and upgrading of Ba-Lai River and Giao-Hòa and Chẹt-Sậy confluences" has been submitted by the province's Department of Agriculture and Rural Development (DARD) to the province People's Committee. The dredging of Ba-Lai River is to extend over 23 km to extract a total volume of 19.1 million m^3, including 8.5 million m^3 of sand which will be transferred to the company project manager [4] to offset part of the cost of the operation [Trung Chánh, 2022]. This dredging project should last 5 to 6 years, for a total cost estimated at 900 billion VND, *i.e.* more than 13 times the construction cost of Ba-Lai dam itself. To date, work has not begun

4. Công ty cổ phần đầu tư xây dựng phát triển (Société anonyme d'investissement et de développement).

[Figure 2/6.3]
Downstream: accretion of Ba-Lai River estuary and coastal erosion (12/2019)

because the project has still not been approved and the financing finalized, to the regret of the management board of the CTy-TL-BT: «Dredging upstream of the dam remains at project stage, but feasibility studies are in progress».

There is another explanation for the clogging of riverbed, which particularly affects the section located downstream of the dam: the exponential development over past twenty years of aquaculture on both banks of Ba-Lai River (Bình-Đại & Ba-Tri districts). Indeed, digging thousands of breeding ponds for shrimps and fish has generated millions of m^3 of earth, which are partly discharged directly into the river or indirectly via inland canals. A simple calculation is sufficient to appreciate the volumes involved: to dig a 1 ha pond (10,000 m^2) to a depth of 2 m, 20,000 m^3 of soil must be extracted. Given the several thousand hectares of ponds dug in the Bình-Đại district (see below), we reach impressive volumes of soil (1,000 ha = 20 million m^3).

Finally, the encroachment on the banks of the reservoir's water body and the widening of the right-of-way on the Giai-Hòa canal is a mechanical consequence of interruption of the river's flow. The filling up of its bed accentuates its horizontal spread even more, causing erosion of its banks synonymous with landslides.

In recent years, these landslides have washed away several houses and portions of land in Long-Hòa[5] and Long-Định communes, where some households were compensated by the DARD [Trần Thành Thái *et al.*, 2021]. It should be noted that the phenomenon also affects hamlets located downstream of the dam, as was the case in 2019 in Đại-Hòa-Lôc commune (see below).

2.3 Downstream: accretion of Ba-Lai River estuary and coastal erosion

On the district's coastal strip, two phenomena combine: coastal erosion and accretion of the Ba-Lai River estuary (see Figure 2/6.3).

Province-wide, the coastline is being eroded over a total length of 19.4 km (2019), including Bình-Đại district, accompanied by an increase in landslides in recent years. The worsening of this phenomenon has become a major concern for the authorities.

Regarding the specific impact of the Ba-Lai dam, the interruption of river flow into the sea has changed the direction and strength of sea currents. Concretely, the coastal flow along Thừa-Đức and Thới-Thuận communes has increased and is eroding the coastal strip. According to the vice-president of the people's committee of Thới-Thuận commune, over the last 10 years erosion has removed a strip of land 700 m long by 5 to 10 m wide and is advancing annually from 1 to 2 m.

At the same time, the interruption of river flow downstream (24 to 28 days/month depending on the season) means that the river offers no resistance to the penetration of the sea, which has a double impact on the Ba-Lai River estuary.

On the one hand, ecosystems have undergone a profound modification in an environment which has become largely salinized. On the other hand, the short periods of water release do not prevent a strong marine accretion, whose sediments come partly from the erosion of the littoral strip of Thừa-Đức and Thới-Thuận communes. The results of Nguyễn The Bien's calculations (2014) show that over nine years (2002–2010), nearly 2.6 million tons of marine sediments were deposited in the estuary (see satellite photo 2/6.1). Since the estuary is between 5 m and 7 m deep, the layer of sediments – which reaches an average of 6 meters – emerges in the form of strips of land up to 500 m wide. As an unexpected positive effect, these areas created by accretion are beginning to be used by landless farmers and are expanding the area for harvesting wild clams (con nghèu) (see below).

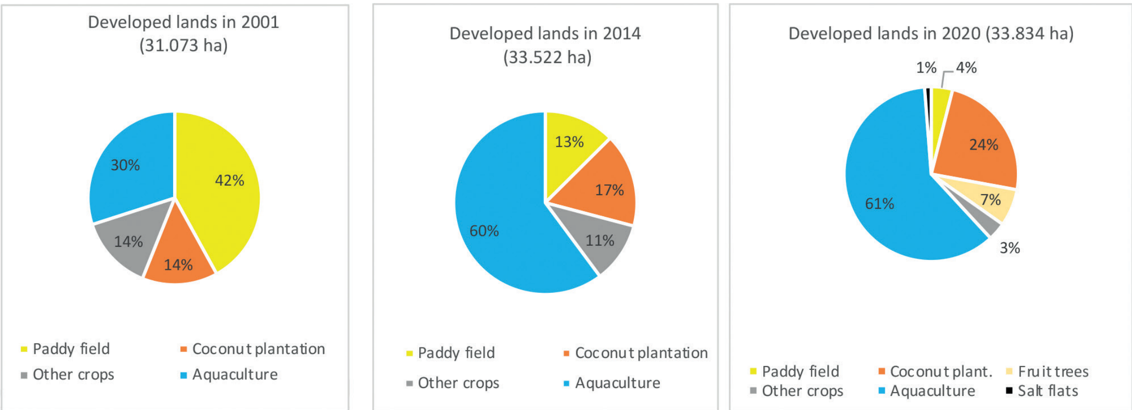
Ultimately, if nothing is done, especially increasing the frequency and duration of water releases, Ba-Lai River estuary will be filled in the medium term.

2.4 Surface and groundwater pollution

Pollution in all its forms, whether real or perceived, is a recurring subject often raised spontaneously by local authorities and farmers. However, it is difficult to determine the share of events (decrease in agricultural production, human and animal diseases, etc.) whose origins are genuinely associated with pollution.

5. Thus, a resident of Long-Hòa commune explains that part of his plantation of fruit trees was swallowed up when a strip of land 10 m wide by 30 m long collapsed.

[Figure 2/6.4]
Distribution of dominant productions in territory of Bình-Đại district



The sources are multiple:
– Accumulation of solid waste (packaging, various objects) near the dam.
– Discharge of domestic wastewater directly into the lake-reservoir from both banks.
– Discharges of polluted water from intensive aquaculture and agriculture (pesticides, herbicides, fertilizers, drug treatments for livestock, heavy metals).
– Wastewater discharges from livestock (pigs, ruminants).
– Industrial discharges (shrimp processing workshops, tanneries, etc.).

These organic materials, solid waste and chemical components are obviously not discharged by the reservoir's neighboring communes alone, but potentially come from all humans, agricultural and industrial settlements distributed upstream of the river and its tributaries. Their virulence is further enhanced by the rising temperatures of shallow stagnant waters. An executive of the dam's management committee explains that periodic water releases allow the water in the reservoir to be drained, in the knowledge that daily water quality measurements show the level of pollution is generally low. On the other hand, during the period that elapses between two successive releases – *i.e.*, at least a fortnight – the water is progressively loaded with polluting compounds, water used by farmers and "aquaculturists", water treatment plants that do not have sufficient treatment capacity to eliminate all these compounds, and by households that are not connected to domestic water distribution networks.

Secondly, the question of water pollution affects the entire network of interdependent inland canals that mesh the territory. In fact, the construction of the dam was accompanied by additional development work (locks, filling in certain canals, etc.), which modified the circulation of water. In the zone upstream of the dam, the reduction in flows circulating in the canals, the absence of an outlet when the water level of the reservoir is at the same level, or even the combination of incompatible activities (salt aquaculture and agriculture) cause certain canals to become reservoirs of largely contaminated stagnant water (wastewater, runoff from agricultural land, discharge of water from aquaculture ponds). This situation is a source of growing tension between users and different uses. For example, a woman resident of Thạnh-Trị commune explains that for domestic uses (laundry, body care, but not cooking and drinking), she pumps water directly from the canal near her house even though she knows that it is polluted, adding «when I shower, I try not to think about it».

A resident of Thợi-Thuận commune believes that even if water releases make it possible to «wash» pollution from the riverbed, they are also sources of pollution since the water from the drained reservoir enters the canals that run inland.

3. Variable impacts depending on the hydro-agricultural spaces

3.1 Reconfiguration of agrarian systems and land use

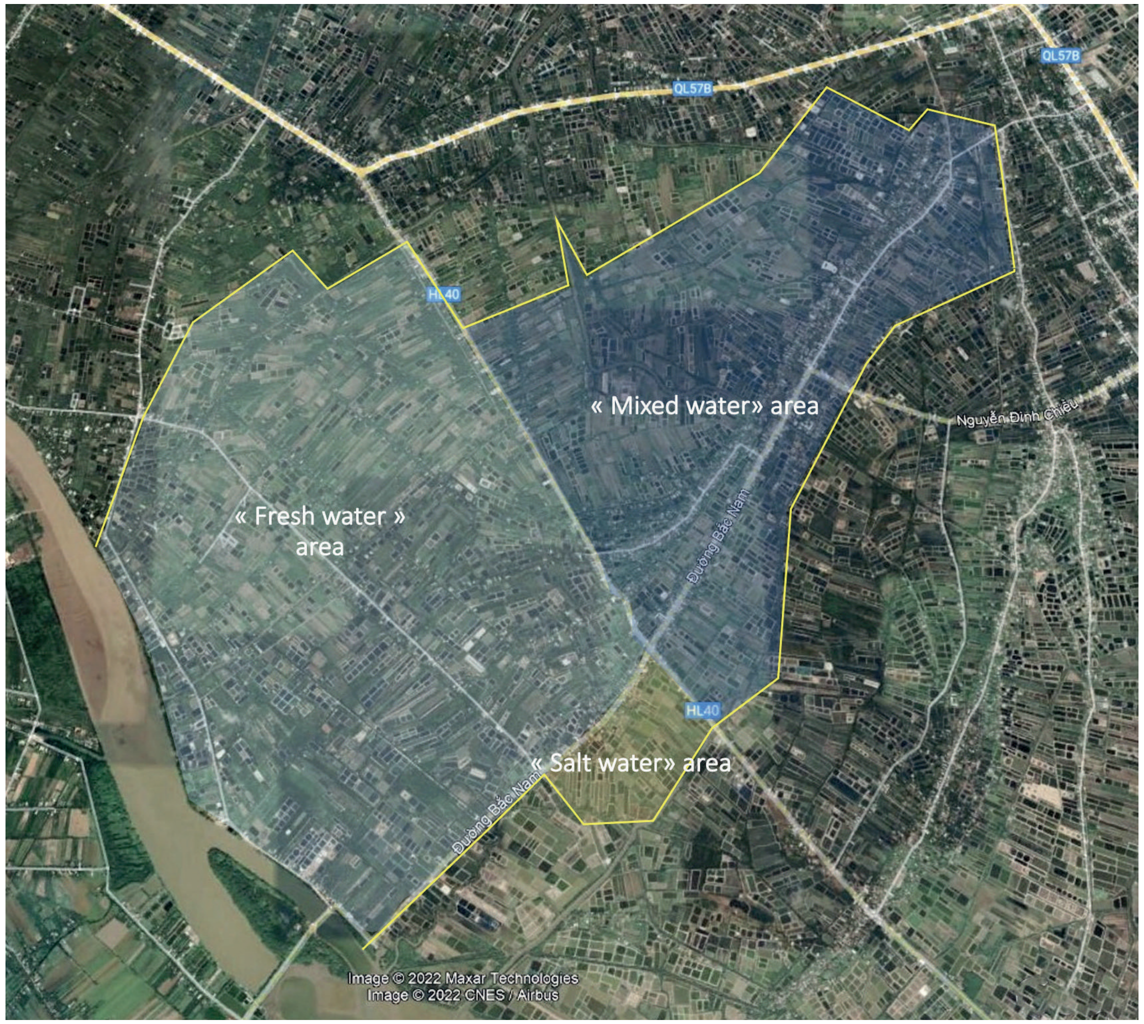
Over the past twenty years, there has been a profound change in the agrarian systems and land use in Bình-Đại district. This is not an exclusive consequence of the dam, but of the conjunction of several factors: 1] the evolving demands of the market for specific products (specific types of fruit, specific types of shrimp), both from a quantitative and qualitative point of view, which determines the purchase prices for producers; 2] the responsiveness and adaptability of producers to respond to these evolving demands within the framework of transformations of hydro-agricultural spaces and ecosystems generated by the dam operation; 3] the deeply unequal distribution of factors of production (labor, land and financial capital) available to farmers to seize market opportunities (many inhabitants have no land except their residential plot and the adjoining garden); 4] the development of "invasive" production, in particular saltwater shrimp farming, which is becoming widespread and making it difficult to adopt alternative choices; 5] psychological characteristics specific to each farmer (ability to take risks, etc.).

A few figures allow us to appreciate this profound change in land use.

In 2001, out of the total area of Bình-Đại district (42,760 ha), arable land occupied 31,073 ha (*i.e.* 72% of the total area of the district); it was made up of 42% rice fields (13,038 ha), 14% coconut plantations (4,390 ha), 14% other crops (4,340 ha: maize, potatoes, cassava, fruit trees) and 30% dedicated to aquaculture production (9,305 ha) [Ngo Xuan Quang *et al.*, 2017].

In 2014, just over 10 years after commissioning of the dam, the figure was reversed. Of total arable land (33,522 ha), land under cultivation only accounts for 40% (13,350 ha), with rice-growing areas shrinking by two-thirds (4,212 ha), while the areas dedicated to aquaculture production reach 60% (20,172 ha), a proportion which, moreover, is deliberately underestimated, since part of their area is not considered because it falls outside the framework of provincial planning (see below). This massive transfer from rice-growing to aquaculture is coupled with a second major evolution: the development of a plantation economy dominated by coconut trees (41% of total land under cultivation) and longan trees (19%). Compared to 2005, the area of the former has increased by 31% and the latter by 37%. [Ngo Xuan Quang *et al.*, 2017].

[Figure 2/6.5]
Zoning into three areas - Thạnh-Trị commune



Finally, between 2014 and 2020, decline in rice cultivation was accentuated, as was that of the «other crops» category, to the benefit of coconut plantations (7,760 ha, *i.e.*, 28% more than in 2014) and fruit trees (2,225 ha) [Ben Tre Statistical yearbook, 2020]. As for the previous period, the share of aquaculture has been knowingly reduced and would have even slightly decreased in absolute value according to the statistics of the province (19,691 ha).

This reconfiguration of land use has resulted in the spatialization of hamlets bordering Ba-Lai River into three large hydro-agricultural areas (dam downstream area, intermediate zone, upstream area), in which the dam plays a pivotal role (see above Figure 2/6.2).

3.2 Dam downstream area

Since the commissioning of Ba-Lai dam in the early 2000s, salt concentrations in water and the depth of saline intrusions into inland canals and arroyos have increased dramatically in the dam downstream area. As a result, from a diversified agrarian landscape (rice-growing, fruit tree plantations, extensive shrimp farming / rice-shrimp model), there has been a complete shift in agricultural production in the space of a few years (disappearance of rice farming) towards saltwater aquaculture, mainly shrimp farming.[6] To support this transition, the State – which has assigned this area to aquaculture – has implemented a number of support measures: reduced-rate loans from the Agricultural Bank; training in aquaculture techniques, especially for the most modest households (DARD in Bình-Đại district).

The chief of one of hamlets of Đại-Hòa-Lộc commune summarizes this upheaval in a few words: «Before the construction of the dam, there were rice and plantations of fruit trees, and the lifestyle was quite steady. Since then, situation has changed a lot: in 3 or 4 years, everyone has started farming shrimp. From there, some inhabitants became very rich while others lost everything and went bankrupt: this has created a socio-economic imbalance and tensions in the hamlet."

It must be said that aquaculture, and especially intensive shrimp farming, are productions with high added value. Successes and examples of rapid and spectacular enrichment (several billions of VND) have acted and still act as poles of attraction. But it is also a high-risk activity.[7] While some make a large initial investment profitable in a few years, others, less fortunate, suffer the consequences of repeated diseases that affect shrimp (pollution, mortality of fry) and sink into a spiral of indebtedness.

The interviews show that the successive failures of the shrimp farmers are experienced as a personal failure from a technical and economic point of view, but also as a social downgrading. The stigma placed by those who succeed on those who lose is a source of frustration, humiliation, and discomfort for the latter (loss of self-confidence), which unfortunately sometimes leads to tragedies (break-up of the family unit, cases of suicide).

Ultimately, in addition to its random outcomes, intensive aquaculture follows a purely capitalist model: it is based on and plays on the deep pre-existing inequalities of access to the factors of production (especially capital and land), which it maintains and exacerbates. It is therefore logical that new actors have appeared in recent years (foreign and Vietnamese companies, wealthy individuals) attracted by the prospect of large and rapid profits, which has accelerated the trend for land concentration and increased local socio-economic inequalities.

Two activities were immediately and severely affected by the disruption of the river regime: fishermen and shellfish breeders/harvesters.

6. However, in the two coastal municipalities there are still small areas of agricultural crops (pocket of freshwater aquifer), plantations of mango trees and cucurbits (watermelons; melons).

7. Several expressions characterize this risk-taking:
- When a breeder goes bankrupt: "The shrimp ate the *sổ đỏ*". This expression refers to the fact that most bank loans are secured by the mortgage of land ownership certificates (*sổ đỏ*: red booklet).
- Shrimp farming "It's a game of money and it's the only legal game in Viet Nam!".

The fishing sector is logically the most affected. Upstream of the dam, the modification of ecosystems has caused the disappearance of many species of fish. But above all, the water releases regularly empty the reservoir of part of its fish and shellfish stock, a stock which does not have time to recover. A 2017 survey in three communes in the district upstream of the dam indicates that more than 50% of fishermen had to retrain in the first ten years after the dam became operational [Ngo Xuan Quang *et al.*, 2017].

Downstream, the drastic reduction of the river size between two emptying of the reservoir and the lack of water circulation have had a devastating impact on fish stocks, to the point that fishing activities have almost disappeared. Similarly, «bloody clam» (*con sò*) farms near the dam have disappeared, as release of water physically rips the shellfish from their support.

In the estuary (Thới-Thuận commune), shellfish farms ("bloody clams" and oysters) are affected by the instability of the salt concentration in water, the ideal level for normal development of clams being at around 25‰. During freshwater releases, this level falls to 10‰, to which are added the polluting elements diluted in the reservoir water. Conversely, when the dam is closed, the river current no longer resists sea penetration; salinity levels then reach 40–50‰. In this same commune, the harvest of wild clams (*con nghèu*) on its coastline is managed by a cooperative (HTX Rang Dong). Considered as a common asset, shellfish are harvested by inhabitants according to a set of rules which guarantees a daily payment to all several times a month as a harvester. Due to the same imbalances in salinity levels, the cooperative's income has decreased, a drop which affects the harvesters' remuneration, which has fallen in recent years from an average of 500,000 vnd/day to 300,000 vnd/day (vice-president of commune People's Committee).

3.3 Intermediate zone

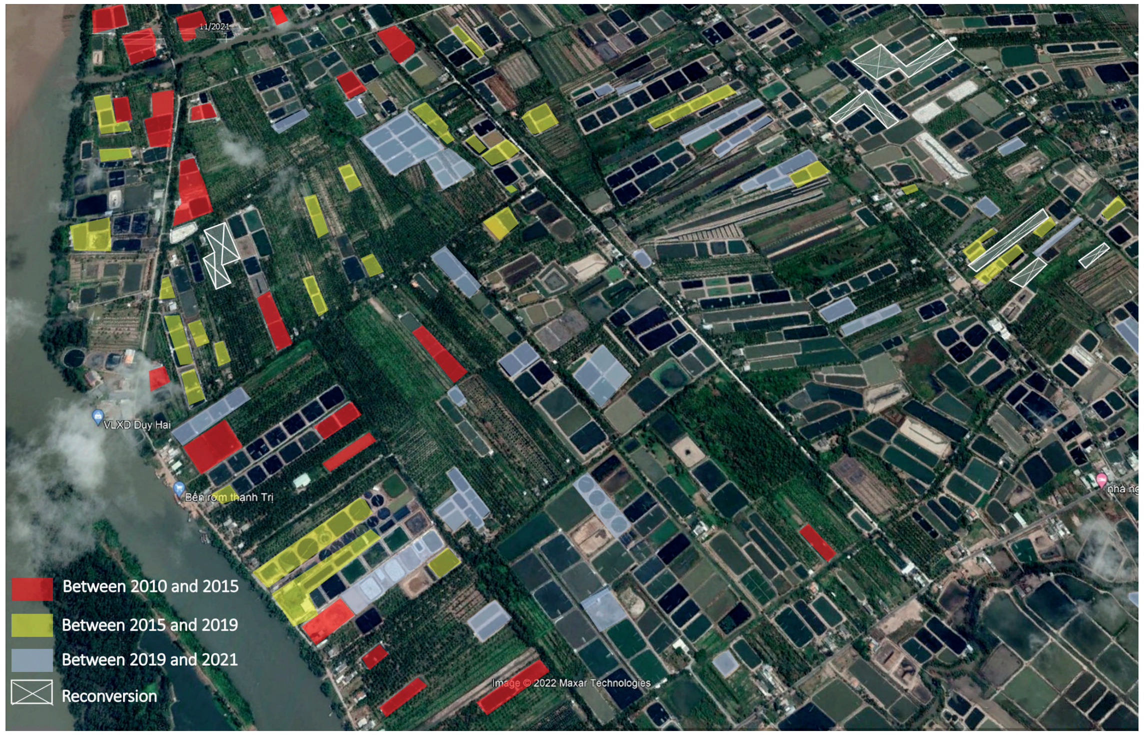
In this area located upstream near the dam (Thạnh-Trị and Phú-Long communes), rice cultivation has almost disappeared: although socio-economic reports from these two communes still report substantial areas of rice fields (200 ha for the Thạnh-Trị commune only)[8], this is contradicted by our field observations and examination of satellite photos. It has been replaced by plantations of high-yielding coconut trees, which remain predominant, but also by strong development over the past fifteen years in saltwater aquaculture, mainly intensive shrimp farming.

Since the construction of the Ba-Lai dam, DARDs of the province and district have drawn up a plan which determines areas dedicated to agriculture and freshwater aquaculture, and those which can develop saltwater aquaculture. An example is the case of Thạnh Trị commune which officially has 494 hectares devoted to aquaculture in areas where it is authorized (*i.e.*, 38% of developed lands in the commune). The map (see Figure 3/6.5) shows the division of the commune's territory into three areas: a "freshwater" zone dedicated to agriculture, in which saltwater aquaculture is theoretically prohibited; a "saltwater" zone; and a "mixed zone" (freshwater and salt-water).[9]

8. This figure seems largely overestimated (see below).

9. Saltwater passes through a series of canals fed by the mouth of the main arm of the Mekong River (*cửa Đại*) which marks the border between Bình-Đại district and the province of Mỹ-Tho.

[Figure 2/6.6]
Extract freshwater area - Thạnh-Trị commune (2021)

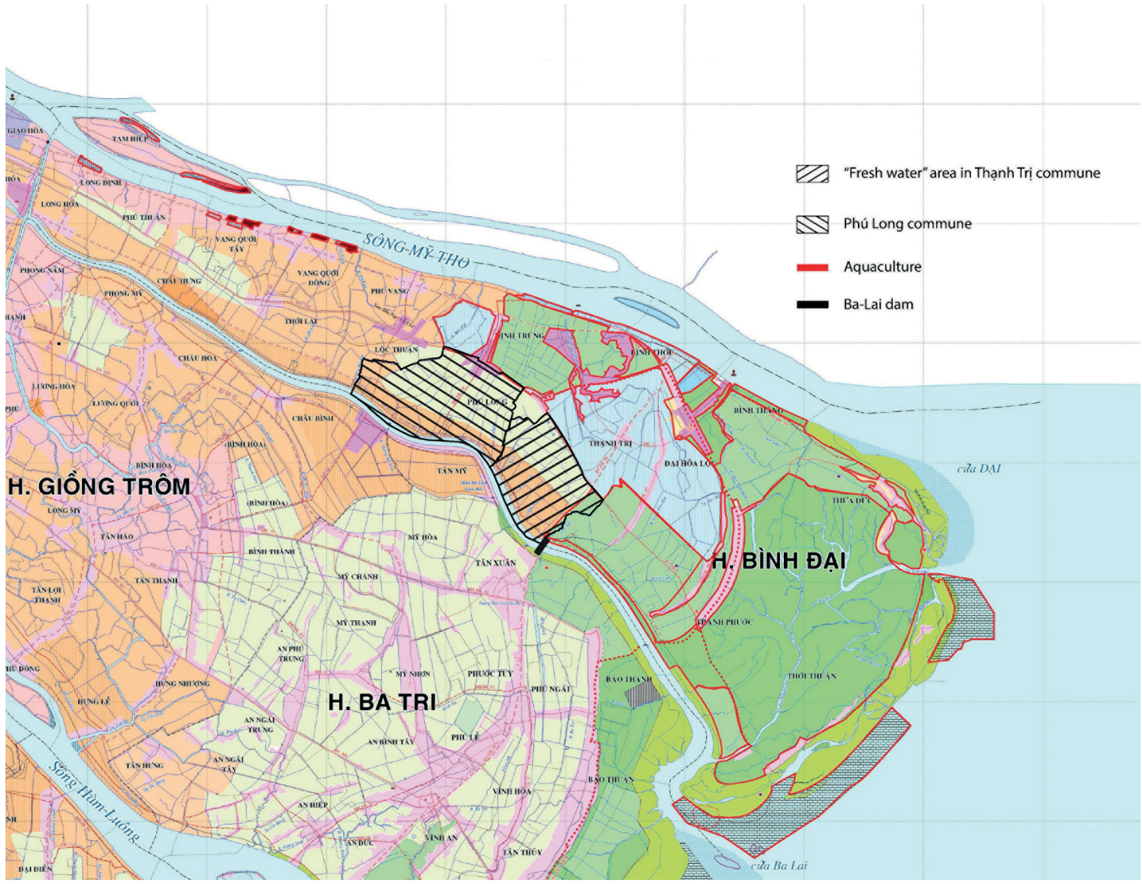


To evaluate the level of enforcement of this land use plan, we have isolated part of this «freshwater» area on a time series of satellite photos. Comparing photos from 2010, 2015, 2019 and 2021 (see Figure 2/6.6) leaves no doubt that many ponds have been dug illegally over the past decade, while local authorities have enforced drastic measures over the period, in particular destruction of drillings and shutdown of electricity supply (indispensable for pumping). A Commune People's Committee executive told us that 358 drillings were thus destroyed in the «freshwater» zone, and ranchers were required to make a commitment not to re-drill wells for drillings. A shrimp farmer from Bình-Thạnh-2 hamlet says that most farmers refused to sign this commitment and proceeded with new drilling.

The argument put forward by the breeders is above all an economic one, since the profit derived from a shrimp pond is much higher than that from a field of coconut palms. It is also relevant to question the feasibility of the retraining requirement. In reality, the soil and groundwater are salty but above all, the ponds must be filled in, requiring considerable volumes of soil that are no longer available (see above).

This desire to eliminate illegal saltwater shrimp farming appears clearly in the land use plan (projection in 2020) drawn up by the DARD of the province in 2016 (see Figure 2/6.7). The «freshwater» zone of Thạnh-Trị commune and the whole of Phú-Long commune, dedicated exclusively to agriculture and livestock

[Figure 2/6.7]
Land use planification (projection in 2020) by the DARD of the province



according to the DARD planning, contain no reference to aquaculture activities, which are nevertheless widely developed: instead, plantations of coconut palms, sugar cane, fruit trees and rice fields are planned. This denial of reality explains and justifies the pursuit of a radical policy of violent destruction of the means of production necessary for breeding.

Moreover, the cohabitation of farmers with saltwater shrimp breeders – imposed by the latter – generates and crystallizes strong tensions between the various groups of actors, which sometimes turn into open conflicts.

Firstly, between the breeders and the local authorities: according to the former, in the absence of viable alternatives, the violence of the measures implemented by the latter has created a deep distrust, in the context of increasing drilling destructions in recent years. This resentment is more deep-seated as the situation is an open secret, with everyone knowing perfectly well who is operating this or that pond.

Secondly, there are the tensions between farmers and aquaculturists (saltwater). Indeed, the brackish water drilling of shrimp farms

combined with infiltration of water into the soil and edges of the ponds further increases salt content in water tables. But above all, the fact that breeders discharge water from their ponds (containing water chemical treatment, medicinal treatments, dejections), without prior decantation, into canals whose water is intended for irrigation and domestic uses further exacerbates tensions. This observation is valid for all hamlets where saltwater shrimp farming and agricultural crop-plantations cohabit, giving an «invasive» dimension to the former beyond a certain development threshold.

Finally, tensions exist within the aquaculturist group. These tensions follow an upstream/downstream gradient. The intensification and generalization of shrimp farming generates increasing pollution of water discharged into the arroyos, canals, and river, and accelerates the spread of diseases (white spot disease, shrimp liver disease).

3.4 Upstream area

In the upper third of the district, rice cultivation combined with fruit growing and small family livestock dominated until the mid-1990s. It has been gradually replaced by a market-oriented plantation economy. In the upper part of the intermediate zone, coconut plantations predominate, except for a few aquaculture ponds, which become scarcer the further upstream one goes in the district. In the upstream zone itself, coconut plantations gradually give way to fruit tree plantations, with a few rice fields and pockets of market gardening.

The only source of water used for irrigation is pumping from arroyos and canals that communicate directly with the Ba-Lai River, since the groundwater contains salt and/or alum. In this context, most of the farmers we met have a positive appreciation of the reservoir, since it provides abundant water for irrigation. This availability has also accompanied and favored a transition that began in the mid-2010s, when «traditional» plantations of longan, sugarcane and coconut trees competed with higher value-added fruit plantations (grapefruit, mandarin, banana and recently jackfruit). But the two recent periods of salinization-drought (2016 & 2019–2020) have tempered the enthusiasm of many of them, and provoked violent criticism (see below). These two events have had a devastating impact on the plantation economy, as the Ba-Lai dam blocks the drainage of saline intrusions transiting through the Giao-Hòa canal (see Figure 2/6.8).

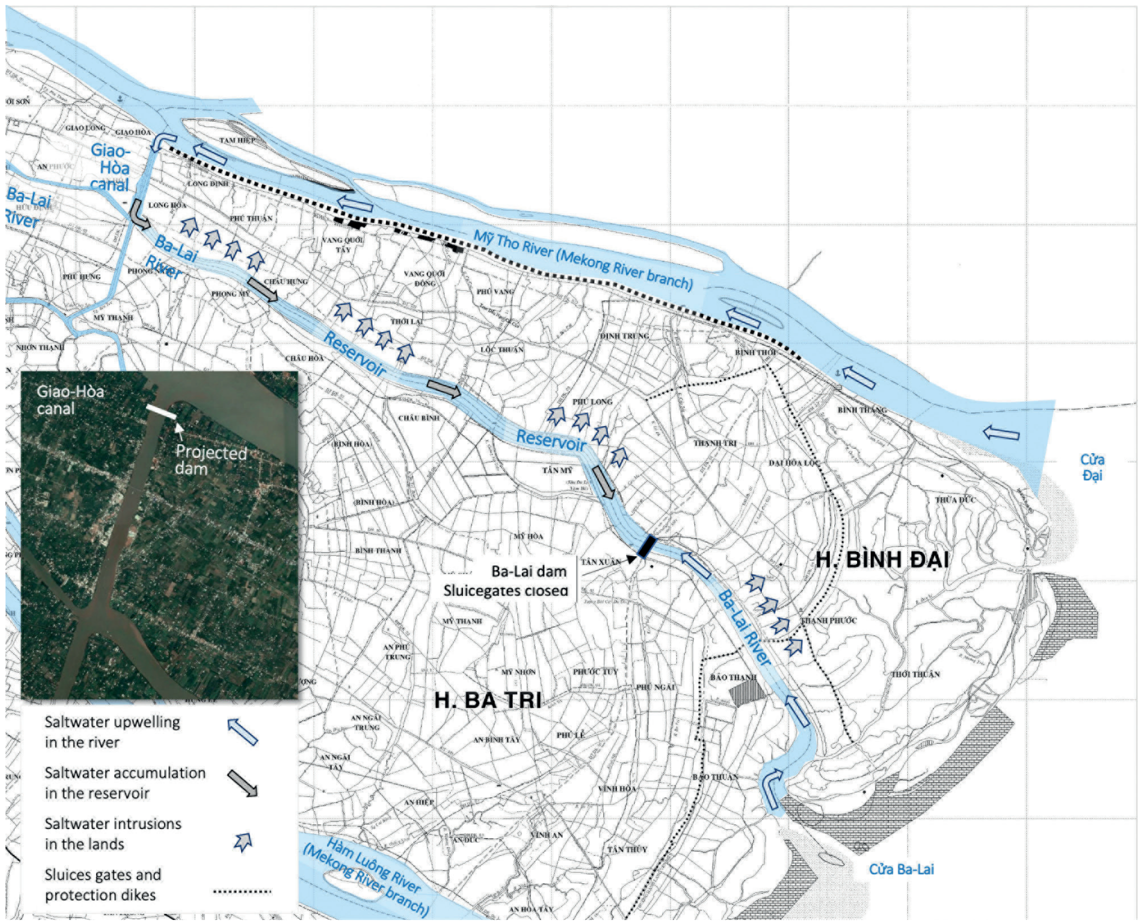
While the 2016 salinization period was relatively short (20 days), moderate in intensity (on average 6‰) and resulted in significant yield declines rather than the destruction of plantations, it nonetheless contributed to a revision of cropping systems. Thus, in Long-Hòa commune, farmers and local authorities directly attribute the drastic decline in rice-growing areas to this episode of salinization: they fell from about one hundred hectares to less than five hectares after 2016, marking the near-disappearance of rice-growing in this part of the district.

The 2020 salinization period was much more violent in both duration (3 months) and intensity (peak 15‰). Although coconut trees tolerate moderate salt levels, production declined by 30%–50%. However, the damage was most severe in the orchards. In the Long-Hoà commune, farmers estimate that they lost between 50% and 70% of their fruit production; the commune has been declared a natural disaster zone and 90% of households have been officially registered as affected, and the majority compensated by the State.

During this period, households had to purchase freshwater not only for their domestic needs but also to irrigate plantations, and at prohibitive prices. Despite this investment, one farmer explains that he lost 200 jackfruit trees out of the 300 planted in 2017. And adds: «As the province only compensates trees that appear in planning (coconut, grapefruit, longan) and no other species, I lost everything. And in neighboring Châu-Hừng commune community it's worse, because 60 to 70% of farmers had planted jackfruit trees.»

Faced with this dramatic situation, the inhabitants have many questions. On the one hand, in the emergency, why were the dam's sluicegates not opened to lower the water level and avoid saltwater penetrating into the arroyos and canal? Moreover, as a preventive measure, why were sluicegates not built on the banks of the Ba-Lai River at the entrance to arroyos and canals, as in communes bordering the Mỹ Tho River (Mekong River branch)? Finally, why has the construction of the Ha-Hóa dam, to stop the rising saline waters at the entrance to the Giai-Hòa canal, still not begun despite the project being in place for several years (see Figure 2/6.8)? On this last point, CTY-TL-BT explains that the project is still under study.

[Figure 2/6.8]
Impacts of the Ba-Lai dam: periods of salinization-drought (2016 & 2019–2020)



4. Conclusion - Recommendations

In about twenty years, the Ba-Lai dam has profoundly changed the hydraulic dynamics, ecosystems, agrarian landscapes and, more globally, the living conditions in Bình-Đại district.

Along with its undeniably positive effects on production methods and access to domestic water – which are part of the overall provincial program of adaptation to climate change – its operation has caused direct and indirect damage of various kinds.

1] Ba-Lai dam is embedded in an incomplete protective scheme that has proven unable to contain recent severe saline upwelling. In an emergency, provincial authorities had three temporary dams built in 2020 to protect Bến-Tre city. It is therefore necessary to finalize this arrangement as soon as possible, with construction of the An-Hóa (Giao-Hòa canal) dam as a priority (see Figure 2/6.8).

2] The rigid and technocratic timetable which sets the dates and duration for opening and closing the dam's sluicegates should be the subject of open consultation between the various groups of stakeholders (from political decision-makers to farmers)[10], to find compromises on resource uses that take the serious environmental degradation observed into account.

In concrete terms, the rapid accretion of the riverbed and Ba-Lai estuary requires the rhythm and duration of reservoir emptying to be increased. If nothing is done, the estuary will be filled in the medium term, and the dredging of riverbed – which represents a considerable financial burden – will have to be repeated cyclically. These regular emptying operations will also have positive impacts on: 1. water circulation in the canal systems inland; 2. water pollution in the reservoir; 3. penetration of saline intrusions; 4. landslides on the banks of the body of water. But it will also have several disadvantages, the main one being the reduction of the volume of water stored in the reservoir.

3] The pollution of soil, surface and ground water must be a priority, as the situation is rapidly worsening. The treatment of this complex issue can take different forms: a regulatory apparatus associated with controls on individual and collective behavior; awareness-raising among young people; promotion of less polluting agricultural practices. They should be accompanied by developing drainage networks for domestic, agricultural and aquacultural wastewater.

4] The discrepancy between official planning for agricultural land use established by the DARD and the actual reality is a source of serious tensions between local authorities

10. Policy makers, technical services, water treatment plant managers, local authorities, presidents of cooperatives (coconut, clams), farmers, aquaculturists and fishermen.

and aquaculturists (destruction of drillings; cessation of electricity supply; etc.). Beyond this coercive approach – whose results are inconclusive – the difficult cohabitation of «freshwater» and «saltwater» production models calls for the establishment of a space in which farmers and aquaculturists can confront and exchange ideas, to find an acceptable compromise to both parties. This is particularly true on the sensitive issue of wastewater treatment and discharge. Without this, the situation can only get worse.

5] The retrospective study of the two periods of salinization-drought (2016 and 2019–2020), highlights deficiencies in communication with users, while daily measurements of water salinity levels were being carried out at various points on the Ba-Lai River, its tributaries and the Giao-Hòa canal (see chapter 11 in "A COP26 assessment report of the GEMMES Viet Nam project"). It therefore seems essential to improve the efficiency of information dissemination channels, to alert farmers in real time about the evolution of water quality and limit damage caused by contaminated irrigation water.

All these issues are related to the lack of a holistic approach and poor coordination between upstream and downstream areas. Finally, it now seems necessary to think about the consequences that the multiplication of hydraulic infrastructure (dams, sluicegates) planned in Bến Tre province will have (see note 3). Are there viable alternatives to the complete anthropization of the natural environment? How can we anticipate the social and economic impacts of this artificialization on the lives of the population (vulnerability; increased inequalities; migrations [Focus 7]; reconfiguration of social structures), and how can we accompany inhabitants so that they adapt as best they can to the degradation of the environment and of agricultural production conditions caused by climate disruption?

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Focus 7

Migration as adaptation

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Abstract

This focus explores the relationship between changes in the environment and migration decisions. It is based on a literature review and multisite qualitative research into rural-to-urban migration in a context of environmental changes, in particular from the Mekong Delta to Ho Chi Minh City. Key results show that environmental changes act as an underlying factor in the migration decision, masked by economic factors. Insufficient incomes from the agricultural sector and the lack of alternative job opportunities emerge as the primary reasons for moving – as consequences of the economic context, environmental changes and limited availability of farming land. Environmental hazards do affect livelihoods, but they are rarely identified as migration factors by migrants themselves. Economic and social dynamics feed populations' aspirations for upward social mobility, and propel them towards urban areas. Moreover, the research highlights that while out-migration from the Delta replaces or complements on-site adaptation strategies, it also can lead to multidimensional vulnerability in urban areas. Low-skilled rural migrants often make a long-term temporary move rather than a permanent one, before returning to the hometown where they have kept their land. However, land availability and current environmental trends in the Mekong Delta call the durability of these strategies into question. Therefore, it is increasingly necessary to support the local population in the Delta by developing local job opportunities and livelihood aids – especially for landless farmers – as well as to provide information on the medium- and long-term impacts of climate change. At the same time, it is equally important to accompany migrants in their migration via dedicated public support structures, to prevent them from entering urban poverty.

Tóm tắt

Trọng tâm này khám phá mối quan hệ giữa những thay đổi về môi trường và các quyết định di cư. Nó dựa trên một tổng quan tư liệu và nghiên cứu định tính đa địa điểm về di cư từ nông thôn ra thành thị trong bối cảnh về những thay đổi môi trường, đặc biệt là từ khu vực Đồng bằng sông Cửu Long đến Thành phố Hồ Chí Minh. Các kết quả chính cho thấy những thay đổi về môi trường đóng vai trò như một yếu tố cơ bản trong quyết định di cư, bị che lấp bởi các yếu tố kinh tế. Thu nhập không đủ từ ngành nông nghiệp và thiếu các cơ hội việc làm thay thế nổi lên là những lý do chính để di cư – như những hệ quả của bối cảnh kinh tế, thay đổi môi trường và hạn chế về đất canh tác. Các hiểm họa môi trường có ảnh hưởng đến sinh kế, nhưng chúng hiếm khi được chính người di cư xác định là các yếu tố di cư. Động lực kinh tế và xã hội nuôi dưỡng khát vọng của người dân đối với sự dịch chuyển xã hội đi lên và thúc đẩy họ hướng tới các khu vực thành thị. Hơn nữa, nghiên cứu cũng nhấn mạnh rằng mặc dù việc di cư ra khỏi Đồng bằng, bản thân nó đã thay thế hoặc bổ sung bằng các chiến lược thích ứng tại chỗ, nó cũng có thể dẫn đến tình trạng dễ bị tổn thương đa chiều ở các khu vực đô thị. Những người di cư nông thôn có kỹ năng thấp thường di cư tạm thời trong một khoảng thời gian dài trước khi trở về quê hương nơi họ có phần đất đai của mình, hơn là di cư vĩnh viễn. Tuy nhiên, đất đai hiện hữu và xu hướng môi trường hiện tại ở Đồng bằng sông Cửu Long khiến độ bền của các chiến lược này là một vấn đề đáng bàn. Thế nên, ngày càng cần thiết phải hỗ trợ người dân địa phương ở Đồng bằng bằng cách phát triển các cơ hội việc làm tại địa phương và hỗ trợ sinh kế – đặc biệt là cho những nông dân không có đất - cũng như cung cấp thông tin về tác động trung và dài hạn của biến đổi khí hậu. Đồng thời, điều quan trọng không kém là đồng hành với người di cư trong quá trình di cư của họ thông qua các cơ cấu hỗ trợ công riêng biệt để ngăn họ lâm vào tình trạng nghèo đói khi ở thành thị.

Résumé

Ce focus explore la relation entre les changements de l'environnement et les décisions migratoires. Il se fonde sur un état de l'art et une recherche qualitative multisituée portant sur la migration rural-urbain dans un contexte de changements environnementaux, en particulier depuis le Delta du Mékong vers Ho Chi Minh Ville. Les résultats clefs montrent que les changements environnementaux contribuent à la décision migratoire en tant que facteurs sous-jacents, dissimulés derrière les facteurs économiques. Les revenus insuffisants retirés du secteur agricole et le manque d'opportunités d'emploi alternatives ressortent comme les raisons premières de partir – conséquences du contexte économique, des changements environnementaux et de la disponibilité limitée des terres agricoles. Les aléas environnementaux affectent les moyens de subsistance, mais sont rarement identifiés comme des facteurs de migration par les migrants eux-mêmes. Les dynamiques économiques et sociales alimentent les aspirations des populations à une ascension sociale, et les orientent vers les zones urbaines. De plus, la recherche met en lumière que l'émigration depuis le Delta, tout en remplaçant ou complétant les stratégies d'adaptation sur site, peut aussi mener à une vulnérabilité multidimensionnelle en zone urbaine. Les migrants ruraux peu qualifiés opèrent souvent un déplacement temporaire de long-terme plutôt qu'un déplacement permanent, avant de retourner dans leur commune d'origine où ils conservent leur terrain. Cependant, la disponibilité des terres et les évolutions environnementales actuelles dans le Delta du Mékong questionnent la durabilité de ces stratégies. Ainsi, il est de plus en plus nécessaire de soutenir la population locale du Delta en développant des opportunités d'emploi locales et des aides de subsistance – notamment pour les agriculteurs sans terres – ainsi qu'en informant sur les impacts du changement climatique à moyen et long termes. En parallèle, il est tout aussi important d'accompagner les migrants dans leur migration par des structures publiques de soutien dédiées, afin de les prémunir d'entrer dans la pauvreté urbaine.

According to the last national census, the Vietnamese part of the Mekong Delta numbered 17.3 million people in 2019 – 18% of the national population – on 12% of the country's total surface area [GSO, 2020]. Delta inhabitants have developed livelihoods based on seasonal transformations in the environment, and the rhythm of flooding – including adapted cultures, protective infrastructures, housing on stilts and boat transportation. In this deltaic context, flooding is not unequivocally considered as a threat, but also as a resource for agriculture. It contributes to alluvial deposition, fisheries, water quality, and rice field deacidification [Danh and Mushtaq, 2011], as mentioned in other contributions to this report, particularly Focus 3 and Focus 5 in this chapter. Given the favorable conditions for agriculture, the large majority of delta inhabitants earn their living from agriculture. In 2019, the Mekong Delta represented 48% of the country's cereal-planted surface area, 54% of paddy-planted surface area, and 72% of the aquaculture surface area [GSO, 2021]. But irregular environmental changes are disrupting these activities. Confronted with the changing environmental conditions identified in the COP26 GEMMES Viet Nam project report of 2021 [Espagne *et al.*, 2021, chapters 9 and 10], Delta farmers have had to adapt to maintain their incomes and livelihoods, either through on-site adaptations, or migration.

Historically, the Delta has been populated by migration waves, and the local population is made up of "open peasant settlements", relatively unstructured in comparison with the population of the Northern Red River Delta [Rambo, 1977, p.187]. Today, the Mekong Delta is characterized by a very high out-migration rate. The last national statistical census, conducted in 2019, reveals that the out-migration rate of the Mekong Delta is up to 4.5%, with a net-migration rate of - 4%. These are the highest out-migration rate and the lowest net-migration rate of all the country's regions. Most of the migration flows head to the Southeast Region, including Ho Chi Minh City and neighboring industrial provinces such as Binh Duong province [GSO, 2020]. In 2019, Ho Chi Minh City had an in-migration rate of 9.1%, Binh Duong province 21.7% and Dong Nai province 6.6% [GSO, 2020][1]. The 2014 intercensal survey on migration and urbanization counted the number of inter-provincial in-migrants and out-migrants by regions in the same year – *i.e.* people aged over-5 who reported having a different province of residence 5 years prior to the time of the survey. Out of all the out-migrants from the Mekong Delta recorded on that date (762,555 people), 76.5% had moved to the Southeast Region (583,358 people) [GSO and UNFPA, 2016].

This focus aims to document the potential relationship between changes in the environment and migration decisions in the Mekong Delta. We question to what extent migration can be considered as an adaptation strategy to environmental changes[2] in that context. Questioning migration as adaptation implies asking to what extent migration occurs in reaction to environmental changes, but also interrogating the impact of migration on vulnerability. This paper reviews a number of previous projects which tackled the issue of the link between environment and migration in the Mekong Delta. From there, we present preliminary results from a multisite research project on rural-to-urban migration directed towards Ho Chi Minh City, in a context of environmental changes.

1. The in-migration and out-migration rates of a territorial unit reflect the number of people from other territorial units who immigrate to and emigrate from that territorial unit in proportion to the population of that territorial unit. These numbers include only official internal migrants, defined as residents of a specific administrative unit, who lived in a different administrative unit five years earlier, and aged 5 or older at the time of census enumeration [GSO, UNFPA 2010].

2. We choose to use the term "environmental changes" to encompass the multiplicity of changes in the environment of the Delta that affect the daily life and future projections of its inhabitants, whether they are of climatic or anthropogenic origin, since it is often challenging to dissociate the two. It refers to slow transformations of the environmental conditions such as sea level rise and salinization, disturbed periodic ones such as flood and drought, or rapid-onset events such as landslides. Environmental changes include the manifestations of climate change but also the consequences of local anthropogenic actions on the Mekong Delta which accelerate natural phenomena (groundwater extraction fostering land subsidence for instance), or which disturb local ecosystems (soil and water pollution for example).

1. Migration and environment: academic controversies and political agenda

1.1 Academic controversies

Migration related to environment and/or climate has been generating a growing field of literature internationally, especially since the late 2000s [Cattaneo *et al.*, 2019; Black *et al.*, 2011a; Tacoli, 2009; Hunter, 2005]. Research in particular highlights the multiplicity of factors which converge in the migration decision, and the difficulty in isolating and quantifying environmental migration [Gemenne and Cavicchioli, 2010; Véron and Golaz, 2015].

A landmark study on the topic was published in 2011 by the Foresight project. Based on multiple international case studies, it identifies five categories of migration drivers: economic, political, social, demographic and environmental [Black *et al.*, 2011b]. The report highlights the interactions between the multiple drivers, and the various ways in which the environment can influence migration. It reveals that "environmental change is as equally likely to prevent migration as it is to increase it" [*ibid.*, p.104], by impacting the livelihoods and resources of affected households. It points out in particular the vulnerability of "trapped populations" unable to achieve migration, and the benefits migration can bring to individuals, households and communities in departure and destination areas. In the Foresight project's analysis, low-elevation coastal zones stand out as major areas of challenges in terms of population's vulnerability to the impacts of environmental change.

One critical field of research also alerts against potential neoliberal drift, acting to enforce the desirability of migration in support of a vision of development deliberately orientated towards industrialization and urbanization [Paprocki, 2018]. In light of this, some authors choose to focus rather on non-migration strategies, and on immobility in the face of environmental change [Sengupta and Samanta, 2022; Mallick *et al.*, 2022].

1.2 International political agenda

Despite these debates, environment-induced migrations have been established as a priority in the international political agenda. In its last report, the Intergovernmental Panel on Climate Change presents migration, in particular internal migration, as a possible response in the face of climate change. At the same time, it highlights that the relations between climate change impacts and migration vary in line with the socio-economic characteristics of individuals – in particular gender – and with the political context [IPCC, WG2, 2022, chapters 6, 7, 8]. Population displacement in reaction to climate change has also been mentioned in the Sendai Framework for the reduction of disaster risks 2015-2030 [UN, 2015, Art. 33].

In addition, dedicated international cooperation frameworks have emerged, such as the multi-stakeholder platform on population displacements in the context of sudden- and slow-onset disasters (especially cross-border ones), which followed the Nansen initiative launched in 2012. The ten Nansen Principles of 2011 are recommendations "to guide responses to some of the urgent and complex challenges raised by displacement in the context of climate change and other environmental hazards" [Kalin, 2012, p.1]. They complete the Guiding Principles on Internal Displacement adopted by the United Nations Commission on Human Rights in 1998. Later, the Global Compact for Safe, Orderly and Regular Migration was released by the United Nations in 2018 [UN General Assembly, 2018, Art. 18]. More recently, the Global Mayors Task Force on Climate and Migration was launched in 2021 by the C40 Cities and the Mayors Migration Council. These cooperation frameworks aim to share experiences and provide a policy framework built using a bottom-up approach, and these international guidelines are intended to be turned into national legislations by states.

1.3 Migration and environment studied in the Vietnamese Mekong Delta

In Viet Nam in particular, the crucial challenge of the link between environment and migration has been highlighted by previous research in the Mekong Delta, and several major studies have provided insight into the question over the past 15 years: some of the main ones are reported below.

In 2007–2009, the European Commission-funded Environmental Change and Forced Migration Scenarios project (EACH-FOR) – implemented in partnership with the International Organization for Migration – examined multiple international case studies. In particular, it considered whether regular flooding, its intensification and its increased frequency in the Vietnamese Mekong Delta could trigger migration and population relocation. The study, based on three-months' fieldwork in An Giang province, Ho Chi Minh City, Hanoi and Phnom Penh (Cambodia), finds that "environmental change (flooding in this case study) is shown to be a trigger for independent migration decisions when livelihoods are negatively affected, for example when crops are lost, generally on more than one occasion" [Dun, 2011, p.217]. It includes internal and international, seasonal, temporary or permanent migration. It does not identify environmental change as the main cause of migration. Instead, authors use the concept of "socio-ecological tipping points" to emphasize the importance of the socio-economic and political context in which the environmental changes occur [Warner *et al.*, 2010, p.708].

Over the same period, the large German-Vietnamese WISDOM project (Phases I and II), conducted between 2007 and 2013, also drew upon the concept of tipping points. Within the broader mission of providing the Mekong Delta with a water information system encompassing both natural sciences and socio-economic processes, Garschagen and colleagues chose to focus on peri-urban interfaces, which are affected by socio-economic transformation, biophysical degradation and climate change impacts [Garschagen *et al.*, 2011]. The concept of tipping points here designates the "decisions, events and access-portfolios" which lead from one section to another on an individual- or household-level "dynamic resilience pathway", that may include migration [*ibid.*, p.157].

In 2013, the Mekong Migration Network and the Asian Migrant Center – with the support of the Rockefeller Foundation – published a study on climate change and migration in the Greater Mekong Subregion[3]; initiated at the end of 2011, it compared two case studies from Myanmar and Viet Nam [MMN and AMC, 2013]. The Vietnamese case study was based on a survey of 50 households, focus group discussions and interviews with key informants, conducted in an agricultural hamlet of Can Tho City in the Mekong Delta. Environmental changes – potentially linked to climate change – included increased extreme hydro-climatic weather, more extreme warm weather, soil degradation or impoverishment, less rainfall, irregular flooding, and drought. Salinity was also recognized as a growing threat by local leaders and authorities, but not by residents. The study establishes a correlation between environmental changes and migration, through the negative impacts of environmental changes on the livelihoods and health of local inhabitants, and on soil and water quality (notably through increased pollution). However, the research also points out that migration would still occur independently of environmental changes, as a reaction to the low incomes and lack of jobs locally, in contrast with the employment and education opportunities available in urban areas. It urges that both climate change and mobility be taken into consideration as "issues of global justice" [*ibid*, p.11].

3. The Greater Mekong Subregion covers Cambodia, the People's Republic of China (specifically Yunnan Province and Guangxi Zhuang Autonomous Region), the Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam.

Later on, between 2014 and 2017, the MECLEP project, "Migration, Environment and Climate Change: Evidence for Policy" – funded by the European Union and implemented by the International Organization for Migration (IOM) and a consortium of partners – highlighted poverty and livelihood insecurity as the main reasons for migrating from rural Mekong Delta areas to Can Tho and Ho Chi Minh City, including migration from a relocation site [Nguyen *et al.*, 2017; Chun, 2015]. A quantitative survey was completed by 1,232 households in six communes in Ho Chi Minh City, Long An province and Ca Mau province. It finds a positive correlation between specific forms of environmental stress (particularly erosion, cyclones and floods) and migration, but points out that other important factors may also have been at play [Entzinger and Scholten, 2016]. It reveals how, in that context, environmental and economic factors might overlap. Interestingly, the results also show that the observed migration is more likely to be a long-term move than a short-term one. From a qualitative perspective – based on fieldwork in two communes exposed to seasonal flood and riverbank erosion in Long An province and Dong Thap province respectively, as well as two sites in Can Tho and Ho Chi Minh City – Chun identifies a list of key assets which influence households' vulnerability, their livelihoods and their decision regarding mobility in conditions of environmental stress: house ownership, access to agricultural land, financial planning skills and diversified income-generating skills, agency and confidence, as well as health and able-bodiedness [Chun, 2014].

In 2016, a multisite research project led by Koubi and colleagues documented the link between the temporality of the hazard and the decision to migrate [Koubi *et al.*, 2016]. The authors compared four districts in four provinces as departure areas, two in the Mekong Delta, one on the South-Central Coast and one in the Red River Delta, with Ho Chi Minh City and Hanoi as destinations. The study was based upon 1,200 completed questionnaires, for which half the respondents were migrants and the other half non-migrants. It shows the importance of the actual speed of the event and of time perception by the local population in the decision to migrate. According to results based on respondents' perceptions of the weather event(s) they experienced over the past 5 years, rapid-onset and short-term events (such as flood or typhoons) were significantly likely to lead to a decision to migrate, whereas slow-onset and long-term events (such as drought or salinity) had little to no influence.

Finally, a more discrete study has also applied a quantitative method to the case of the Mekong Delta; it was conducted in 2015 by Oanh and Truong, based on a survey with 200 participants (migrants and non-migrants) in Ben Tre province and Dong Thap province (two communes in each). The authors identify only a small statistical correlation between the impacts of climate change and the migration decision [Oanh and Truong, 2017], through the impacts of climate change on local production activities (breeding, fishing and farming), overall quality of life (including incomes, access to food, housing and infrastructure), and the quality of the environment (water and soil). This leads them to point out that other factors must also affect migration.

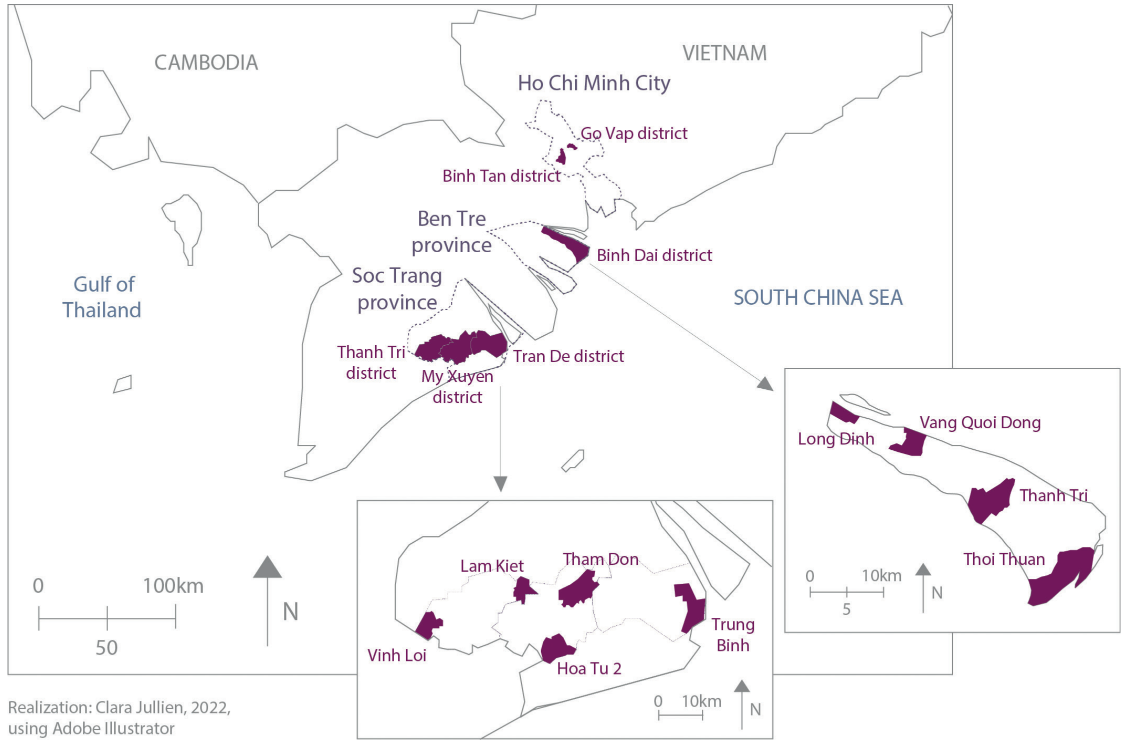
Previous studies identify a tenuous link between environment and migration, often through the impact of environmental disturbance on farming incomes. However, the methodologies implemented do not allow for detailed understanding of the causal chains at play, or the perceptions of migrants and local populations regarding environmental changes. Therefore, to follow up on this literature, a multisite research project has been conducted since 2020, to document rural-to-urban migration in Viet Nam in a context of environmental changes.

1.4 Research setting

From June 2020 to June 2022, around 120 rural migrants were encountered for in-depth qualitative interviews in Ho Chi Minh City (in Go Vap and Binh Tan districts), around half of them from the Mekong Delta. In addition, fieldwork was conducted in Binh Dai district, Ben Tre province, in order to collect information via interviews with local authorities and families of migrants, supplemented by a recent fieldwork study located in Tran De, My Xuyen and Thanh Tri districts, Soc Trang province [4] [Figure 2/7.1]. The two districts studied in Ho Chi Minh City enabled the observation of two types of urban fabrics which have been densified by migration flows at different periods of time (since the 1990s in Go Vap district, and since the 2000s in Binh Tan district), and which present different economic profiles today (a bigger tertiary sector in Go Vap district, and more industry in Binh Tan district). The two areas studied in the Mekong Delta were chosen for their exposure to different hazards (salinization in Binh Dai district, Ben Tre province, Tran De district and My Xuyen district in Soc Trang province; fresh water flooding in Thanh Tri district, Soc Trang province). In addition, the areas studied in Soc Trang province included rice farming, along with shrimp farming in the eastern area, while rice farming had totally disappeared in the communes studied in Ben Tre province. Finally, the two areas were selected for their different distances to Ho Chi Minh City.

4. The data analysis is currently in progress. The elements presented here are preliminary.

[Figure 2/7.1]
Location of study sites



Realization: Clara Jullien, 2022, using Adobe Illustrator

2. Preliminary results from fieldwork research

2.1 The environment as an underlying factor of migration, among converging ones

The insights from both the arrival areas and the departure areas converge towards the same observation, in line with previous studies conducted on the climate-migration topic in the Mekong Delta. Environment stands out as an indirect factor of migration, easily hidden behind the economic factor. Indeed, the connection between environmental change and migration lies predominantly in the impact that changing natural conditions might have on farming activities, and therefore local inhabitants' livelihoods in rural areas of the Delta.

Insufficient incomes from agriculture, and lack of alternative job opportunities

The interviews conducted in Ho Chi Minh City, with rural migrants who arrived from thirty years to three months before the meetings, reveal that although exposure to environmental hazards is often present in the migration stories, it is very rarely mentioned spontaneously by the interviewees as a factor in migration. Instead, almost all the interviewees primarily mention economic difficulties as the main reason for migrating. The majority of the interviewees previously earned their living from agriculture, or – in the case of people who migrated at a young age – came from families relying on agriculture as their principal source of income. They express insufficient incomes combined with lack of local job opportunities as their main reason to opt for migration.

This statement from interviewees themselves is coherent with the accounts from the migrants' families, interviewed in Binh Dai district, Ben Tre province as well as Tran De, My Xuyen and Thanh Tri districts, Soc Trang province; they explain the departure of their relatives (in most cases their children) as a reaction to the lack of local opportunities to attain the level of income they aspire to. The same statement is made by some representatives of the local authorities at the commune level in departure areas. Reflecting on the departure of young people, a local official from the social services of the People Committee of Vang Quoi Dong commune in Binh Dai district explained that they leave because the People Committee has not been able to provide them with enough support to do farming or access other suitable jobs. In that commune, according to the same official, some 2 households out of 3 have at least one member who works elsewhere. The population of Vang Quoi Dong relies on coconut manufacturing, as the commune is critically affected by drought during the sunny season and floods during the rainy season, particularly in recent years. The years 2016 and 2019–2020 especially brought extreme episodes of drought and salinization due to high heat and scarce rain (see Focus 6). According to the commune's People Committee, coconut manufacturing represents 40% of the commune's local economy, agriculture and aquaculture represent 20%, while the remaining 40% consists of the remittances sent back by workers in other communes and people abroad, as well as interest on investments. The departure of young people is becoming problematic for the People Committee, since coconut manufacturing is beginning to experience a shortage of labor for physical tasks. On that note, the distance to Ho Chi Minh City does not seem to have a significant impact, since the same trends of migration towards the metropolis and its surroundings are observed at the study sites in Ben Tre province and Soc Trang province.

Interpreting this statement about the lack of job opportunities – expressed by local authorities, by migrants themselves and by their relatives – involves keeping in mind the subjective and relative nature of the concept of poverty. For some households, the idea of "insufficient income" might express extreme precarity and refer to survival mechanisms. But for other households, it might refer to a more relative sense of poverty, in comparison with others, with what could be achieved, in reference to a certain standard of what is considered to be a decent or desirable income. Migration might therefore occur in households with very different economic situations, from relatively wealthy households sending their children to study in the city, to households suffering from financial precarity whose members migrate in a final effort to make ends meet. On that subject, an aspect has been pointed out by previous international research and notably by the EACH-FOR project, as well as the MMN and AMC project, in the Mekong Delta [MMN and AMC, 2013; Warner *et al.*, 2012]: migration may not be an accessible option to the most destitute households, because it requires capital – be it financial capital for transportation and settlement, or social capital for support in finding a job and accommodation at arrival. However, this result has not been verified in the MECLEP project [Entzinger and Scholten, 2016]. In addition, in another geographical context (the Ganga-Brahmaputra Delta), some research found that capital-rich households were less likely to migrate than others [Mallick, 2022].

Economic context, environmental changes and land availability

The economic insecurity reported by migrants and their relatives results from difficulties in the farming sector, as well as the lack of alternative economic activities. Global market dynamics, as well as the variation of local demand in Viet Nam, have generated highly volatile selling prices in the farming sector, and inflation of input prices, resulting in pressure on farmers, especially small-scale ones. But the economic context is not the only parameter involved, and is not isolated from other parameters, particularly the environment. Current environmental changes in the Mekong Delta have put the farming sector under great pressure. Salinization, disturbed flood patterns, repeated drought and erosion have all affected farming conditions (for more details please refer to Focuses 1, 3, 4, 5 and 6). These climate change-related hazards have been exacerbated by anthropogenic actions in the Mekong River Basin, such as sand extraction, groundwater extraction, dams, and urbanization accelerating land subsidence. In the case of Vang Quoi Dong, the same official of the People Committee sees improving the dike and irrigation system as an incentive for young people to stay in the commune and maintain agriculture. They can also benefit from special loans to rehabilitate coconut farms. Environmental conditions, especially salinization, are seen by this official as contributing to the migration decision, since they affect both agriculture and living conditions.

In addition, one can mention pollution as an anthropogenic environmental parameter likely to affect local populations directly or indirectly. In Binh Dai district, Ben Tre province, water pollution generated by local industries and aquaculture farms, along with settlements located upstream on the Ba Lai River, was mentioned by several local farmers as a major handicap in maintaining their operations. In addition, the water sometimes contains excessive concentrations of alum (see Focus 6). Accessing clean water and accessing water with the right level of salinity are two cumulative challenges.

In an extensive understanding of what the environment encompasses – and stepping aside from climate change in the strict sense of the term – the surface area of farm land emerges as a major environmental influence on agricultural income. Many factors can contribute to progressively reducing land surface. First, the subdivision of the land among siblings over time via inheritance leads mechanically to a diminution of the land surface for each household. Second, erosion may affect the plot of land. Third, public development projects, such as infrastructure projects or industrial zones, may lead to a reduction of available land surface. Finally, households facing difficulties and constrained by debts may be forced to sell part (or all) of their farm land, especially in the context of an inflated land market. The land areas might not be sufficient to develop a commercial farming activity, or even subsistence-oriented agriculture. In a context where farming is more and more oriented towards market and exportation, and not only household subsistence, this reduction of farm land can be critical, especially for younger generations choosing whether or not to follow in their parents' footsteps in the agriculture sector. Also, in extreme cases, this situation can force some destitute households into landlessness and over-indebtedness. Farm land often acts as a safety net for households, as it can guarantee subsistence food supply. It is also an asset for mortgages, a guarantee to get a loan, and a legacy for children [Pulliat, 2013]. In that context, some of the studies mentioned have pointed out the particular vulnerability of landless farmers, whose livelihoods rely entirely on hired labor to farm land they do not own, or in other sectors [Garschagen *et al.*, 2012; Warner *et al.*, 2012].

In the face of these changing environmental conditions, farmers implement adaptation strategies. To some extent, migration can be interpreted as one of them. But one of the reasons that makes this link difficult to pinpoint with precision is the fact that migrants themselves, as well as relatives in their hometowns, do not necessarily identify environmental changes as migration factors. The connection between harsh environmental conditions and economic difficulties leading to migration is rarely expressed – and even less so in terms of climate change impact. Environmental changes remain overshadowed by the broader "unprofitable farming sector" umbrella, which suggests that they are not the only reason for migrating nor the ultimate/proximate cause.

Societal mutations

Research on migration has long shed light on the multifactorial nature of the phenomenon. In the current context of the Mekong Delta, and more broadly of Viet Nam, social factors are particularly important in internal and international migration: societal mutations, especially since the 1990s, have shaped new conditions for migration flows to develop. Two major technical changes – the relaxing of the *hộ khẩu* residential registration system and the development of the transportation system – have been key factors in the development of internal migration [Li, 1996], and the apparition of the migration corridors towards the South-East region that we observe today. In that context, the promotion of urban lifestyles and the diffusion of international urban cultural references have contributed to enhancing the appeal of urban areas. The vision of the modern city as opposed to rural farm land acts as an incentive to turn away from agriculture and enter modernity and globalization. Modernity refers here to the multiplicity of options that the city has to offer. The city is the place where one can access diversity and life experience. It is seen as a potential stepping-stone towards foreign countries. Migrating therefore means obtaining choices, at least in theory, when initially viewed from the rural hometown.

In addition, another crucial element of Vietnamese society that shapes contemporary migrations is the importance of education. Encompassing wealthy households sending their children to study in the cities, less well-off households nevertheless dedicating their savings to send their children away to study, parents migrating themselves to fund the education of their children, and young adults migrating in anticipation of their education or the education of their future children, education is at the core of the migration decision. In that sense, we observe a generational shift between elder people who largely had no opportunity to access education, and young people who have been exposed to a broader portfolio of options over the past two decades as a result of the education expansion policies initiated in the 1990s [Truong *et al.*, 2021].

To sum up, although migration decisions often involve changes in environmental conditions in the Mekong Delta, they take place within economic and social dynamics feeding populations' aspirations to upward social mobility, which for some seem unachievable if they stay in the farming sector.

Direct impacts of environmental changes

Finally, in addition to the indirect impact they have on migration through agriculture, environmental changes can also have more direct consequences on local populations by threatening their personal safety or affecting their housing. These direct consequences are seen following rapid-onset disasters such as storms, or repeated and prolonged disasters such as drought or high seasonal floods. Thus, given the future climate projections, the potential direct impacts of environmental changes are likely to be growing concerns.

The direct and indirect causal chains from disruptive factors to migration are illustrated in Figure 2/7.5.

2.2 Migration as an adaptation strategy, an alternative to on-site adaptations

Changing activity within the primary sector

To fully understand the context in which the migration occurs, it is worth mentioning some of the alternative options that local households might implement when faced with difficulties. Migration might replace some of them, or might occur in complement to them. For the upper-part of the Delta, literature reports changes in the rhythm of rice-field harvests as a way to cope with changing environmental conditions [Chapman and Darby, 2016]. For the case of rice farming in particular, we refer to Focus 5 of this chapter. The switch from rice farming to aquaculture, and in particular shrimp farming, is another typical strategy adopted by populations (c.f. Focus 6). Our fieldwork in Binh Dai district, Ben Tre province, and in Tran De, My Xuyen, and Thanh Tri districts, Soc Trang province, confirms that this switch is triggered by both economic opportunity and salinization. The very high profit that can potentially be gained from shrimp farming provides an incentive for households to turn their fields into ponds, in a context that is less and less suitable for rice farming. However, once again, the idea of minimal cost (here the initial investment to develop a shrimp pond) comes into play in preventing part of the population from being able to access this option. In reference to the high unpredictability of this activity, we refer to Focus 6 on the impacts of the Ba Lai dam.

In a highly salinized environment such as Binh Dai district, Ben Tre province, another option is to develop coconut farming, or other fruits that offer a high tolerance to salt. Nevertheless, these fruits crops make a relatively low profit, which in addition is likely to vary considerably according to changes in demand. As such, they might not appear very attractive to younger generations, especially when land surfaces are insufficient to harvest large quantities. Yet some varieties with high yields remain profitable, and the low labor requirements – especially in the case of coconut fields – makes them suitable for older generations.

In Ben Tre province, coconut farming has led to the development of a coconut manufacturing industry, which provides another sector of employment for the local population. However, despite their place in the secondary sector, the manufacturing warehouses specialized in food processing – whether seafood or fruits – remain highly sensitive to environmental conditions, in the present changing environmental context. Indeed, certain on-site adaptation strategies might potentially be heavily impacted by climate change.

Turning away from food production and food processing

Another alternative is to leave any employment sector that relies directly or indirectly on environmental conditions. Locally, within Binh Dai district, the conversions are focused mostly on small-scale entrepreneurship in the case of households who have a small financial capital or access to land and buildings, or on the construction sector. The growing construction sector in rural areas generates a local job market, but offers irregular working schedules and incomes, as well as very tough working conditions. It is of course inaccessible to older people. Overall, the main growing alternative to farming is to become a worker in a local factory. In the case of Binh Dai district, becoming a factory worker means migrating towards the massive industrial park of Giao Long in the neighboring district of Chau Thanh [Figure 2/7.2]. The future industrial zone of Phu Thuan will create a new local pool within Binh Dai district. The local recruitment centers under the supervision of the Department of Labour, Invalids and Social Affairs of Ben Tre province help to make the connection between employers and young people. In addition, migrants very often receive the support of their personal network to find a position. However, the industrial sector only offers a time-limited solution, as factories rarely employ workers over 40 years old.

[Figure 2/7.2] **Migrant workers leaving Giao Long industrial park in Chau Thanh district at dusk and commuting back to their hometown in Binh Dai district, on the main road connecting the two districts through An Hoa bridge.**
Photo credit: ©Clara Jullien - 02/04/2022

Migration within the Mekong Delta

The current industrialization policy implemented in the Mekong Delta is already generating alternative options to farming, leading to a local intra-district or intra-province migration, which absorbs part of the migration that would otherwise be directed towards other provinces and major urban and industrial hubs, such as Ho Chi Minh City or Binh Duong province. This migration can be temporary or circular, returning to the hometown on a weekly or bi-weekly basis, or – if the distance allows it – commuting on a daily basis. Thus, out-migration away from the Mekong Delta towards other Vietnamese regions, especially the South-East, needs to be put in perspective within a broader map of migration including intra-district, inter-district and inter-province migration within the Mekong Delta, as well as international migration.

Within the Mekong Delta, the development of industrial parks, as well as the growing local service sector generated by urbanization, both counteract long-distance migration. In Binh Dai district in particular, the development of Ben Tre province towards the East with a focus on developing industries – especially related to the sea and energy infrastructures – addresses the issue of migration by providing local employment that is less directly dependent on natural resources. But even though industrial parks and local urban centers might seem disconnected from their natural environment and exempt from vulnerability to environmental changes when compared to agriculture, they remain located in an area affected by subsidence and sea level rise, and therefore potentially exposed to submersion in the long run. For instance, the industrial park of Giao Long, in Chau Thanh district, next to Binh Dai district suffered severe floods at the end of May 2022. The long-term sustainability of this transition needs to be considered in order to optimize the use of investment.

Building protective infrastructure

To reduce exposure and vulnerability to submersion, flood, salinization and erosion, one of the main strategies implemented consists in building protective public infrastructure such as dikes, dams and sluicegates. Infrastructure can significantly reduce exposure, but a zero-percent risk can never be guaranteed. As stated in Chapter 12 of the COP26 GEMMES Viet Nam project report, "adaptation resources have mainly been spent on large-scale hard infrastructure, which is often designed without full recognition of the systemic nature of the risks and uncertainties associated with future climate change. [...] Some infrastructure is still necessary, but some may also increase existing risks or create new ones" [Espagne *et al.*, 2021, p.556]. Issues of dysfunction or coordination between different equipment

[Figure 2/7.3] Failing public sluicegate in Long Dinh commune, Binh Dai district, Ben Tre province
Photo credit: ©Clara Jullien - 01/04/2022

and localities might reduce its efficiency. This is particularly the case in Long Dinh commune studied in Binh Dai district, where the sluicegates along the Mekong River have failed since their construction, and proven useless in limiting salt intrusion [Figure 2/7.3].

Consequently, on a much smaller scale and in a more rudimentary way, households in this commune implement similar mitigation via infrastructure on their plots of land, using handmade "sluicegates". In fact, water management in general generates a large range of coping mechanisms to maintain farming and aquaculture activities, including collecting rain water for personal consumption, stocking fresh water from the river dam during rainy season, purifying water extracted from the canals, or, in last resort, buying water at a very high price. On that point, we again refer to Focus 6 of this report and Chapter 11 of the COP26 GEMMES Viet Nam project report of 2021, on the impact of the Ba Lai dam [Espagne *et al.*, 2021].

Relocation procedures

In addition to infrastructure, relocation has proved effective in reducing exposure to hazards. As pointed out by previous research [Miller, 2019; Nguyen *et al.*, 2017; Chun, 2015; Dun, 2011; Warner *et al.*, 2010], the social and economic consequences of relocation must be considered to obtain a full picture of the outcome resulting from relocation procedures. Furthermore, a case encountered during fieldwork in Binh Dai district highlights the need for the timeframe of relocation procedures to be coordinated with local planning. In Vang Quoi Dong, one interviewee reported having been relocated twice. First, some 10 years ago because erosion was threatening his house, and then a second time some three years ago when construction of the local dike began on the plot of land where he had been relocated. Aged in his fifties, this man was taking care of his mother and working as hired worker harvesting coconuts, while his wife and children were working in Ho Chi Minh City. At the time of the first relocation, he was thinking of buying the plot of land that had been allocated to him for 20 years. Instead he was relocated back to the shore, where erosion is still affecting housing. The mismatch between relocation planning and dike planning made it impossible for this household to make future plans. As they do not own any farming land, insufficient local income sources led most members of this household to migrate to Ho Chi Minh City. This situation caused the household to split up, in order to combine both caring for the older generation and seeking an income.

The different categories of adaptation strategies are shown in Figure 2/7.5.

2.3 Migration and vulnerability, the limits to adaptation

Multidimensional vulnerability at destination

Migration might appear to migrants themselves and their relatives as a solution to escape insecurity, including exposure to environmental conditions. However, low-skilled migrants with limited economic and social capital are likely to face multidimensional vulnerability in the city as well, at legal, economic, social and environmental levels. They encounter harsh working conditions in urban areas and industrial parks, such as short-term working contracts, verbal-agreement jobs, difficult labor tasks, long work schedules and extra shifts. The cost of renting accommodation, plus the costs of living, can contribute to relative financial vulnerability. This can lead to precarious housing conditions in urban areas, that migrants nonetheless put up with in order to save as much money as possible. The savings are often sent back to their relatives in their hometown, and – in some cases – the distance can lead to social isolation in the city. People who might have benefitted from public social and financial aid in their hometown (through poor people status, loans, cattle or loving homes) can find themselves helpless without this support.

This vulnerability was particularly visible during 2021, notably during the lockdown, with massive dismissals in the industrial sector and constraints in the informal sector imposed by social distancing measures. In September 2021, after the reopening of Ho Chi Minh City, we observed chaotic flows of migrants returning to their hometowns, unemployed and having depleted their savings.

[Figure 2/7.4] A house built by a migrant couple in their forties in Vinh Loi commune, Thanh Tri district, Soc Trang province, using the savings from their work in a factory in Dong Nai province, and borrowed money from relatives. The house is complete, but the couple plans to continue migrating for few more years to pay back their debt and build up a small capital, in order to open a small business in Vinh Loi. They choose to rent out their 3,000 m² of farmland instead of farming it as the land surface is small.

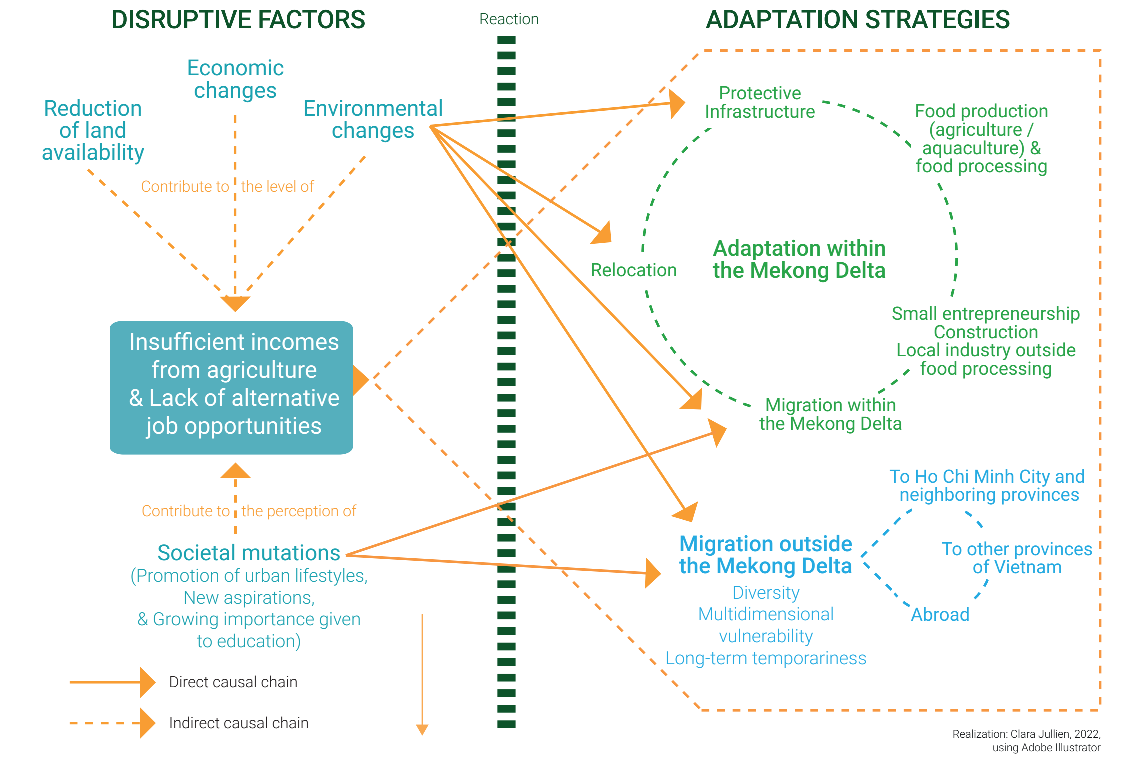
Photo credit: ©Clara Jullien - 17/06/2022

Long-term temporary migration

In addition, the land market in urban areas, in particular Ho Chi Minh City, makes it very challenging for most workers to access land ownership in the city. In that context, migrants often intend to return to their hometown later in life, sometimes after decades, notably at retirement age [Figure 2/7.4]. A common pattern seems to be to migrate at a young age until their physical condition no longer meets the requirements for working in the city. This particularly applies to the industrial and the construction sectors, which chiefly employ young people. In fact, in many cases, migration should be interpreted as a long-term temporary move rather than a permanent one. In expectation of their return – and as a safety net – rural migrants keep their land in their hometown. The land is often maintained and cultivated by other family members in their absence. In many cases, the land will only be transmitted once the young members who migrated come back to the hometown. The plan is for them to resettle on their plot of land and to cultivate it at least for their own food supply. However, complications may interfere with this plan in the near future. The potential problem of decreased farm land area mentioned earlier could lead to a lack of land to come back to. At the same time, the impacts of environmental change may alter the conditions of the land and make it unsuitable for farming. Therefore, land availability and environmental change call the durability of this fallback solution into question, and make the effectiveness of these adaptation strategies uncertain. These changes in environmental conditions could contribute to redefining migration timelines and inter-generational relationships.

The key points of this analysis are summarized in the following figure [Figure 2/7.5]:

[Figure 2/7.5]
Out-migration from the Mekong Delta as a response to direct and indirect impacts of environmental and socio-economic changes



This schema does not concern student migration and marriage migration.

3. Conclusion and recommendations

In the context of Southern Viet Nam, rural-to-urban migration and environmental change are two concomitant dynamics, with one main intersection point being the mutation of the farming sector in the Mekong Delta. While climate change puts increasing pressure on the Delta's conditions for agriculture, social transformations and modern economic orientations lead the rural population towards urban areas and industrial zones. These migrations may take place over relatively long distances to reach Ho Chi Minh City, Binh Duong province or Dong Nai province. They may also simply cover a few kilometers, to join the closest industrial park or food processing factory. Young migrants today have a wider range of choices compared to their parents, who might have migrated 20 or 30 years ago. But they are also left with dilemmas, with one foot in the city and one foot in their hometown. They aspire to achieve a different lifestyle and embrace a certain vision of modernity in contrast with their rural origins, but above all they seek stability and financial security when the local agriculture sector is seen as insufficient. Fieldwork reveals how standards are changing, in particular in terms of education, which contributes to younger generations turning their backs on farming. However, it also reveals insecurity and financial hardship for some of the households relying on agriculture as their main source of income in the Mekong Delta. The factors behind these economic difficulties are various; among them, changing environmental conditions are making adaptations a necessity. For households who can rely on financial and social capital alongside technical knowledge, these changes might be relatively easy to implement, and could eventually lead to significant increases in earnings – in some cases of conversion to shrimp farming, for example. But for others, the uncertainty generated by environmental change adds to uncertainty on the agriculture market. Migration can be interpreted as an attempt to cope with and reduce this uncertainty. The fieldwork studies conducted in both the Mekong Delta and Ho Chi Minh City shed light on both sides of migration, from the departure area to the destination area. Several critical points stand out, where uncertainty may turn into insecurity:

1] First, there is a need to raise awareness among farmers concerning the possible environmental scenarios for the Mekong Delta in the medium- or long-term future. Indeed, one major source of uncertainty is linked to the confrontation of the temporality of climate change with the temporality of the migration decision-making process. The migration decision is made within a projected timeframe of a few years to several decades (when planning to resettle back in the hometown for retirement). However, the evolution of climate in the hometown does not seem to be taken into consideration by migrants or their families in that timeframe. The changes observed in the environment through their impacts on harvests (loss of harvests due to drought or flood, salinization and alum saturation of water) are not necessarily perceived as a long-term and inexorable phenomenon. Instead, adaptations are implemented locally on a short-term basis, by households with limited resources. Therefore, communication on climate change aimed at the local population must clarify the different timelines of environmental changes – and of the adaptations implemented – in order for households to be able to construct informed adaptation strategies, whether they involve migration or not.

2] Second, as it is already being implemented, it is necessary to continue promoting the development of alternative sectors of employment and professional training within the Mekong Delta, in parallel to the agriculture and aquaculture sectors (see development plans of the Mekong region, and chapter 2 of the present report). These alternative options are meant to increase minimum incomes and employment stability. This concerns young people, but also older generations. Indeed, in the current situation people over 40 in rural areas of the Mekong Delta could face difficulties in finding off-farm income sources, as the major sectors of industry and construction are not easily accessible to them. Therefore, the development of alternative sectors of employment must be inclusive of all ages, especially since it is becoming more challenging for younger generations to take care of their parents after retirement. These sectors must themselves be protected from climate and environmental impacts.

3] Third, it seems necessary to develop support policies targeting rural migrants from the Mekong Delta and other regions, to ensure safe access to jobs, housing, public schooling, public health care and social security in Ho Chi Minh City and surrounding industrial provinces. Since the contexts of migrations are very diverse, some migrants may face no difficulty at all in meeting their basic needs in the city, especially as transportation and residential registration conditions now facilitate migration. Nevertheless, capital-poor households find themselves in critical situations in the city, working in unsafe and unfair conditions, sheltering in insecure situations, sometimes crippled by debts. Dedicated public structures to accompany migration, other than monitoring temporary residential registrations, could help in preventing migrants from entering downward spirals. The already existing associations of people from the same hometowns in Ho Chi Minh City could orientate migrants towards public support structures.

4] Fourth, livelihood support policies should also be maintained and reinforced in rural departure areas, especially targeting landless farmers in the Mekong Delta. Indeed, households deprived of farm land appear to be particularly vulnerable in the face of environmental and economic shocks. Farm land can guarantee subsistence food supply, a mortgage, loan or legacy. Without land – or if the area of land is critically small – households are more sensitive to any changes, as they rely on hired work.

5] Finally, in connection to the topic of land, relocation planning must prioritize access to job and social networks, while ensuring coherence with other long-term planning. It must grant access to a suitable job market for relocated people, and prevent mismatch between job offers and job demand for the relocated population. In addition, relocation procedures should pay careful attention to preserving the social networks of relocated populations, as they play a key part in household strategies to rebuild livelihoods, reestablish balance and achieve a sense of belonging in the relocation site. Such considerations should help prevent the departure of relocated people, either by returning to their location of origin or migrating elsewhere.

As of today, the link between climate change and migration is still difficult to identify clearly, as it is enmeshed with other economic and social transformations. Nevertheless, with the projected increase in the impacts of climate change on the Mekong Delta, the farming sector, and the direct safety of the Delta's inhabitants, the environment is likely to play a growing role in migration decisions. Therefore, providing safe conditions for migration on multiple spatial scales (short and long distances) and time scales (commuting, circular, temporary and permanent migrations) is crucial in ensuring successful adaptations that effectively allow households to reduce their vulnerability and reduce uncertainty.

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Part 3

LUCAS-GEMMES: Integrated dynamics of adaptation strategies in the Vietnamese Mekong Delta

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Abstract

The predominantly agricultural Mekong Delta region will be profoundly affected by the effects of climate change, such as rising temperatures, sea level rise, and salinization. But recent studies show that other factors, such as sand mining and groundwater exploitation, will also largely contribute to future pressures, particularly through land subsidence. Alongside the fight against climate change, this makes it necessary to design strategies and policies for subsidence mitigation, not only at the individual level (mainly farmers), but also at the institutional level (province and region). Indeed, in the Vietnamese Mekong Delta (VMD), local provinces play a crucial role in the choice and implementation of strategies for the exploitation of natural resources, such as water or sand. However, the VMD is also a complex system in which the decisions of one province can have indirect effects on the other 12 provinces, especially because some provinces share common agro-ecological regions and aquifer areas.

This chapter aims to explore, through simulation of an integrated model, the economic impact on farmers of the adaptation strategies chosen by the provinces under a number of climatic and economic scenarios. It thus builds on the adaptation options evaluated in Part 3 of the report. In particular, one objective is to understand which conditions of inter-province coordination on groundwater exploitation in common agro-ecological areas could improve the economic situation of farmers. To this end, the LUCAS model (an agent-based model for land-use change adaptation strategies in the context of climate change) [Truong *et al.*, 2021] was extended to take groundwater use by farmers into account, as well as the subsidence dynamics and macroeconomic trends from the GEMMES model. In the updated model, called LUCAS-GEMMES, subsidence-related adaptation strategies chosen at the provincial level and their interactions with individual decisions were also introduced.

The simulation is performed with 4 experiments including (i) No provincial adaptation strategies and ignorance of subsidence dynamics; (ii) No adaptation strategies while subsidence impacts the benefit of land-use production; (iii) Individual adaptation strategies combined with the impact of subsidence; (iv) Province and individual adaptation combined with the impact of subsidence.

The results show that decisions in early response to low-level subsidence bring many positive results in resource management, such as significantly reducing water use in the dry season, and reducing the vulnerability area from subsidence and climate change. The results also show a decrease in incomes in case of adaptation. Therefore, it is necessary to have investment solutions (technical support in shrimp farming, studying for new upland crops in the dry season) for new land-use types that could compensate for the economic benefits lost when applying policies that restrict people in the use of resources.

Tóm tắt

Đồng bằng sông Cửu Long (ĐBSCL) là vùng sản xuất lương thực chủ yếu của Việt Nam sẽ bị ảnh hưởng rất lớn bởi tác động của biến đổi khí hậu như nhiệt độ tăng, nước biển dâng, xâm nhập mặn. Tuy nhiên các nghiên cứu gần đây cho thấy rằng các yếu tố khác như khai thác cát và khai thác nước ngầm cũng sẽ góp phần vào những tác động này, đặc biệt là do sụt lún đất. Bên cạnh cuộc chiến chống biến đổi khí hậu, cần có chiến lược và chính sách để giảm thiểu sụt lún không chỉ ở người dân (chủ yếu là nông dân) mà còn cần chính sách của nhà nước (tỉnh và cả vùng). Ở Việt Nam nói chung và ĐBSCL nói riêng, cấp tỉnh đóng một vai trò quan trọng trong việc xây dựng chính sách cụ thể và quản lý trong khai thác tài nguyên thiên nhiên bao gồm nước ngầm và cát trên sông. Tuy nhiên, nguồn tài nguyên là một hệ thống phức tạp của cả vùng, do đó quyết định của một tỉnh có thể có tác động gián tiếp đến 12 tỉnh khác, đặc biệt đối với một số tỉnh có chung các vùng sinh thái nông nghiệp và các vùng chứa nước ngầm. Chương sách này nhằm mục đích ứng dụng mô hình trong đánh giá tổng hợp tác động của các chiến lược thích ứng do các tỉnh lựa chọn đến các mặt kinh tế, sử dụng đất và nước của người dân trong một số kịch bản biến đổi khí hậu và kinh tế. Do đó, chương sách được xây dựng dựa trên các giải pháp thích ứng đã được đánh giá trong Phần 3 của báo cáo. Đặc biệt, một trong những mục tiêu là xem xét sự phối hợp giữa các tỉnh trong việc khai thác nước ngầm trong các vùng sinh thái nông nghiệp chung như thế nào để cải thiện kinh tế của người dân. Vì vậy, mô hình LUCAS (Mô hình dựa trên tác nhân cho các chiến lược sử dụng đất thích ứng trong bối cảnh biến đổi khí hậu) [Truong *et al.*, 2021] đã được mở rộng để tính đến việc sử dụng nước ngầm của nông dân, cũng như tác động của sụt lún và xu hướng kinh tế vĩ mô từ mô hình GEMMES. Mô hình LUCAS được cập nhật với tên gọi là LUCAS-GEMMES cho phép nghiên cứu các chiến lược thích ứng biến đổi khí hậu kết hợp với hạn chế sụt lún ở cấp tỉnh với các quyết định sử dụng đất của người dân. Mô phỏng được thực hiện với 4 thực nghiệm máy tính bao gồm (i) Không áp dụng chiến lược thích ứng cấp tỉnh và sự thiếu hiểu biết của việc không đưa sụt lún vào quyết định sử dụng đất; (ii) Không có chiến lược thích ứng trong khi sụt lún ảnh hưởng đến sản xuất nông nghiệp; (iii) Áp dụng các chiến lược thích ứng riêng lẻ dưới tác động của sụt lún; (iv) Sự thích ứng của từng tỉnh và từng cá nhân dưới tác động của sụt lún. Kết quả cho thấy các quyết định ứng phó sớm với sụt lún ở mức độ thấp mang lại nhiều kết quả tích cực trong quản lý tài nguyên như giảm đáng kể lượng nước sử dụng trong mùa khô và theo đó giảm khu vực dễ bị tổn thương do sụt lún và biến đổi khí hậu. Kết quả cũng cho thấy thu nhập từ hoạt động nông nghiệp giảm trong trường hợp thích nghi. Do đó, cần có các giải pháp đầu tư (hỗ trợ kỹ thuật nuôi tôm, nghiên cứu các loại cây trồng cạn mới trong mùa khô) cho các loại hình sử dụng đất mới nhằm bù đắp lợi ích kinh tế bị mất khi áp dụng các chính sách hạn chế người dân sử dụng tài nguyên.

Résumé

La région du delta du Mékong, essentiellement agricole, sera profondément touchée par les effets du changement climatique, tels que la hausse des températures, l'élévation du niveau de la mer et la salinisation. Mais des études récentes montrent que d'autres facteurs, comme l'extraction de sable et l'exploitation des eaux souterraines, contribueront également fortement aux pressions futures, notamment par la subsidence. Au-delà de la lutte contre le changement climatique, il est donc nécessaire de concevoir des stratégies et des politiques d'atténuation de la subsidence, non seulement au niveau individuel (principalement les agriculteurs), mais aussi au niveau institutionnel (province et région). En effet, dans le delta du Mékong vietnamien (DMV), les provinces locales jouent un rôle crucial dans le choix et la mise en œuvre des stratégies d'exploitation des ressources naturelles, comme l'eau ou le sable. Cependant, le DMV est aussi un système complexe dans lequel les décisions d'une province peuvent avoir des effets indirects sur les 12 autres provinces, notamment parce que certaines provinces partagent des régions agro-écologiques et des zones aquifères communes.

Ce chapitre vise à explorer, par la simulation d'un modèle intégré, l'impact économique sur les agriculteurs des stratégies d'adaptation choisies par les provinces dans un certain nombre de scénarios climatiques et économiques. Il s'appuie donc sur les options d'adaptation évaluées dans la partie 3 du rapport. En particulier, un objectif est de comprendre dans quelles conditions de coordination entre les provinces sur l'exploitation des eaux souterraines, dans des zones agro-écologiques communes, la situation économique des agriculteurs peut s'améliorer. À cette fin, le modèle LUCAS (un modèle "basé agents" pour les stratégies d'adaptation au changement d'utilisation des terres dans le contexte du changement climatique) [Truong *et al.*, 2021] a été étendu pour prendre en compte l'utilisation des eaux souterraines par les agriculteurs, ainsi que la dynamique de subsidence et les tendances macroéconomiques du modèle GEMMES. Dans le modèle mis à jour, appelé LUCAS-GEMMES, les stratégies d'adaptation liées à la subsidence choisies au niveau provincial et leurs interactions avec les décisions individuelles ont également été introduites.

La simulation est réalisée à l'aide de quatre expériences : (i) aucune stratégie d'adaptation provinciale et ignorance de la dynamique de la subsidence ; (ii) aucune stratégie d'adaptation alors que la subsidence a un impact sur le bénéfice de la production de l'utilisation des terres ; (iii) stratégies d'adaptation individuelles combinées à l'impact de la subsidence ; (iv) adaptation provinciale et individuelle combinée à l'impact de la subsidence.

Les résultats montrent que les décisions prises en réponse précoce à un affaissement de faible niveau apportent de nombreux résultats positifs dans la gestion des ressources, tels que la réduction significative de l'utilisation de l'eau pendant la saison sèche, puis la réduction de la zone de vulnérabilité à la subsidence et au changement climatique. Les résultats montrent également une diminution des revenus en cas d'adaptation. Par conséquent, il est nécessaire d'avoir des solutions d'investissement (soutien technique dans l'élevage de crevettes, étude de nouvelles cultures de montagne en saison sèche) pour de nouveaux types d'utilisation des terres qui compenseraient les avantages économiques perdus lors de l'application de politiques qui limitent les personnes dans l'utilisation des ressources.

1. Introduction

The Vietnamese Mekong Delta (VMD) is increasingly exposed to climate and environmental changes, triggered by both global climate change and anthropogenic activities in the Delta or upstream in the Mekong River basin: rising temperatures, precipitation changes, increasing saline water intrusions, decreased availability of freshwater (see Part 2, this report, and GEMMES COP26 report [Espagne *et al.*, 2021b]). This is already severely affecting agriculture and aquaculture, which are the main activities in the VMD. Groundwater extraction, which has partially compensated for this vulnerability and enabled the agricultural intensification policy implemented since the 2000s to continue, is in fact worsening the situation by increasing subsidence throughout the Delta [Minderhoud *et al.*, 2020], and hence increasing the risk that large portions of the Delta fall below sea-level within decades.

Although this corpus of solid scientific evidence has only recently surfaced, general awareness of this state of affairs is not new, and many initiatives have begun to be undertaken [Government of Viet Nam, 2018] – especially at provincial level – as to whether or not to authorize the use of groundwater depending on the state of the aquifer zones, to facilitate the construction of retention basins [MONRE, 2017], or to reduce crops that are excessively freshwater-intensive at certain seasons (see Focus 4, this report). However, these initiatives face two major obstacles that severely limit their scope and effectiveness, stemming from the fact that the political division into provinces does not necessarily reflect groundwater resources: some provinces may be located at the confluence of extremely different agro-ecological zones, making it difficult to design a single policy for the whole province; conversely, several provinces may share the same agro-ecological zone, ideally requiring concerted policies of groundwater exploitation to be implemented.

The objective of this chapter is to explore – using repeated simulations of a large-scale integrated agent-based model – which combinations of province-level policies and individual adaptation strategies appear to be sustainable, under a number of climate change and subsidence scenarios. In particular, we are interested in understanding the impact of different forms of coordination (or lack thereof) between actors in the system on the system's overall sustainability, as expressed in terms of average farmer income and debts. In [Truong *et al.*, 2021], a first version of the model called LUCAS was introduced; farmers play the key role, basically driving all the dynamics of the model by individually selecting appropriate land-use types for their plot. This first version aimed to reproduce the distribution of land-use in the Vietnamese Mekong Delta, and to understand the impact of various climate scenarios (*e.g.* changes in temperature and rainfall) on this distribution. The provinces were represented as agents in the model, but their role was limited to providing, or restricting, funding for farmers' adaptation strategies.

The extension of LUCAS (named LUCAS-GEMMES) presented and explored in this chapter reinforces the economic dimension of the model, by allowing farmers to take out loans to invest in land-use changes beyond their initial financial capacity. More importantly, it strengthens the ability of provinces to influence individual adaptation strategies, according to the agro-ecological zone for which they are responsible and the level of subsidence measured: policies available to provinces can include prohibiting certain land-uses in order to limit or even prevent water pumping. The subsidence thresholds at which these policies are triggered, and the coordination between provinces in choosing these thresholds, are among the elements whose importance and relevance we wish to measure in order to provide concrete recommendations. LUCAS-GEMMES, presented in detail in Section 3, therefore allows modelers to explore various combinations of joint or coordinated decisions at the scale of provinces. A number of experiments are carried out and presented in Section 4, detailing the interactions and feedback between provinces and farmers' decision-making processes in a number of scenarios, and allowing conclusions to be drawn as to which strategies, in terms of financial facilities and coordination between provinces, appear to be the most sustainable at the scale of the VMD.

2. Context

2.1 Institutional management of Climate Change in the Vietnamese Mekong Delta

The Vietnamese Mekong Delta is classified into 3 ecological zones (see Figure 3.3) that provide specific properties for agricultural development [Government of Viet Nam, 2017]. The Upstream zone, located in the upstream part of the Delta, has freshwater but also floods during the rainy season; it covers the provinces and cities of An Giang, Dong Thap, Long An and part of the provinces of Kien Giang and Can Tho. The Middle zone, located in the central part of the Delta, is the transitional area between freshwater and brackish water; it includes part of Can Tho and Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre, Tien Giang, and Long An provinces. The Coastal zone is occupied by saltwater and brackish water; it covers the coastal parts of Kien Giang and Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre, Tien Giang, and Long An provinces.

Regarding the general policies of the Government for the region, Resolution 120/2017 [Government of Viet Nam, 2017] is an extremely important document that guides the general strategies for the Delta in response to climate change (see Part 2, this report). This resolution proposed the development of specific agricultural policies for the environment in which they are applied, and in particular the AgroEcological Zones (AEZ). In addition, Decision 324/QD-TTg [Prime Minister of Viet Nam, 2020] detailed the policies of the government for the sustainable development of the Vietnamese Mekong Delta conducted by Resolution 120. It states that the agricultural development of the Delta will be based on 3 agro-ecological zones depending on land suitability and product market. The Decision guided land-use change policies, especially in areas vulnerable to floods, droughts, and saline water intrusion; the main purpose is to change the focus of the Delta from rice production to aquaculture - fruit - rice.

Recently, Decision 287/QD-TTg [Prime Minister of Viet Nam, 2022] has provided planning solutions for the development of the Vietnamese Mekong Delta region for the 2021–2030 period, with a perspective towards 2050; the Prime Minister of Viet Nam oriented the agricultural production structure to adapt to natural condition changes in the three zones:

– The Upstream zone is a key area specialized in producing rice, freshwater aquatic products and fruits. The area should create a diversified, modern and sustainable agriculture, taking adaptation to extreme flooding into account, and playing its role in regulating, managing and absorbing floods for the Vietnamese Mekong Delta.

– The Middle zone is identified as the main area for crop rotations involving rice and vegetables, and for the monofarming of brackish-water aquatic products, depending on seasonal water conditions.

– The Coastal zone should focus on developing saltwater or saltwater - brackish water aquaculture, fishing, on restoring and developing coastal mangrove forests, as well as protecting biodiversity and coastal strips. It should also develop an integrated agroforestry production system, applying the principle that ecological and organic farming practices should be combined with ecotourism activities. Finally it should proactively prevent, avoid, and reduce risks of natural disaster, climate change and sea level rise.

Driven by Government laws and documents for the Vietnamese Mekong Delta (see Part 2), the LUCAS-GEMMES model aims to demonstrate a means of testing possible adaptation strategies in terms of supporting land-use plans in the context of climate change. Many studies have shown that policies play a very important role in land-use decisions and land-use changes, but there is a lack of tools to help decision-makers include these factors in the land-use change model. In this study, we convert the policies of provinces into adaptation strategies for the chosen provinces, depending on their agro-ecology; to do so, we defined a list of the land-use types supported by the law (Decision 324/QD-TTg 2020, 287/QD-TTg 2022), based on the properties of the AEZ. The policy profile can be adjusted depending on the case under study. It is important that provinces know how to react to different subsidence scenarios, depending on the types of cooperation.

2.2 The LUCAS model

The LUCAS (Land-Use Change for Adaptation Strategies) model [Truong *et al.*, 2021] is a spatially-explicit agent-based model [Bonabeau, 2002], designed as a virtual laboratory – at the scale of the Vietnamese Mekong Delta – to simulate and evaluate the performance of different adaptation strategies and their combinations, at different levels, in different climatic, demographic or economic scenarios. The main entities modeled as agents are the farmers, who have to make decisions concerning the type of land-use to implement for their agricultural parcels: their decision is firstly based on individual criteria (such as profitability, land suitability, capacity for conversion to other land-uses, and influence of other farmers). Then an adaptation strategy is applied depending on the risk exposure of each parcel toward temperature, precipitation, and salinity evolution.

Three simple strategies have been presented and evaluated by [Truong *et al.*, 2021] in the framework of the climate scenario RCP 8.5: the first one is based only on individual farmers' choices (they seek an appropriate land-use to eliminate risks), without any help or hindrance from the government; the second one is based only on governmental decisions (attempting to eliminate the risk by improving infrastructure such as dykes, sluice gates etc., or by financially supporting farmer adaptations), without spontaneous adaptation by farmers; and the third one is based on a combination of these two approaches, in which the government supports the individual choices that seem relevant to reducing the impacts of climate change. Unsurprisingly, the latter is measured as the most beneficial for all actors in the system, and appears to be an interesting way to think about and develop feasible adaptation plans.

The LUCAS model offers a proof of concept framework that should make it possible, in future, to explore and compare different combinations of adaptation policies that reconcile bottom-up and top-down dynamics. Nevertheless, by focusing only on environmental changes directly linked to climate change (temperature, precipitation, global sea-level rise), it omits many other very important ones, particularly the strong future impact of land subsidence. Finally, indicators of the models were limited to land-use evolution and distribution, without investigating closely-related economic indicators. These two main aspects are the core improvements provided by the LUCAS-GEMMES model.

3. LUCAS-GEMMES model

The LUCAS-GEMMES model presented in this chapter is an extension of the LUCAS model [Truong *et al.*, 2021], incorporating some of the results of the GEMMES project in terms of subsidence and macroeconomics trends. Adaptation strategies of each province are now spatially heterogeneous (depending on the AEZ and the subsidence of the area). The economic model of farmers' agents now integrates the interest rate dynamics of the GEMMES model. Finally, key indicators are debt and benefits for farmers.

3.1 Overview

Purpose of the model

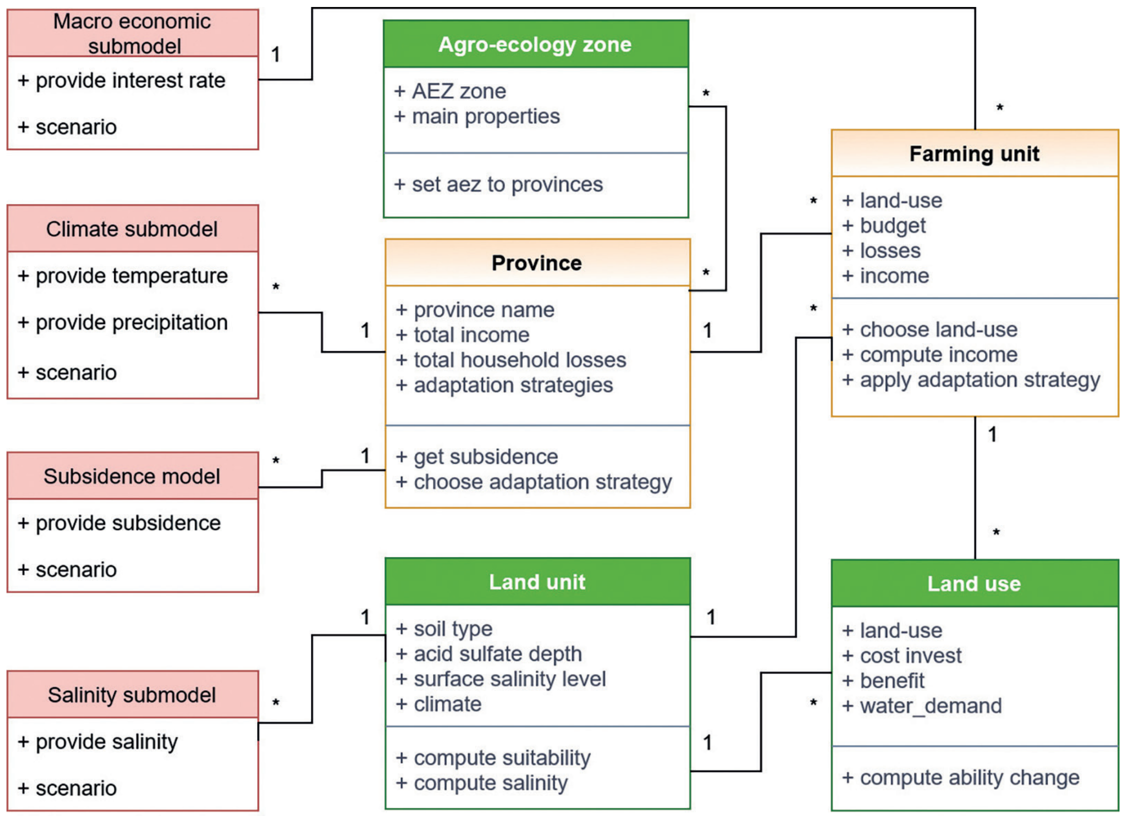
The objective of the model is to investigate spatially heterogeneous adaptation strategies of provinces in the Vietnamese Mekong Delta (taking subsidence and AEZ into account), in terms of water pumping and in interaction with farmers' land-use change decisions, in the context of climate change. For this purpose, coordinated/uncoordinated decisions among provinces will be explored.

Entities, state variables, and scale

The static description of agent types composing the model is provided in Figure 3.1 (see Online Supplementary Material for details). The model consists of 2 types of pro-active agent types that can make decisions at each simulation step: the *farming units* and the *provinces*. In addition, it contains two types of passive entities which are spatially located: the *agro-ecological zone* (AEZ) provides properties for different types of agriculture activities and the *land unit* provides detailed properties of soil texture, soil constraint water, and salinity. Finally, the model is completed with a non-spatial entity: the *land-use* provides information about the various land-use characteristics. In this model, we limit ourselves to the six dominant land-uses of the VMD: 3 rice and 2 rice (*i.e.* 3 or 2 rice crops per year respectively), Vegetables, Aquaculture (Shrimp), Fruit trees, Rice - shrimp.

The *farming unit* is the key entity of the model. It represents both the farmer (with its decision-making capabilities) and their agricultural parcel, which contains a land-use type. It is represented as a 500 m x 500 m cell (the resolution depends on the input data). It is located

[Figure 3.1]
Main entities of the LUCAS-GEMMES model



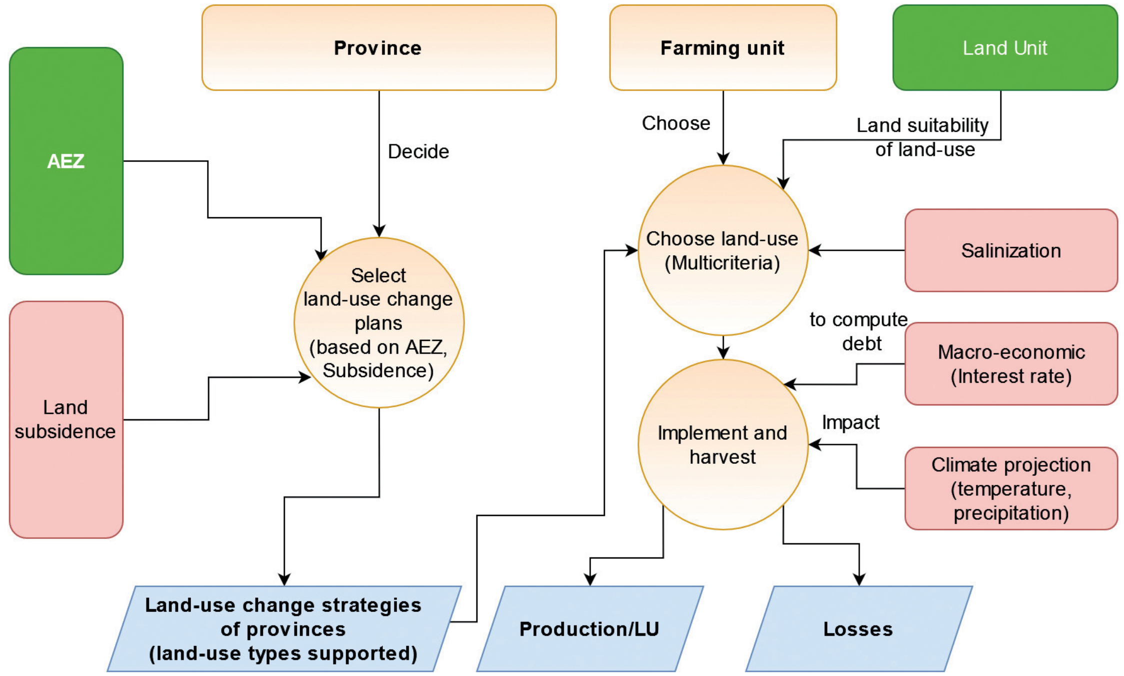
in a province and a land unit. It is also characterized by individual annual income linked to cultivation activities and losses due to impact of climate change.

A *Province* entity is characterized by its name, location and spatial extent, its total budget for loan to farmers each year. The province is located in one or several agro-ecological zones. Thus, it will be able to choose an adaptation strategy for each of its farming units depending on the AEZ and a land subsidence threshold. Each strategy is defined as a list of permitted and prohibited land uses for a threshold in each AEZ.

All these agents are embedded in a global environment defining global variables and in particular providing data coming from exogenous submodels such as interest rate (*macroeconomic* submodel), map of temperature and precipitation (*climate* submodel), map of cumulated land subsidence (*subsidence* submodel), and dry-season surface water salinity map (*salinity* submodel).

The spatial resolution for the farming unit is set to 500m x 500m. Each simulation step lasts one year. The simulation starts in 2015 and stops in 2050.

[Figure 3.2]
Conceptual model of LUCAS-GEMMES



Process overview

The main processes of the LUCAS-GEMMES model are detailed in Figure 3.2. During a simulation the global data from exogenous models are updated with a frequency depending on the submodel: subsidence maps are updated every 10 years, macroeconomic and climate data are updated yearly, and the salinity map is updated every 20 years. From these updated data, exposed areas (*i.e.* areas where climate and salinity conditions overtake the tolerance of rice and shrimp [Truong *et al.*, 2021]) are computed. Concerning the impact of subsidence, we assume that, beyond some threshold, cumulated subsidence will impact agricultural production by decreasing the income of farmers.

Provinces choose adaptation strategies for land-use change: depending on the AEZ and the situation of the land subsidence, they choose to allow or prohibit the land-use switch toward some other specific land-uses. Each province can have one or many strategies for the AEZ and the situation of land subsidence (*e.g.* living with floods, living with floods but saving groundwater): for each AEZ, the province chooses the land-uses allowed depending on a land subsidence threshold reached in the area. This choice corresponds roughly to allowing the pumping of groundwater for agricultural activities, or not. As the subsidence maps are updated every 10 years, the strategies are reevaluated with the same frequency, which corresponds to the plan period in Vietnamese land-use planning.

Finally farming units select land-use candidates from the ones allowed by the strategy of the province (policy), then choose the land-use based on multicriteria decisions that match land unit, income, ability to change (technically), and impact of neighbors (land-use of neighbors) (detailed in Section 3.3 Decision of Farming Unit with constraints of province strategies). Farming units have a budget to switch or maintain the current land-use. They may need an additional budget in the event of a change in land-use; if so, they ask for a new loan (depending on the interest rate). At the end of each year, farming units update their budget and income. In the event that a farming unit was impacted by climate conditions, they will lose the income of the year and individual losses increase in line with cost of implementation. The province updates total household losses at the end of each year.

At the end of each year, the model provides a land-use map, total area for each land-use type, total income from agriculture activities, water demand, and losses caused by climate change and subsidence by province (for each of their AEZ), and for the whole VMD.

3.2 Implementation of the LUCAS-GEMMES model

Input data

Input data of the LUCAS-GEMMES model include the data from the LUCAS model presented in Truong *et al.* (2021): land-use map in 2015, land unit map, dry-season salinity maps[1] for 2030 and 2050 under RCP 8.5 scenario (taking into account global sea-level rise and fluvial discharge changes) [Eslami *et al.*, 2021], maximum and minimum of monthly temperature, and minimum of total precipitation per month in the dry season. The climate data (temperature and precipitation) is aggregated from 31 CMIP6 global climate models (scenario RCP 8.5) projections, downscaled for Viet Nam at 25 x 25 km spatial resolution.

Additional data include the provinces and agro-ecological zones, land subsidence map, and economic data (price and interest rates).

All the raster data (land-uses, subsidence, salinity map, etc.) were resampled with the nearest neighbor method for the same resolution, which is 500 m x 500 m for each pixel.

Provinces and AgroEcological Zones

We use Province and AgroEcological Zone spatial data [Bong *et al.*, 2018] to initialize the related entities. The province is the key administrative level in Viet Nam. Note that we focus on the Vietnamese Mekong Delta only (*i.e.* the continental part of the provinces). In particular, islands such as Phu Quoc, Con Dao, or Nam Du are not taken into account in the model, whereas they are part of the provinces under consideration. AgroEcological Zones are defined to be a homogeneous area in terms of ecological and agricultural features.

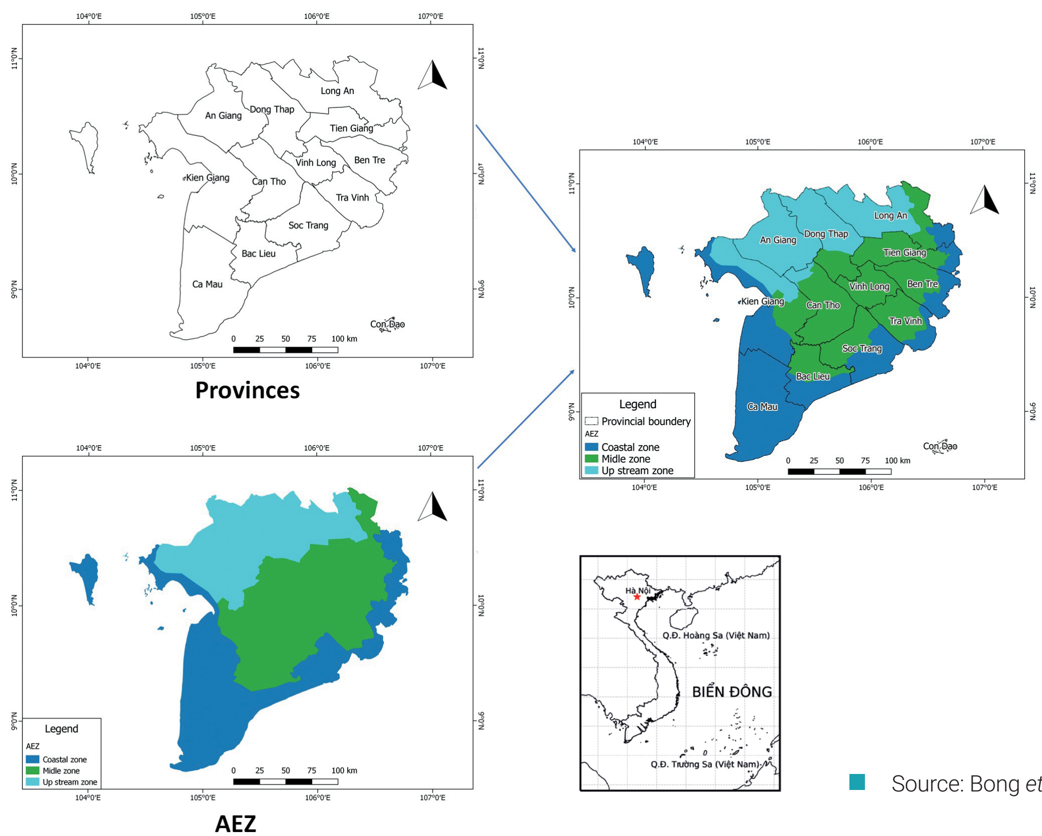
The two types of entities are spatially related: a province contains 1 to 3 parts of the different AEZs.

Land subsidence and water demand of land-use

Minderhoud *et al.* (2020) showed the importance of land subsidence for the future evolution of the Vietnamese Mekong Delta, and the fact that it can have stronger and faster effects than climate change-induced global sea level

1. 90th percentile salinity value during the dry season.

[Figure 3.3]
Spatial relation of provinces with agro-ecology zone



Source: Bong *et al.*, 2018.

rise, at least for the first half of the century. Another important conclusion of this work is that the main driver of current high subsidence rates recorded in the Delta is groundwater extraction.

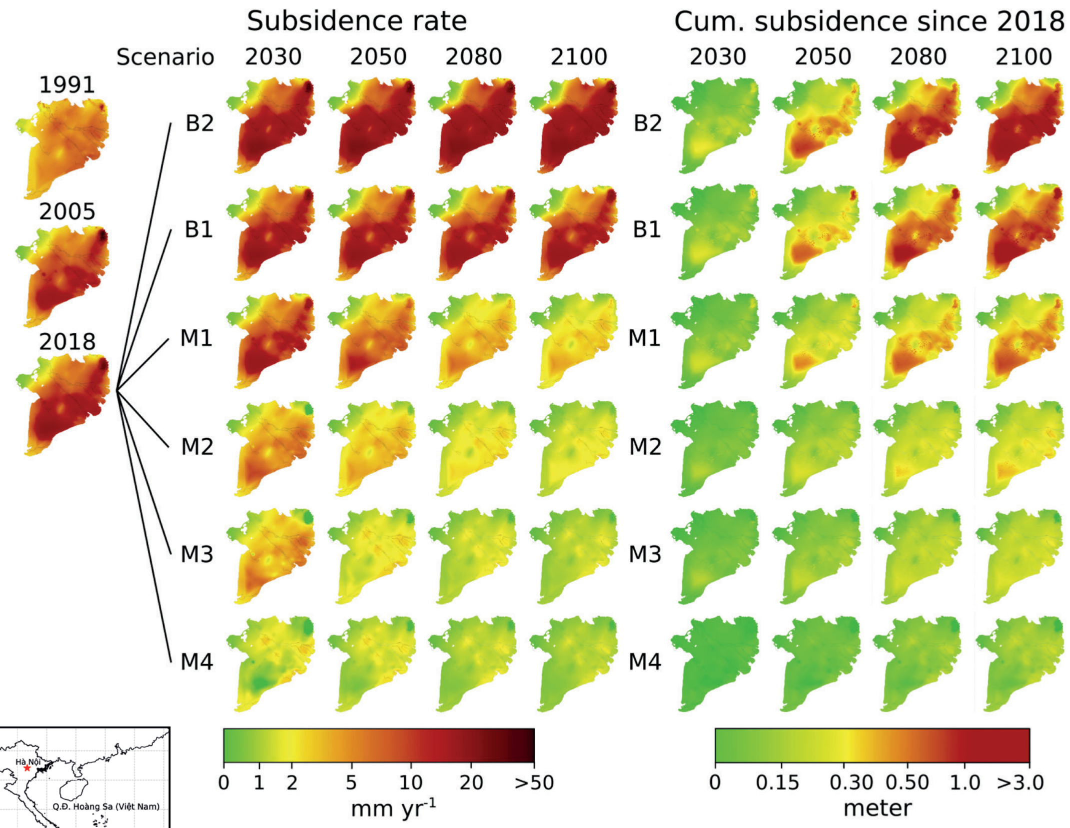
In [Minderhoud, *et al.*, 2020], the authors simulate land subsidence in the Mekong Delta with a time horizon of 2100, depending on several scenarios of groundwater extraction pathways: B2 corresponds to annual growth corresponding to 4% of 2018 volume, B1 to 2% of 2018 volume, M1 to 0% growth after 2020, M2 (resp. M3 and M4) to a gradual reduction of water extraction towards 50% (resp. 25% and 0%) of 2018 volume.

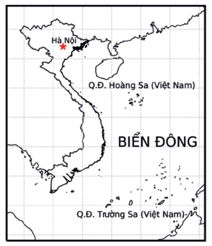
In the model, we focus on the two non-mitigation scenarios (B1 and B2) and the mitigation strategy M1 (maintenance of the same water extraction level). For each scenario, we use a raster data file for every 10 years (2020, 2030, 2040, 2050) containing the cumulated land subsidence of the whole Delta (see Figure 3.4). All the data have been provided by P. Minderhoud and correspond to that presented in [Minderhoud, *et al.*, 2020].

Economic data

As presented in [Truong *et al.*, 2021], the cost and benefit of each land-use (as summarized in Table 3.2) are used in a multi-criteria deci-

[Figure 3.4]
Projections of land subsidence





Projections of subsidence rate and cumulated subsidence in the Delta for different groundwater pumping scenarios. Source: Minderhoud, *et al.* (2020).

[Table 3.1]
Water demand of the various land-uses in the dry season

Land-use	Volume (m^3/ha/season)	Reference
3-rice crops	7 500	Water needs for Winter-Spring according Viet Nam Standard TCVN 8641-2011 (Viet Nam Standard, 2011)
Vegetables	4 658	Vuong & Thach (2019) pointed that the water volume of Green asparagus was 4658 m^3 /ha/season
Fruit trees (Pomelo, mango, longan…)	13 200	100 liters/tree of 6 year old * 10 times/month * 6 months * 2000 trees/ha (ATESO, 2018)

[Table J5]
Average cost and benefit of dominant land-use types in the Vietnamese Mekong Delta

Land-use type	Income (Million VND/ha)	Cost (Million VND/ha)	Labor (Days/ha/year)
3-rice crops	58.48	52.31	92
2-rice crops	42.42	34	78
Rice - shrimp	86.62	61.38	86
Fruit trees	184.00	62	115
Vegetables	88.07	114.24	233
Aquaculture (Shrimp)	277.23	308.18	217

Source: Data survey in Soc Trang Province in 2018, Nguyen *et al.*, 2019; Nguyen, 2021.

sion-making process for farmers when they need to decide which land-use to implement in their farming unit. Income is a key factor in the farmers' decision [Nguyen H. T. *et al.*, 2019].

The cost for Farming Units of the land-use implementation is based on the cost of each land-use type, but also on the cost of credit that could be necessary. The latter is highly dependent on the interest rate. The model thus uses a projection of interest rate evolution developed in the frame of the GEMMES project [provided by Espagne *et al.*, 2021]. This variable enables losses to be calculated in the event that the area is impacted by climate change, saline water intrusions or land subsidence.

Simulation initialization

Initially all the spatially located agents are initialized using the dedicated data file. Then through spatial queries, provinces, AEZ, and Farming Units are linked together (*i.e.* which AEZ is contained in which province, which province or AEZ belongs to which Farming Unit, which subsidence for which Farming Unit or province, etc.). A Farming Unit recognizes the Land Unit, subsidence regions, and the province that it is located in, in order to adapt to the natural conditions and province strategies.

Parameters

The LUCAS model came with a set of parameters (presented in Table 3.3) related to the farmer's decision-making process (the weights related to each criterion) and the tolerance of crops to temperature and precipitation. These parameters have been calibrated by Truong *et al.* (2021) on land-use data.

The LUCAS-GEMMES model introduces one additional parameter that will be explored by simulation in the following Section 4.3: the subsidence threshold used in the province and individual decision-making process.

The climate scenario and subsidence scenario could also have been parameters. To limit the computation time, we have chosen a single climate scenario and a single land subsidence scenario (the worst-case).

[Table 3.3]
List of parameters explored in the LUCAS model

Parameter	Explanation
W_{profit}	The weight profitability criteria
$W_{Suitability}$	The weight of suitability criteria
$W_{LU\_ability}$	The weight of agriculture technical convertibility criteria
$W_{influence\_neigbors}$	The weight of influence index of neighbors
Tolerance temperature for rice	The maximum temperature tolerated
Tolerance precipitation for rice	The minimum precipitation tolerated
Tolerance temperature for shrimp	The maximum tolerable temperature for shrimp
Tolerance precipitation for shrimp	The maximum rainfall sensitivity by shrimp
Subsidence threshold	The subsidence level at which provinces and individual farmers decide to apply adaptation or mitigation strategies

Indicators

The LUCAS-GEMMES model aims to evaluate the effects of adaptation strategies (by farmers and/or guidance by provinces) on land-use distribution. To this end, it has proposed several indicators related to the distribution of each land-use in the Delta, the exposed and vulnerable areas, and the total amount of farmers' losses and benefits.

(i) Land-use maps and land-use areas

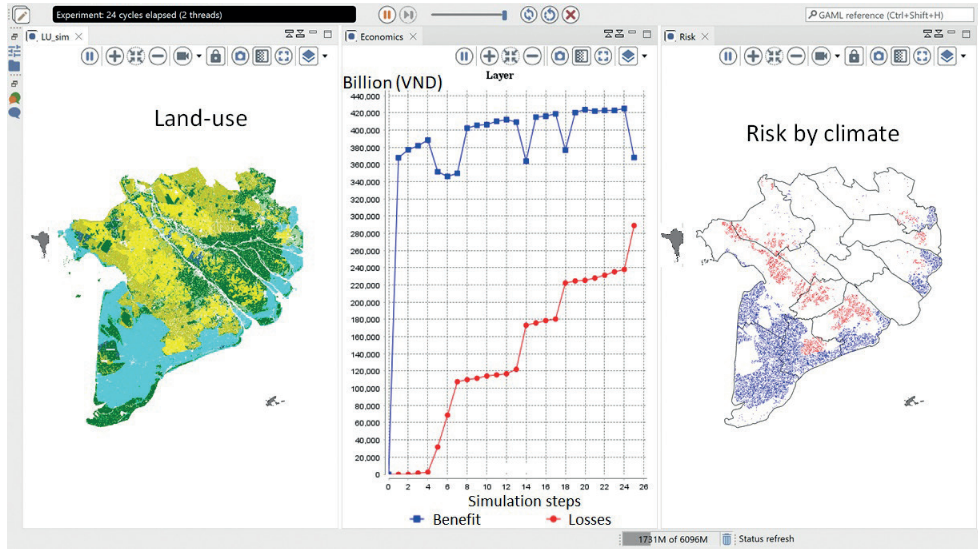
In order to observe the evolution of the spatial distribution of each land-use type, the first indicator provided with the LUCAS-GEMMES model is the map of land-use as a raster map: each pixel (corresponding to a Farming Unit) is displayed with a color representing its land-use type, selected from 3-rice crop, 2-rice crop, Annual crops, Fruit trees, Aquaculture, Forest and Rice-Shrimp (*i.e.* aquaculture). This map also displays the province boundaries to ease analysis at that scale. Figure 3.5 illustrates an example of the simulation's graphic user interface. The left part contains the land-use map.

From this spatial data, we provide an aggregated indicator that helps to quantify the evolution of each land-use area: the surface of each land-use type at the scale of the whole VMD. Even if it is not used here, more precise indicators could be computed if there is a need to analyze the evolution of land-use types at the scale of a province, district, etc.

(ii) Vulnerability maps

In order to identify the areas that may be particularly impacted by environmental changes, the LUCAS-GEMMES model computes whether a Farm Unit is exposed (*i.e.* environmental conditions may damage the crop). We here consider only the effects of changes in temperature, precipitation and salinity intrusions due to climate change. Two types of land-use are distinguished: rice culture (3-rice crops) and aquaculture (shrimp). Concerning rice culture, if the cell concerned is located in an area protected by dyke systems, but the monthly highest temperature in the dry season (December to May) exceeds the rice tolerance threshold and the rainfalls are lower than the tolerance rainfall threshold, the crop is considered risk-exposed.

[Figure 3.5]
LUCAS-GEMMES Graphical User Interface



An example of the LUCAS-GEMMES Graphical User Interface, displaying (left) the land-use map, (center) the evolution of benefits and losses, and (right) the vulnerability map (blue: exposed aquaculture cells; red: exposed rice crop cells).

Aquaculture cells are evaluated as risk-exposed when precipitation is above the cut-off threshold (reducing salinity in the ponds). From this information, a map of vulnerability can be plotted (such as the right part of Figure 3.5). To simplify the visualization, we display only exposed pixels with aquaculture (in blue) and rice crops (in red).

(iii) Water demand of land-use types

As highlighted in Minderhoud *et al.* (2020), groundwater pumping is a highly significant factor in predicting the evolution of land subsidence in the VMD. To estimate the evolution of groundwater pumping volumes under the influence of the adaptation strategies, we compute the evolution of the water demand index for agricultural purposes, depending on the land-use type. The water demand index is calculated to provide an overview of water availability, based on estimated water volumes from usage patterns. This indicator enables the overall water demand of the options to be assessed, to assist in considering the water-saving aspect of the experiments. The calculation of this indicator is not intended as an accurate calculation of the amount of water used according to FAO Penman-Monteith [Allen *et al.*, 1998], nor of the impact of climate change on the water demand of crops. Therefore, this indicator in LUCAS-GEMMES is defined as the annual dry season water requirements of land-use patterns for the study area based on reference sources [Table 3.1].

(iv) Income from agricultural activities and losses triggered by climate change and subsidence

In order to assess the economic impact of land subsidence and the application of the various adaptation strategies, two economic indicators have been implemented:

– the total income of the farmers computing from all the crops in the VMD. As detailed in Section 3.3 Economic submodel: computation of income and loss, incomes are computed on the basis of data provided in Table 3.2.

– the total loss of farmers due to environmental changes. For each crop, if it is in an exposed area, its production is destroyed, its income is reduced to 0, and the invested money is added to the total loss indicators.

These 2 indicators are aggregated at the scale of the whole Delta.

3.3 Sub-models

We describe in the following sections the various dynamics in detail.

Province decisions

The province adaptation strategies that have been implemented are based on the recommendation presented in Resolution 120/2017, and are chosen depending on the AEZ and land subsidence under consideration. Decision 324 also provided the main guidance for 3 AEZ.

A Province adaptation strategy consists in prohibiting the installation of new land-use for some given types: a strategy defines whether a farmer is allowed to switch its current land-use towards another one. This strategy aims only at preventing the implementation of new land-uses for some given types; the rules are thus independent of the current land-use. Table 3.4 summarizes all the possible strategies. As an example, if the province chooses the Living with flood strategy, it becomes forbidden to change any land-use to shrimp, rice-shrimp, and fruit trees.

[Table 3.4]
List of the Province adaptation strategies based on AEZ and subsidence

Adaptation strategy	AEZ name	Subsidence level	Land-use change policy: 3 rice	2 rice	Vegetables	Shrimp	Fruit trees	Rice - shrimp
Living with flood	Upstream zone	subsidence level < threshold$_{AEZ}$	A	A	A	N	N	N
Optimize farmer income	Middle zone		A	A	A	N	A	N
Living with salt water	Coastal zone		N	A	A	A	A	A
Living with flood, protect groundwater	Upstream zone	subsidence level > threshold$_{AEZ}$	N	A	N	N	N	N
Optimize income, protect groundwater	Middle zone		N	A	N	N	N	N
Living with salt water, protect groundwater	Coastal zone		N	A	N	A	N	A

Notes: A = Allowed, N = Not allowed.

A strategy is chosen depending on the AEZ but also the land subsidence level and a subsidence threshold: the province will choose to protect groundwater if the subsidence level is greater than its threshold for this AEZ (which is defined in the Experiments).

Decision of Farming Unit with constraints of province strategies

Select land-use

At each simulation step (*i.e.* each year), farmer agents are able to change their land-use type. To this end, each farmer agent first evaluates the benefits provided by the conversion to each existing land-use type allowed by the Province in its AEZ and land subsidence level, using a weighted mean of the four following criteria, and then selects the land-use type that maximizes it. In order to take the intrinsic inertia of these product change processes into account, we consider that only some of the farmers (randomly selected) will be able to change their land-use at each simulation step. This number of farmers will be defined from a conversion rate parameter.

Let *i* be a farming unit agent, *l* be the current land-use type on the associated farming unit, and *l’* the new land-use type to evaluate; the benefit to convert from type *l* to *l’* is calculated as follows:

– W_c the weight of the criteria *c*. Values have been obtained by calibration by using land-use map in 2015 [Truong *et al.*, 2021].

– $Val_c(i, l, l')$ the value of the criteria *c* for a conversion from the land-use type *l* to the land-use *l’* for the farmer agent *i*.

$$convertibility(i,l,l') = \frac{\sum_{c \in \{profit, suitability, ability, others\}} W_c \times Val_c(i,l,l')}{\sum_{c \in \{profit, suitability, ability, others\}} W_c}$$

Four criteria are taken into account:

– *Profit*: The yearly profitability of each land-use type is one of the main reasons leading to land-use conversion. This factor is an economic adaptation when people try to find a suitable farming model to improve their lives.

– *(Land) suitability*: This criterion represents the adaptation of a land-use type (*i.e.* an agricultural activity) to a specific environment. When environmental conditions change, the adaptation level of land-use types also changes. The suitability evaluation is performed according to the FAO’s work [FAO, 1981]. The four suitability levels are standardized from 0: non-suitable to 1: most suitable.

– *Ability (to convert)*: This criterion measures how convenient it is to switch from the current land-use to another one. In farming systems, the transition from one type to another depends on the conditions in which new farming types can be established. In some cases, some switches (*e.g.* from shrimp to fruit trees) will be very difficult, whereas a switch from deep shrimp ponds in intensive shrimp farming to rice cultivation will not be possible. This ability criterion value is computed using a table of values associated with each transition LandUse1⟶LandUse2.

– *(Influence of) others*: As shown by some studies, farmers are influenced in their production choices by their neighbors [Le *et al.*, 2008]. The value of this criterion corresponds to the proportion of farmer agents in the immediate neighborhood (the 8 cells around the cell representing the farmer) who have chosen this type of land-use.

Economic submodel: computation of income and loss.

As described more in detail in [Truong *et al.*, 2021], given the spatial distribution of land-use, environmental data (soil type, salinity, etc.), and climate data, the model computes whether each Farming Unit is exposed to climate change-related risks. If such is the case, the Farming Unit will lose its investment (as its land unit crop will be destroyed). It thus does not receive any income from its crop and in contrast it increases its loss.

These income and investment costs are computed as follows:

$$Investment = cost(LandUse)*areaSize*(1+interestRate(year)/100)$$
$$Income = income(LandUse) * areaSize$$

During the harvesting step, if the land unit is in the risk area, the income is reduced to 0 and the loss increases.

$$Income = 0$$
$$Losses = Losses + Investment$$

4. Experimental design

In order to test the impacts of the various adaptation strategies in terms of subsidence threshold and cooperation among provinces, we have conducted a set of experiments described in this Section, and whose results are analyzed in Section 5. We investigate two baseline situations and the combination of the various cooperation strategies and subsidence thresholds:

(i) Experiment 1: Baseline 1. An ideal baseline situation where subsidence does not have any effect on production and where no adaptation strategy is selected at the level of provinces and individuals [Section 4.1];

(ii) Experiment 2: Baseline 2. A baseline situation where subsidence impacts the benefit of land-use production, but where the adaptation strategies are chosen without taking subsidence into account, as proposed in Resolution 120/2017 [Section 4.2];

(iii) Experiment 3: individual adaptation. Subsidence impacts benefits and individuals choose their adaptation strategy depending on a subsidence threshold parameter;

(iv) Experiment 4: individual and provincial adaptations. Subsidence impacts benefits and both individuals and provinces choose their adaptation strategy depending on a subsidence threshold parameter.

In all these experiments, we have chosen the worst-case scenario for subsidence: the B2 scenario from [Minderhoud, *et al.*, 2020], corresponding to an annual growth in groundwater extraction of 4% of 2018 volume.

To assess and compare scenarios, key indicators will be the distribution of land-uses and the debt and benefits of the Farming Units.

4.1 Experiment 1: Baseline 1 - No provincial adaptation strategies and no subsidence impact

This first baseline experiment considers an ideal situation without any subsidence impact: the effects on subsidence are not taken into account in either land-use choice or land-use production. This situation is the one that has been explored in [Truong *et al.*, 2021] with the LUCAS model. Land-use choice is thus only impacted by climate change-related factors (temperature, precipitation, salinization due to climate change).

To implement this baseline 1 experiment, no parameters need to be explored, as they do not have any impact on the results: all land-use changes are allowed, except those constrained by changing climate conditions.

4.2 Experiment 2: Baseline 2 - No adaptation strategies while subsidence impacts the benefit of land-use production

In this second baseline experiment, we consider the situation where subsidence impacts land-use benefits, but where (individual or province) adaptation strategies do not take it into account. We assume that the benefit of land-use will decrease when subsidence occurs. This means that all land-use changes are allowed by the Province independently of the land subsidence level. In this baseline experiment, we want to show the land-use and other indicators when people do not recognise the impact of subsidence or when they do not know how to adapt specifically to subsidence. This is the baseline to which the following experiments will be compared.

4.3 Experiment 3: Individual adaptation strategies against the impact of subsidence

This third experiment corresponds to the exploration of individual adaptation strategies taking the subsidence level into account, based on Baseline 2: subsidence impacts the benefits of land-uses. In this experiment, provinces do not apply adaptation strategies depending on the subsidence level. This experiment thus explores the situation where farmers react without any guidance from local governments.

The farmers' selection is impacted by decreasing profits, and the profit impacts land-use selection. The subsidence adaptation strategy is triggered only when cumulated subsidence reaches a given threshold. That is the parameter that will be explored in this experiment: it may take a value among 0.1 m, 0.2 m, 0.5 m, and 1 m.

4.4 Experiment 4: Province and individual adaptation under impact of subsidence

The fourth experiment is based on Resolution 120/2017: it promotes new strategies in the VMD to deal with the effects of climate change. A specificity is that the Resolution introduces the notion of AgroEcological Zone, in which specific strategies should be applied. In the Upstream zone, a "Living with flood" strategy is recommended, in the Middle Zone an "Optimize farmer income" strategy, and in the Coastal Zone, a "Living with salt water" strategy. All these strategies are the ones presented in Table 3.4, applied when the land subsidence level is higher than the given subsidence threshold.

This fourth experiment is based on Experiment 3, to which an adaptation mechanism implemented at the province scale has been added. As a consequence, Experiment 4 considers the situation where subsidence impacts land-use benefits, and where both individuals and provinces apply subsidence-related adaptation strategies when the subsidence level reaches a given threshold. Individuals will thus choose their land-use under the possible constraints of the province, and the impact of the subsidence on their current land-use.

5. Results

The 4 experiments of the LUCAS-GEMMES model described above were launched on the GAMA platform [Taillandier *et al.*, 2019] in its 1.8.2 RC1 version [https://gama-platform.org/] at the scale of the whole VMD.

The results of the 4 experiments are analyzed through 5 indicators (see Section 3.2 Indicators for more details):
(i) Map of land-uses in 2050 and area of dominant use types;
(ii) Areas vulnerable to climate change and land subsidence;
(iii) Water use savings in the dry season to fight land subsidence;
(iv) Incomes from experiments with different response levels to the effects of subsidence;
(v) Total economic losses in the agricultural sector due to environmental changes.

These indicators are presented and analyzed separately in the next sections. However, to have a clear overview of the situation, it is necessary to consider, analyze and synthesize all of them together.

5.1 Land-use maps and land-use area

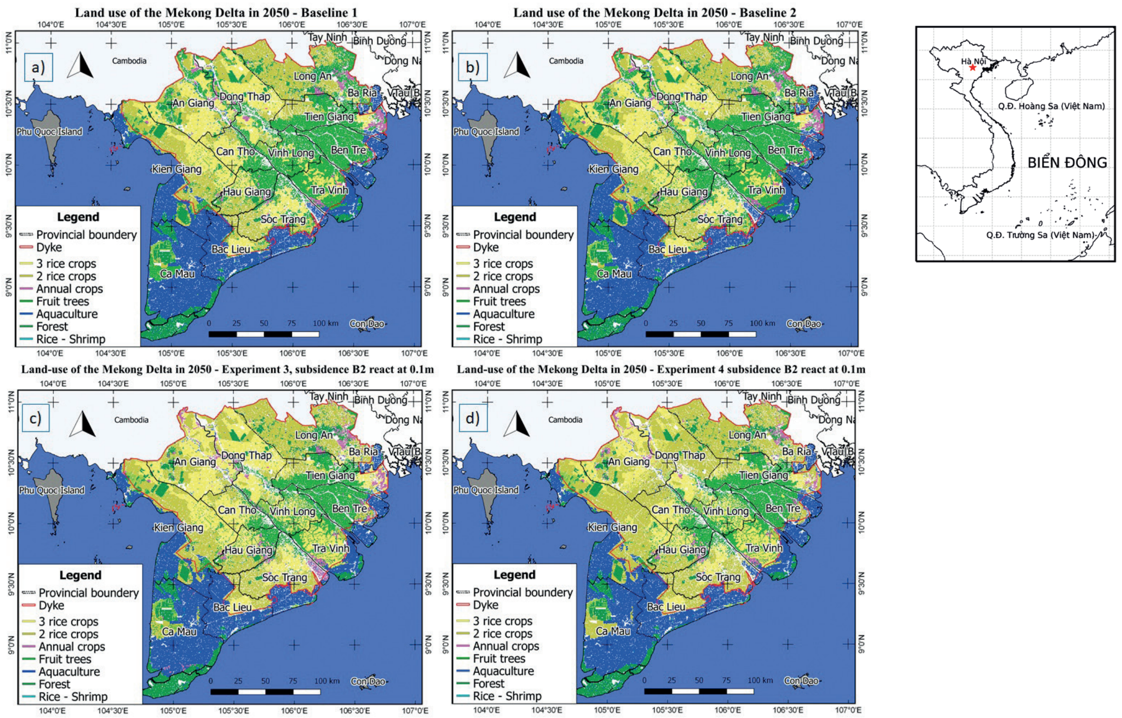
Land-use maps are the leading criterion taken into account by environmental and agricultural policy makers for sectoral planning. Figure 3.6 displays the land-use spatial distributions resulting from the 2 baseline experiments and the 2 experiments with applying adaptation strategies: the subsidence threshold to trigger adaptation strategies is chosen at 0.1 m for these 2 experiments. For the sake of space, we have limited our results to a single subsidence threshold, the one that provides the most different results. To analyze the results, we will cluster land-uses in 2 main groups: tree-crops (fruit trees, 2 and 3-rice crops, etc.) and aquatic land-use (rice-shrimp, shrimp, etc.).

As depicted in Figure 3.6 (a) and (b), the land-use maps from Experiment 1 and Experiment 2 are similar: the aquaculture area has expanded between now and 2050, 3-rice crop land-use still dominates in the Upstream zone, and fruit trees occupy the Middle and Coastal zones. This is a normal trend as people have shown a tendency to choose land-use mainly based on the existing tradition of production, profit and no pressure in conversion without taking into account the risk factors due to climate and the impact of land subsidence, lack of surface water and groundwater in extreme conditions.

For Experiment 3 [Figure 3.6 (c)], as individual farmers take the impact of subsidence on incomes into account, attempting to reduce their water demand in the dry season in the Coastal area, the level of conversion to fruit trees in Ben Tre and Tra Vinh appears lower than in the two baseline experiments. Similarly, 3-rice crops land-use in Soc Trang and Bac Lieu has almost disappeared, mostly replaced by 2-rice crops.

Considering Experiment 4 [Figure 3.6 (d)], where the adaptation policy of the provinces is applied based on the characteristics of the AEZ and the land subsidence, the spatial land-use distribution map is largely different in terms of rice crop land-uses. Land with 2-rice crops prevails in the whole Delta, whereas different adaptation policies are applied. For the An Giang and Dong Thap Muoi provinces, the policy of flood discharge and crop cutting following the spirit of Resolution 120 has oriented the development toward 2-rice crops. We get a similar evolution for Soc Trang and Ca Mau provinces, with 2-rice crops in areas affected by saline intrusion. In parallel with the flood discharge policy, fruit trees only focus on developing in stable dike areas and the foothills, helping to avoid conflicts over surface water use.

[Figure 3.6]
Land-use map in 2050 of 4 experiments

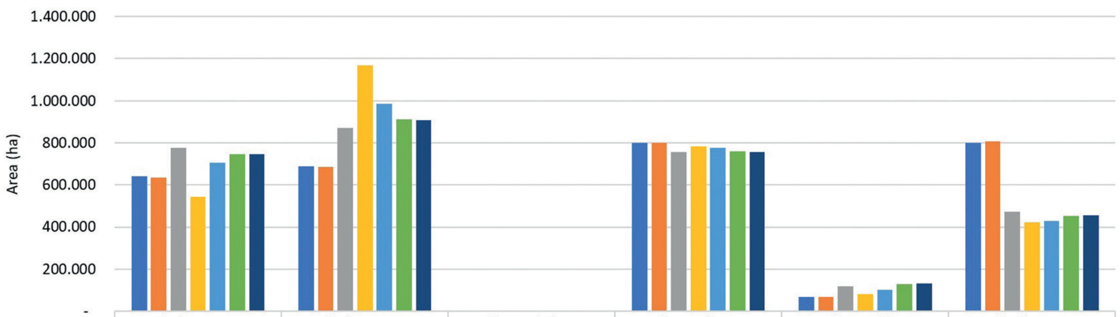


a) Experiment 1: Baseline 1; b) Experiment 2: Baseline 2, subsidence impact; c) Experiment 3 subsidence react at 0.1m; d) Experiment 4 subsidence react at 0.1m.

In addition to the spatial distribution map (displayed in Figure 3.6), the total area of each land-use type is also important to support land management. Figure 3.7 shows the total area for each land-use type over the 4 experiments. For Experiment 4, we display the results with the four values of the land subsidence threshold (0.1, 0.2, 0.5 and 1.0 m) used to trigger adaptation strategies.

The results show a trend to transform 3-rice crops into other land-use types. While in Experiments 1 and 2, the 3-rice crops is strongly converted into fruit trees (in coastal provinces), in Experiments 3 and 4, a shift toward 2-rice crops appears clearly (in particular for low values of land subsidence threshold, *i.e.* in cases where either individuals or provinces apply adaptation strategies at an early stage of land subsidence). This is appropriate in case of extreme weather and policies to limit groundwater extraction. A second (smaller)

[Figure 3.7]
Area of land-use of 4 experiments in 2050

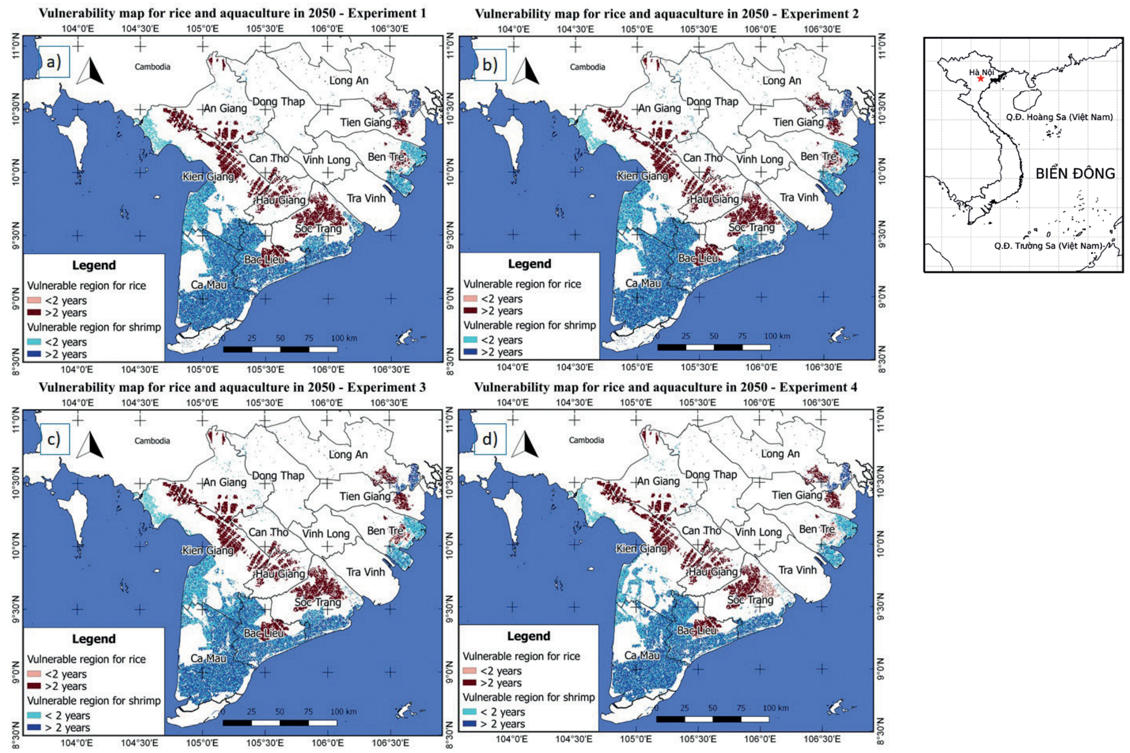


	3-rice crops	2-rice crops	Rice – shrimp	Aquaculture	Vegetable	Fruit trees
EXP1	640.425	687.875	-	799.475	70.050	800.425
EXP2	635.500	686.750	-	799.475	69.775	806.750
EXP3	778.050	872.425	-	755.175	118.550	474.050
EXP4 - 0.1m	544.125	1.166.150	-	781.950	83.200	422.825
EXP4 - 0.2m	705.000	984.900	-	775.875	103.850	428.625
EXP4 - 0.5m	745.525	912.700	-	760.775	127.900	451.350
EXP4 - 1.0m	745.725	907.575	-	755.625	131.350	457.975

impact of the application of province adaptation policies (when the subsidence threshold parameter takes low values) is a reduction of the area for fruit trees and vegetables, and an increase in the aquaculture area. A special point that needs to be considered is that the rice-shrimp area in 2050 disappears. Based on the simulation results, all rice-shrimp areas were reduced gradually and converted to shrimp through to 2040.

The main result of the chart in Figure 3.7 presents different ways of converting 3-rice crops. In the baseline experiment, the 3-rice crops would mainly be converted to fruit trees in the coastal provinces (Ben Tre, Tra Vinh), while in experiments 3 and 4 they are converted to 2-rice crops. The total area of fruit trees in 2050 of Experiment 1 and 2 would be 800 to 806 million hectares: between 70% and 90% higher than in the adapted ones. This highlights the value of adaptation strategies that protect groundwater and reduce the risk of water shortage for fruit trees in the dry season compared to the baselines. Inversely, when applying the policy to protect groundwater as soon as projected land subsidence reaches 0.1 m (EXP4 - 0.1 m): the area of 3-rice crops would be significantly reduced by conversion to 2-rice crops compared with the other adaptation experiments. The 2-rice crops area the event of provinces applying the adaptation for a subsidence threshold 0.1 m would be nearly 70% higher than the baselines (reaching 1.67 million hectares). However, there is not much difference when applying these strategies for the subsidence levels 0.5 m and 1.0 m. In terms of resource protection, applying early adaptation policies is crucial to resource protection. But the economic point of view needs to be considered and analyzed in Section 5.4.

[Figure 3.8]
Vulnerability maps of 4 experiments



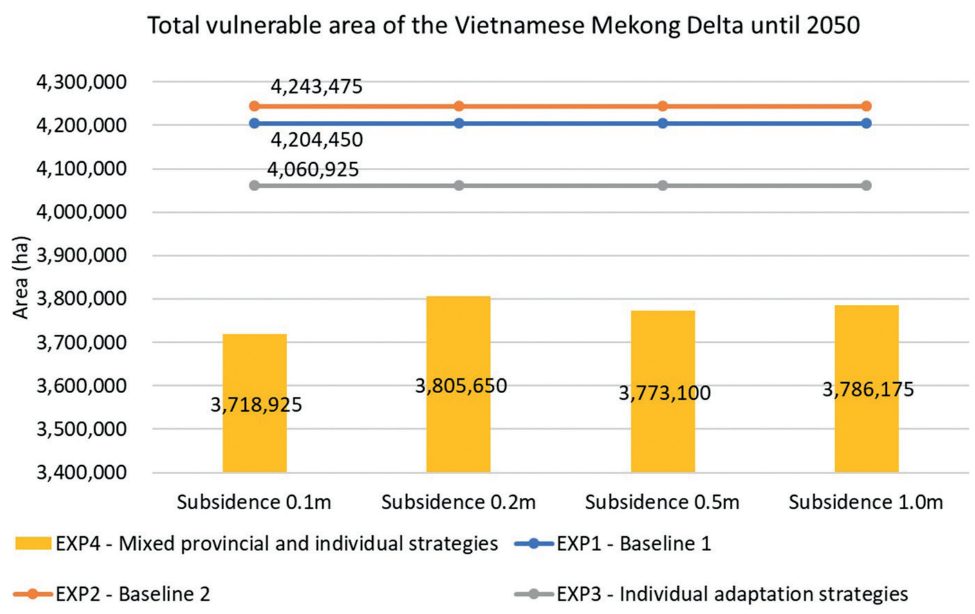
a) Experiment 1: Baseline 1; b) Experiment 2: Baseline 2, subsidence impact;
c) Experiment 3: subsidence react at 0.1m; d) Experiment 4 subsidence react at 0.1 m.

5.2 Vulnerability assessment

Figure 3.8 presents the vulnerability maps of rice and shrimp land-uses resulting from the four experiments (once again for Experiments 3 and 4, we only display the results for a subsidence threshold of 0.1 m). The LUCAS-GEMMES model computes these maps based on the number of years a land unit is at risk over the simulations. The more heavily impacted the area, the darker the color. In the two baseline experiments, these maps are similar. In experiments 3 and 4, some areas such as Soc Trang have reduced the vulnerable areas, in particular for rice crops in the Coastal area (red color in the Figure 3.8), thanks to the application of adaptation strategies.

The maps for Baseline Experiments 1 and 2 show that the impacted areas are mainly located in Ca Mau, Bac Lieu (for shrimp), Soc Trang, Kien Giang (rice and shrimp), coastal regions of Ben Tre and parts of Tien Giang, An Giang, and Long An (rice). The provinces of An Giang, Dong Thap, Long An, and Tra Vinh contain large 3-rice crops areas but are not affected by climate conditions, thus the transformation from 3-rice crops to 2-rice crops

[Figure 3.9]
Vulnerable area for rice and shrimp of 4 experiments



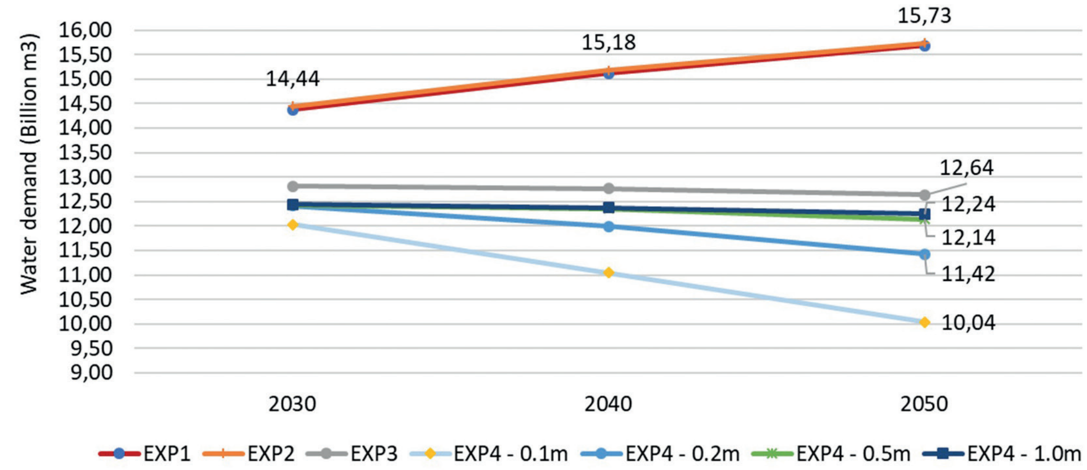
in these provinces does not contribute to narrowing the vulnerable area in these provinces.

In order to compare the vulnerable area of the four experiments, we compute the total vulnerable area for rice and shrimp during simulation and plot it in Figure 3.9. First, it appears that the areas for Baseline 1 and Baseline 2 are significantly greater than for the two other experiments with adaptation. In Experiment 3, although the vulnerable area is significantly narrowed compared to the two baselines, the total vulnerability area when people self-adapt to subsidence levels was significantly higher (more than 300,000 ha cumulatively) than this area of Experiment 4 (provinces reacted at subsidence threshold from 0.1 m to 1.0 m). This is due to the fact that the multi-criteria optimal selection mechanism of farmers is still driven by the highest income (land-uses with the highest profit are still occupying the area) and newly converted land-use was not supported for reducing risk. For Experiment 4, we can observe that the total vulnerable area is reduced even further; more specifically, when the province applies adaptation strategies early (*i.e.* with a low subsidence threshold), the affected area would be reduced by 50,000–80,000 ha compared to the cases of slow responses (subsidence thresholds higher than 0.2 m).

5.3 Water saving to mitigate subsidence

Evolutions in water volume demand, aggregated at the scale of the studied area, are plotted in Figure 3.10 for years 2030, 2040, and 2050. The two baseline Experiments 1 and 2 keep a high annual water use regime because farmers converted to land-use that

[Figure 3.10]
Water demand evolution



For the 4 experiments with various values of the subsidence threshold.

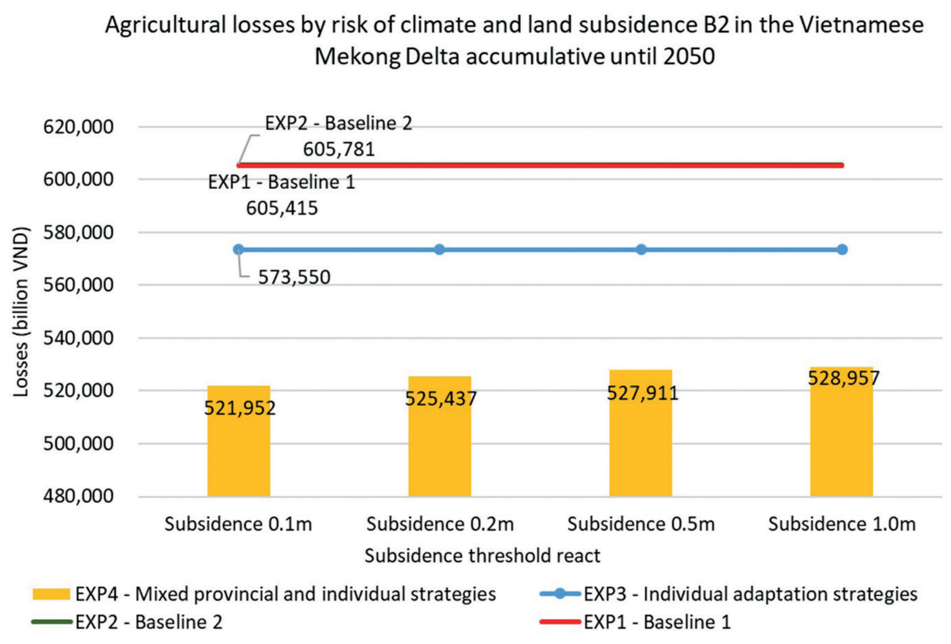
consumes much more water. For the experiments that apply provincial adaptation strategies, the results show that the amount of water used is reduced significantly compared to other cases when provincial strategies are early responses (saved more than 5 billion m^3 in EXP 4-0.1m compared with the baselines). In the case of people's self-awareness and early adaptation (EXP3-0.1m), the results show that the amount of water used is also significantly lower, even if this is not as efficient as the application of provincial adaptation strategies.

Considering the relationship between water demand and land-use [Figures 3.6 and 3.7], water demand reduction seems to be mainly due to the conversion from 3-rice crops to 2-rice crops. It is well noted that it does not directly help in reducing subsidence (because these cultivation types use surface water), but indirectly enhances surface water resources. In An Giang and Dong Thap areas, when cutting crops and receiving floods, it serves to store surface water for cultivation. Besides, the saved water can be run off into canals and ponds to irrigate fruit trees and vegetables, where farmers can cultivate dry crops in the dry season.

5.4 Analyzing incomes and losses with adaptation strategies

Figure 3.11 plots the cumulative loss due to climate and salinity conditions in 2050. It shows first that Baselines 1 and 2 represent a significantly larger amount of financial loss than the two other experiments; this is coherent with the larger exposed area (as depicted in Figure 3.9). The results of Baseline 1 and Baseline 2 experiments are very similar and high, due to risk in aquaculture: the affected areas are mainly Farming Units with 3 rice crops and shrimp farming land-uses. We can

[Figure 3.11]
Accumulated losses of 4 experiments



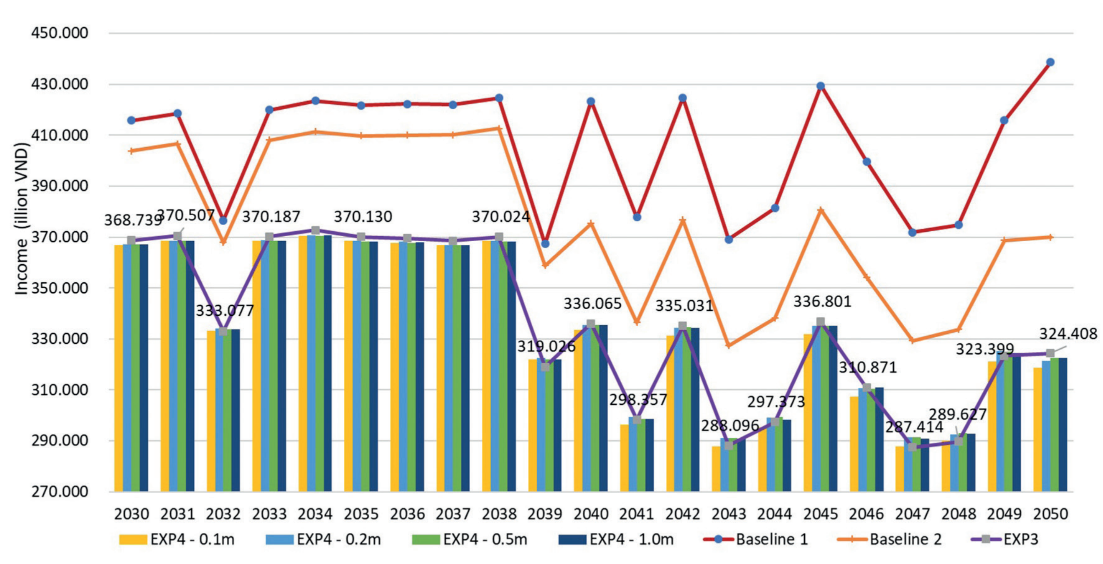
nevertheless note that the loss values do not differ between Baseline 2 and Baseline 1, because they share the same land-use selection behavior.

As far as Experiment 3 is concerned, the amount of money lost is lower than Baseline losses. This phenomenon occurs because farmers applied the adaptation strategies (selecting land-use based multicriteria evaluation among the land-use candidates, supported by the strategies of the province) so that vulnerability to climate, salinity and subsidence is reduced.

In Experiment 4, the loss is significantly lower than in Experiment 3, with a lower value showing an improvement in the situation when provinces apply adaptation strategies at a low subsidence threshold (0.1 m) compared to a late, serious threshold (1 m). Even if the total losses of EXP4-0.1m are the lowest, large shrimp areas with investment levels around 6 times higher than for rice can be subject to potential risk from climate factors. From a qualitative point of view, the Province adaptation strategies (prohibiting some land-use from being created) seem to have a positive effect from an economic point of view, as they reduce losses; but when people select a new land-use, it can be impacted by climate change. This shows the need to invest in climate change-adaptive shrimp farming techniques to minimize the damage caused by climate change.

Figure 3.12 summarizes the results in terms of farmers' incomes. It compares the total incomes in the ideal case, when incomes are not affected by the subsidence (Baseline 1), with the situations where they are and no adaptation strategies are implemented (Ba-

[Figure 3.12]
Evolution of annual incomes for the 4 experiments until 2050



seline 2), and situations where adaptation strategies are applied (Experiments 3 and 4). The results show a large inter-annual variability of income, caused by strong impacts of weather conditions for some years (as simulated in the climate projections data used in this study).

Under ideal conditions, the transition to suitable farming systems with high returns would make a positive contribution to the economy of the Delta, despite the risks of climate change. However, when the impact occurs, profits drop significantly (Baseline 2). For the adaptation experiments, the experiments applying strategies at low subsidence levels showed a severe decline in incomes. In this situation, the conversion from 3 crops to 2 crops would strongly impact the income of farmers. The price to pay for protecting natural resources would be high in this case. However, when considering the impact of climate change and calculating the balance with costs lost due to impacts, it shows that choosing to apply a flexible adaptation strategy will bring great benefits to the people and better resource protection. Besides, farmers can choose highland crops in the dry season to improve their income.

6. Conclusion

This chapter aims to go one step further than [Truong *et al.*, 2021] in illustrating the possibilities offered by the agent-based approach to modeling socio-environmental systems. In particular, it introduces agents at a new decision-making level, the provinces, with the ability to influence or constrain, through regulations or incentives, individual farmers' decisions. These new agents also have new perceptions and knowledge, such as land subsidence measurements, and an ability to use this information to make decisions that may differ from their neighbors, for example by applying different subsidence thresholds to trigger certain policies. This addition increases the richness of the behavior produced during the simulations, but in return, the model obviously becomes more complex to explore and interpret.

This chapter also illustrates the role that integrated models like LUCAS-GEMMES can play in combining the results of several other models at different scales. This is the case of those produced within the GEMMES project: downscaled climate projections from CMIP6 global climate models, inputs from the macroeconomic model [Espagne *et al.*, 2021] and projections from a land subsidence model [Minderhoud *et al.*, 2020] are all used to parameterize the scenarios used as contexts for the simulations. Finally, the chapter also provides an understanding of how certain policies described in legal decisions or reports can be implemented as behaviors or decision-making by artificial agents. This is the case, for example, with Resolution 120/2017 or Prime Minister's Decision 324/QD-TTg, both of which frame climate change adaptation policies in the Vietnamese Mekong Delta as well as the response to subsidence.

By adding the local adaptation behaviors of farmers, which were already presented in the first version of the model, LUCAS-GEMMES thus enables a wide range of adaptation and mitigation strategies to be explored. In particular, this can allow decision makers to analyze the results both qualitatively, in the form of combinations of local and global land use strategies, and quantitatively, in the form of indicators: farmers' income and losses, area at risk of salinization due to climate change, estimated water used by crops, etc.

We found that the application of policies to restrict certain land-uses at low subsidence levels (0.1 m) is more effective in mitigating climate change risks. This is because it helps to reduce water consumption during the dry season and minimizes the damage caused by climate change. However, it has the negative consequence – when applied abruptly – of contributing to a decrease in farmers' income, which would tend to show the need, in reality, of additionally focusing on the construction of water supply structures, support for agricultural techniques or the development of dry season crops to improve people's livelihoods when an adaptation solution is chosen.

This lack of policy support for farmers from the provinces is one of the limitations of the current model. Another limitation is that LUCAS-GEMMES only takes the results of other models as input, without for the moment relying on a more important coupling: the choice of agricultural production thus has no influence on land subsidence, salinity intrusion or macroeconomic dynamics, which are considered as exogenous. This essential point, which greatly complicates the model but which appears necessary to increase its realism, will be further investigated in subsequent studies.

Despite this limitation, simulations using the current model were able to provide some interesting insights, particularly regarding the impact of cooperation between provinces, represented here as a coordinated choice of provinces sharing the same agro-ecological zone. These virtual experiments allow us to confirm numerically that coordination between provinces makes it possible to maintain farmers' overall incomes at reasonable levels, whereas the absence of coordination will penalize them. One of the interesting aspects of agent-based modeling is that it can explore not only the decisions, but also the interactions between actors at different levels. From this perspective, LUCAS-GEMMES could be a promising tool for policy evaluation in the Vietnamese Mekong Delta, enabling awareness of the value of cooperation to be raised among provinces and national decision-makers, when a common property such as aquifer zones [Olstrom, 1990] is shared and exploited by several actors with sometimes divergent views

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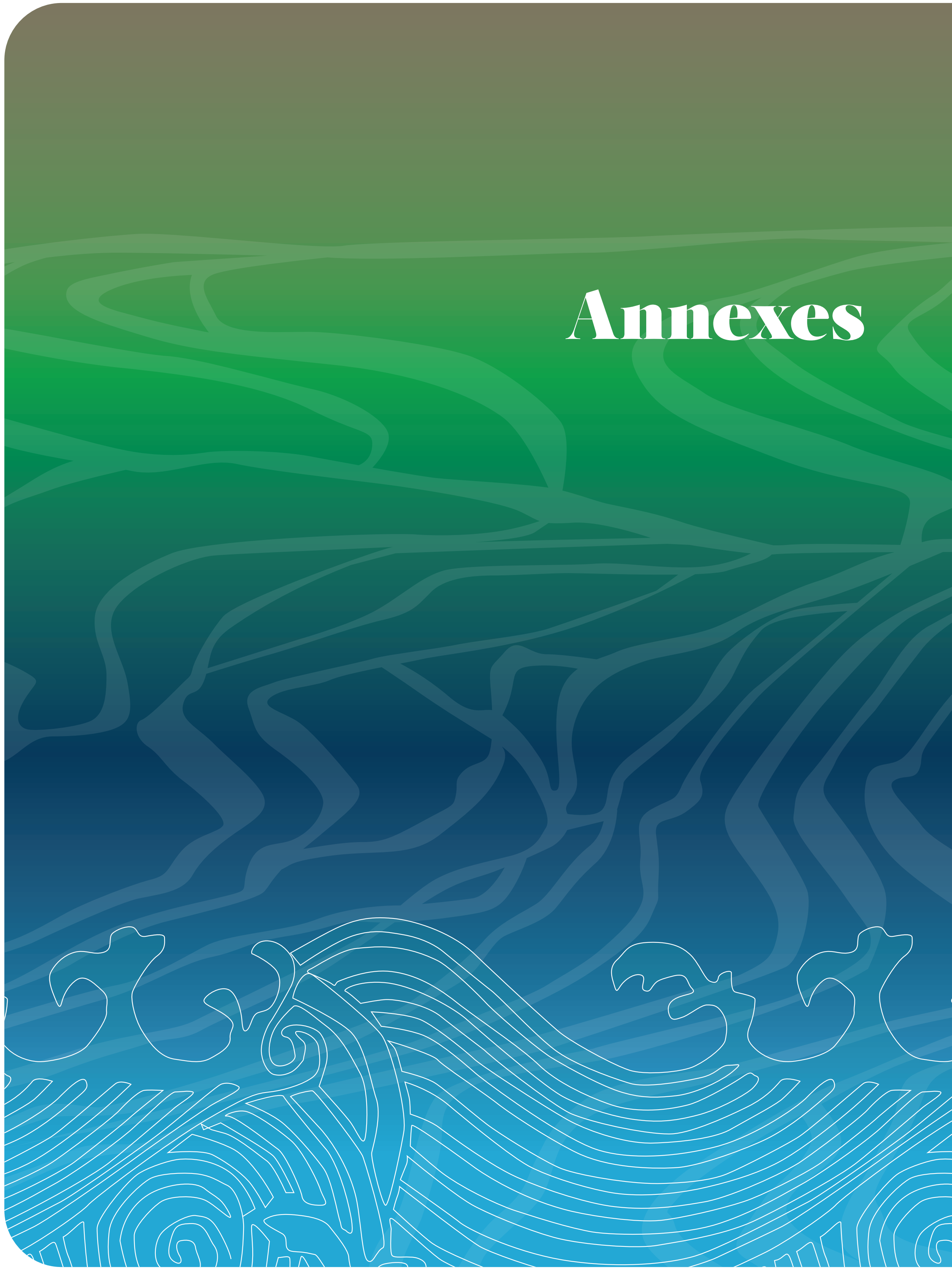
Annexes



CONTENT FIGURES

PART 1

PART 2

Focus 1

Focus 2

Focus 3

Focus 4

Focus 5

Focus 6

Focus 7

PART 3

CONTENT TABLES

PART 1

PART 2

Focus 3

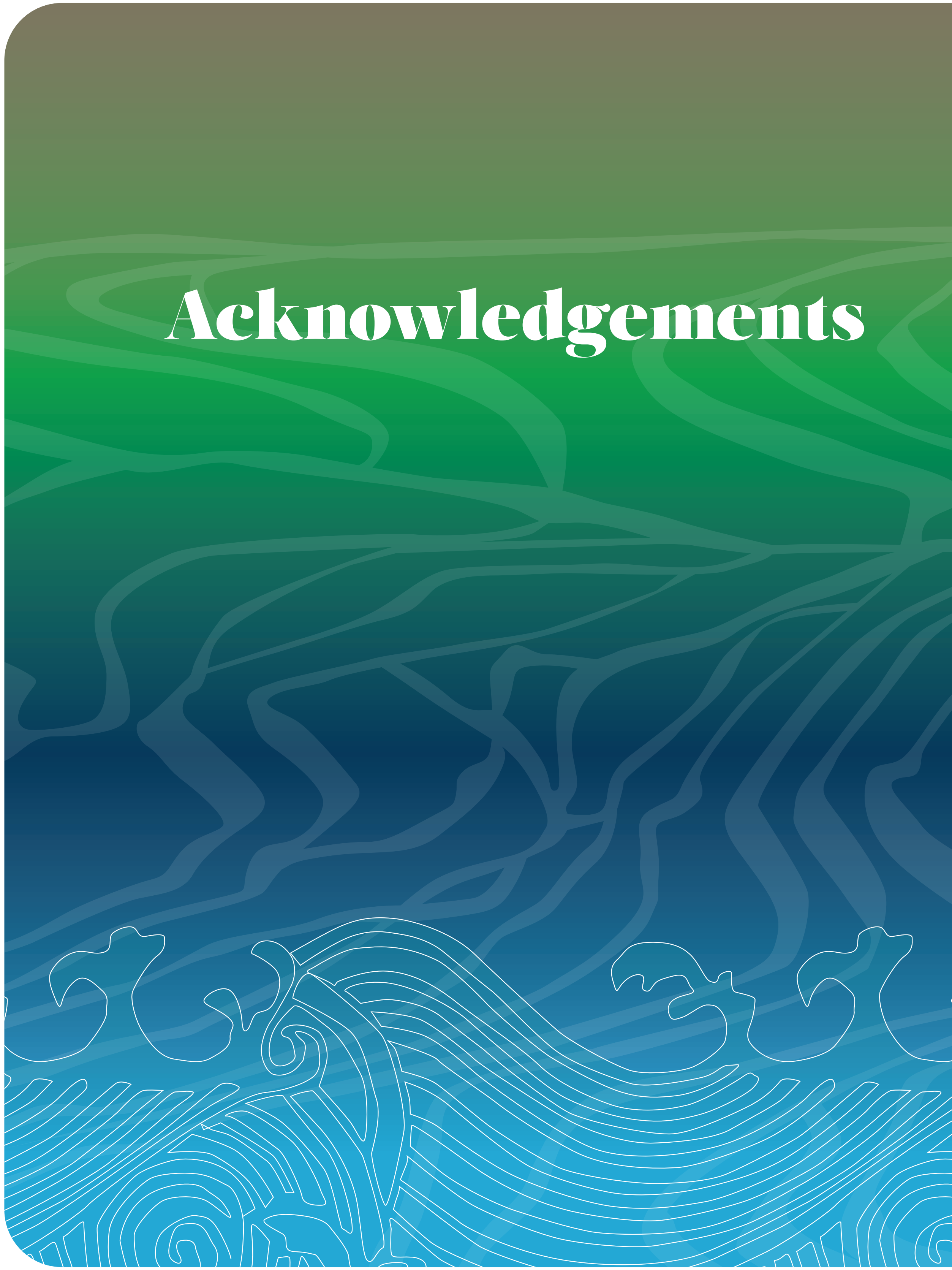
PART 3

CONTENT BOXES

PART 1

ABBREVIATIONS

AEZ	Agroecological zone
AFD	Agence Française de Développement
AWD	Alternate wetting and drying
CARE	Asian center for water research
CESBIO	Centre d'Etudes Spatiales de la Biosphère
CEC	Central Economic Committee, Viet Nam Communist Party
CMIP	Coupled Model Intercomparison Project
COP	Conference of the Parties
CTU	Can Tho University
CWMCC	Center of Water Management and Climate Change
DCC	Department of Climate Change (MONRE)
DMFA	Dutch Ministry of Foreign Affairs
DUT	Delft University of Technology
DWRPISV	Division for Water Resources Planning and Investigation for the south of Viet Nam
EFEO	Ecole Française d'Etrême-Orient
GCM	Global Climate Model
GDP	Gross Domestic Product
HCMC	Ho Chi Minh City
HCMUT	Ho Chi Minh City University of Technology
HNUENR	Ha Noi University of Environment and Natural Resources
IER	Institute for Environment and Resources
ICED	Institute for Circular Economy Development
ICOLD	International Commission on Large Dams
IGE	Institut des Géosciences de l'Environnement
IMHEN	Vietnam Institute of Meteorology, Hydrology and Climate
INRAE	Institut National de recherche pour l'agriculture, l'alimentation et l'environnement
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche sur le Développement
IRIT	Institut de Recherche en Informatique de Toulouse
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
JSPS	Japan Society for the Promotion of Science
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LMC	Lancang-Mekong Cooperation
LUCAS	Land Use Change for Adaptation Strategies
MPI	Ministry of Planning and Investment
MONRE	Ministry of Natural Resources and the Environment
MoU	Memorandum of Understanding
MRB	Mekong River Basin
MRC	Mekong River Commission
NEU	National Economics University
NGO	Non-governmental organization
NLU	Nong Lam University
NU	Newcastle University
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SIWRP	Southern Institute for Water Resources Planning
SSP	Shared Socio-economic Pathway
UEB	University of Economics and Business
UNEP/GRID	United Nations Environment Programme/ Global Resource Information Database
UNIPD	University of Padua
UP1	Université Paris 1, Panthéon-Sorbonne
UR	University of Rouen
UT	University of Toulouse
UU	University of Utrecht
VMD	Vietnamese Mekong Delta
VNCS	Viet Nam National Space Center
VNU	Viet Nam National University
VNU-HCM	Vietnam National University of Ho Chi Minh city
WU	Wageningen University
WWF	World Wide Fund for Nature



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