Master's Thesis – Water Science and Management

Impact of land subsidence on the population and land use in the Mekong delta

Applying environmental feedback to the Shared Socio-economic Pathways to provide projections for delta regions

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Summary

The Shared Socio-economic Pathways (SSP) provide global projections of future land use and population. These are modelled in integrated assessment models such as the Integrated Model to Assess the Global Environment known as IMAGE (PBL, 2019). Because, global models do not take local environmental feedback into account, downscaling the SSP scenarios and translating these one to one upon a delta, such as the Mekong delta which is relatively large and important on a global scale, can cause the global models to project changes that will not occur in certain areas. This negatively affects the reliability of the projections, providing a challenge for large delta regions; especially with a high population density and intensive agriculture, as these are prone to local environmental feedback, e.g. land subsidence (Minderhoud, 2019). The SSP are used in planning for areas, therefore it is not only of scientific relevance to make the SSP scenarios as accurate as possible but also relevant for society.

The question this research tried to answer is: what is the impact of land subsidence on the projections of the SSP models for the Mekong delta region and its inhabitants? The impact was shown by firstly displaying the projection of the land use and population density of the Mekong delta for each SSP. Showing the overall amount of rice cultivation and number of inhabitants in the Mekong delta and how these are spatially distributed throughout the delta. Secondly, by displaying the projections of relative sea level rise (RSLR) for each SSP. Showing that for each SSP scenario a substantial part of the Mekong Delta will be under sea level in 2100, for the more extreme scenarios even earlier, and comparing this with the current situation. Thirdly, by showing how the expected RSLR alters the land use opportunities in the Mekong delta. Displaying how the projected land use opportunities are diminished by the RSLR, since large parts of the delta are likely to be located below sea level in the coming century. Fourthly, by explaining how the population and its resources are affected by the RSLR. Classification of the elevation for the projected rice and population shows the effect of RSLR on the population and it resources. Finally, by showing to what extent there is a mismatch between the SSP projections of land use and population and the feasible land use and population density, when taking the effects of RSLR into account.

1. Introduction

The Mekong delta holds roughly 20 million inhabitants and spans an area of approximately 94,000 square kilometres (Delta Alliance, 2020). After the second Indo-Chinese war (1955-1975) the delta area developed quickly, and agricultural intensification has become eminent in the delta area. This intensification led to economic development and population growth, increasing the pressure on the area (Kolko, 2008). In the decades to come, sea level rise and land subsidence are likely to impact the amount of habitable areas in the delta (Minderhoud, 2019; 2020). The Intergovernmental Panel on Climate Change (IPCC) places the Mekong delta in the top 3 of most vulnerable areas to be affected by sea level rise caused by climate change (Pachauri et al., 2014). If the sea level rises by 1 metre, ignoring the land subsidence, 38% of the delta would be situated below sea level (Collins et al., 2017). With ongoing land subsidence, even larger parts of the delta may become situated below sea level (Minderhoud et al., 2019). Under a 3 to 5 degrees Celsius warmer climate (ICEM, 2013), with higher sea level and progressive land subsidence the pressure on the inhabitants of the delta will thus be immense.

1.1 The Shared Socio-economic Pathways (SSP)

Climate change will thus likely have an impact on the region; more specifically, it will have an impact on the land use in the delta. Therefore, it is necessary to explore scenarios for the Mekong delta to determine how the delta can remain sustainably existing. Preferably, such scenarios are in line with the scenarios from the Intergovernmental Panel on Climate Change (IPCC), the Shared Socio-economic Pathways (SSP). The SSP are scenarios used to estimate what this change in land use will be at global scale, according to five different scenarios (*Table 1.*) (Riahi et al., 2017 & Doelman et al., 2018). The SSP scenarios are represented as story lines of global socio-economic development, with changes in population density and land use, and inherent pathways for emissions of greenhouse gases and aerosols. These scenarios are developed at the global scale, with regional differences. Thus, the SSP's can be utilised as a starting point for long term scenarios in the Mekong delta.

The emissions projected by the SSP's are driven by several variables: different developments in population, gross domestic product (GDP), animal product consumption, land use change regulation, crop yield improvement, livestock system efficiency, and effectiveness land-based mitigation together make up consistent story lines of how the future develops, as represented by the SSP scenarios (Table 1; Doelman et al., 2018). A story line is calculated and applied on a global scale by integrated assessment models (IAM) such as the Integrated Model to Assess the Global Environment known as IMAGE (PBL, 2019). The SSP scenarios thus result in developments of global society, differing in terms of socio-economic development, as well as climate change driven by the associated greenhouse gas emissions. The combinations of the resulting climate change and the capacity of the global society to mitigate emissions or adapt to impacts define the challenges for the future for each scenario.

There are five SSP scenarios and each of these scenarios has their own set of challenges and storyline (Riahi et al., 2017 & Doelman et al., 2018). The SSP scenarios are ranked in socio-economic challenges for mitigation and adaptation (*Figure 1*). Each SSP scenario has a different socio-economic development, different emissions, and different climate projections (*Figure 2, 3, 4*). The climate projections can be translated into Representative Concentration Pathways (RCP) to simulate sea level rise.

SSP 1, the sustainability scenario, reflects a scenario in which society has become extremely sustainable and has the means to achieve this level of sustainability. The global population growth decreases and even the overall population decreases after 2040, illiteracy decreases heavily. The share of renewable energy increases and the demand for energy decreases. A strong focus is put on sustainability together with an increase of the GDP. (Riahi et al., 2017 & Doelman et al., 2018)

SSP 2 represents 'the middle of the road' scenario, that might evolve if society would continue on the current path. Sustainability is not a top priority, but it is also not neglected and there is a medium level of wealth in the world; it is truly a middle of the road scenario. This scenario follows the same trend of decreasing illiteracy as SSP 1. However, the focus is less on sustainability, and the population and GDP trend are not as favourable as in the previous scenario. (Riahi et al., 2017 & Doelman et al., 2018)

SSP 3, regional rivalry, is a scenario in which sustainability is not a priority and there are little financial means available to deal with the pressure created from this. The global population continues to grow while the GDP increases only gradually. Energy production relies more on relatively cheap coal, while the demand continues to increase. Illiteracy increases significantly. So, even without a focus on sustainability there is minimal economic and societal development. (Riahi et al., 2017 & Doelman et al., 2018)

SSP 4, the inequality scenario, is a more intricate scenario. There is a large inequality between different regions: there are high income regions that have trends similar to SSP 1; furthermore, there are medium income regions that have trends similar to SSP 2; moreover, there are low income regions that have trends similar to SSP 3. Combined these provide an intricate global estimation, with large differences in GDP, emissions, population growth, and energy production and demand. Globally the population growth and level are similar to SSP 2, the GDP is less favourable than in SSP 2. While energy production and demand, together with emissions, are more favourable than in SSP 2. (Riahi et al., 2017 & Doelman et al., 2018).

In SSP 5, reflecting the fossil fuelled development, there is a lot of wealth created by using fossil fuels for (economical) development. However, this comes at a cost: there are extreme levels of carbon emissions and (local) sustainability is neglected, economic development is of the highest priority. This scenario follows the same population and education trends as SSP 1, while the GDP is even higher. This is economic growth is built upon oil, gas, and coal. Resulting in high global emission levels, amounting to high levels of radiative forcing.

Table 1. The five Shared Socio-economic Pathways (Doelman et al. 2018)

	SSP1 Sustainability	SSP2 Middleof the Road	SSP3 Fragmentation	SSP4 Inequality			SSP5 Fossil-Fueled development
				High income regions	*Medium income regions*	*Low income regions*	
Population (billion) (2050/2100)	8.5/7.0	9.2/9.1	10.0/12.8	9.2/9.5			8.6/7.4
GDP(thousand 2005 US$ per capita) (2050/2100)	34/81	25/59	18/22	25/38			44/139
Globalization of trade	Highly globalized	Moderately globalized	Less globalized	Highly globalized		Less globalized	Highly globalized
Animal product consumption	Reduced preference for animal products	Current preference for animal products	High preference for animal products	Current preference for animal products			High preference for animal products
Land-use change regulation	Strict regulation	Moderate regulation	Little regulation	Strict regulation	Moderate regulation	Little regulation	Moderate regulation
Crop yield improvement	High yield improvement	Moderate yield improvement	Low yield improvement	High yield improve-ment	Medium yield improve-ment	Low yield improve-ment	High yield improvement
Livestock system efficiency	High efficiency improvement	Moderate efficiency improvement	Low efficiency improvements	High efficiency improve-ment	Moderate efficiency improve-ment	Low efficiency improve-ment	High efficiency improvement
Effectiveness land-based mitigation	Very effective	Moderately effective	Not effective	Moderately effective			Very effective

Figure 1. SSPs mapped in the challenges to mitigation/adaptation space (Sfdiversity, 2020**)**

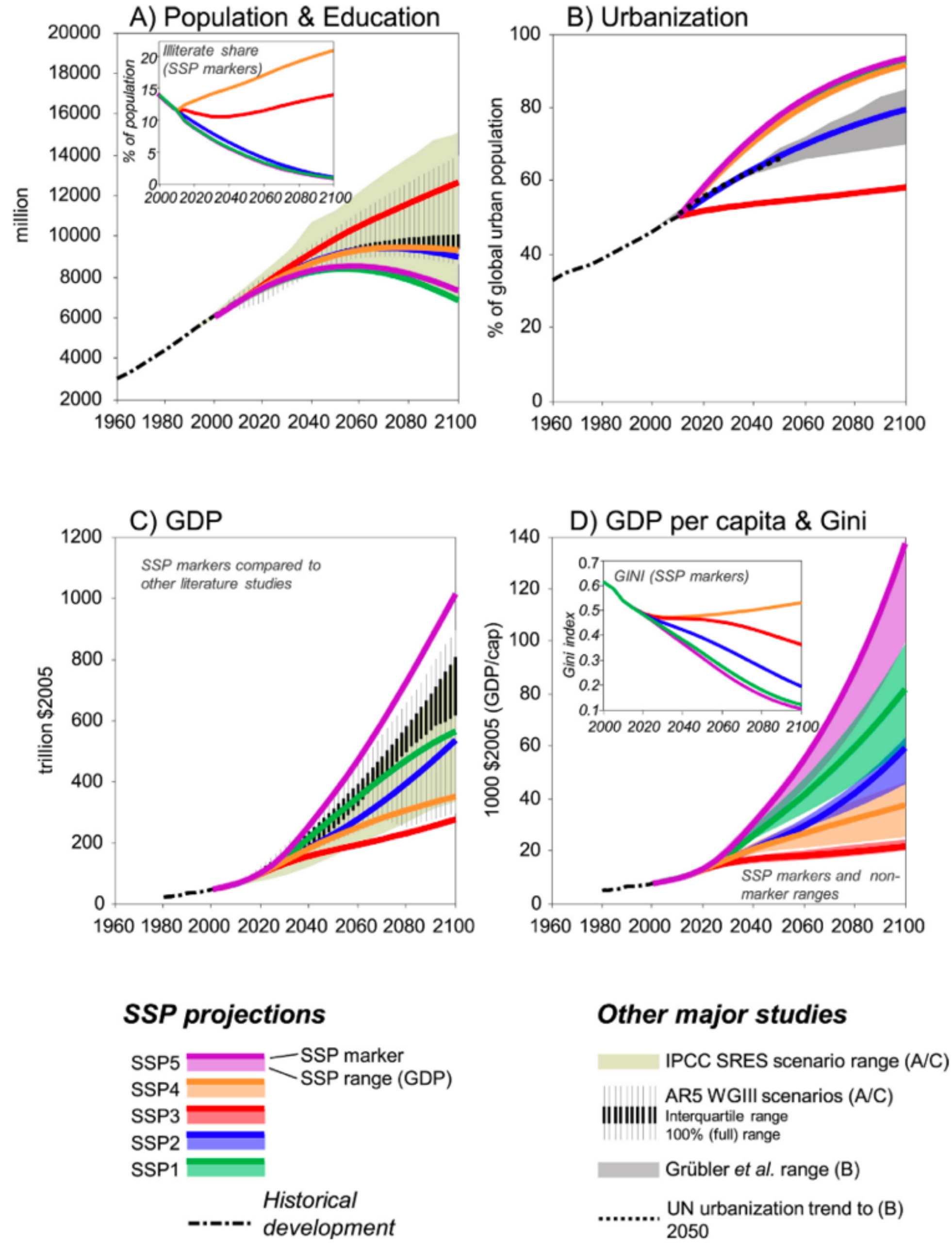


Figure 2. Global population and education, urbanization, GDP, and GDP per capita for each SSP scenario (Riahi et al., 2017)

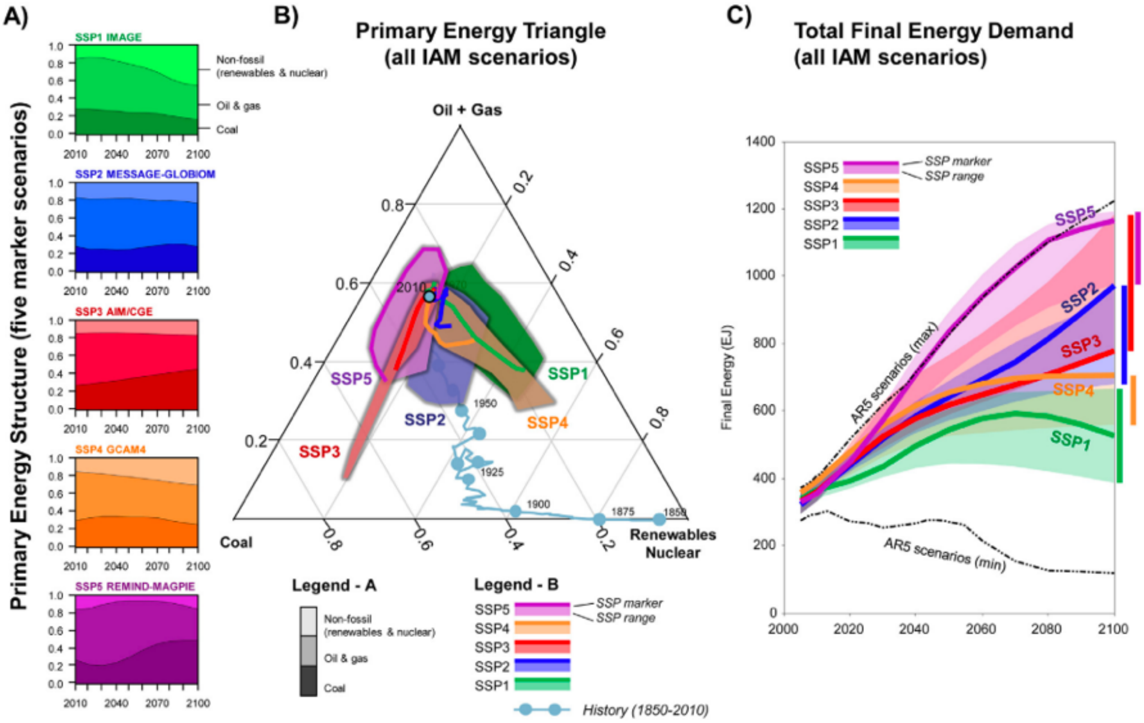


Figure 3. Global energy structure and demand for each SSP (Riahi et al., 2017)

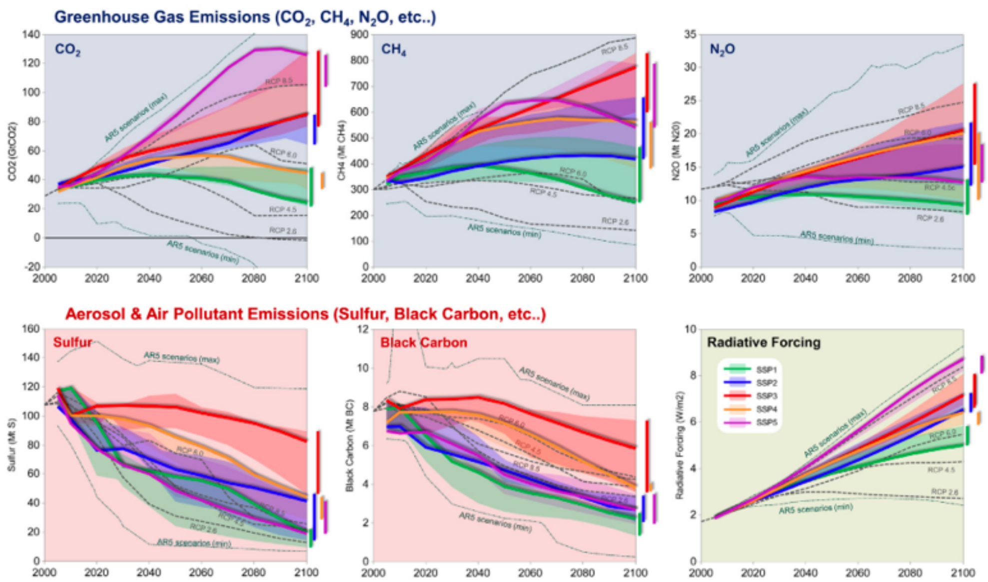


Figure 4. Projected global emissions and radiative forcing for each SSP scenario (Riahi et al., 2017)

1.2 Problem description

The SSP scenarios provide projections of future land use and population. However, these scenarios do not take local environmental feedback into account, since it is a global model. Omitting local factors in IMAGE, a model used to calculate the SSP scenarios, can cause the global models to project changes that will not occur in certain (local) areas. When this occurs for a significant number of regions, then it will have an impact on the global projections; which would therefore become less accurate. This provides a challenge for large delta regions; especially with a high population density and intensive agriculture, as these are prone to land subsidence (Minderhoud, 2019). Downscaling the SSP scenarios and translating these to a delta, which can be relatively large and important on a global scale and is heavily affected by local environmental feedback, can influence the reliability of the projections, as is the case with the Mekong delta.

An example of this local environmental feedback is the change of land area into flooded area, more specifically: when the land subsidence is not taken into account. This subsidence is a local feedback that does not have a large enough impact on global scale to be considered relevant. However, it is relevant; the Mekong delta, a large area on a global scale, is heavily affected by land subsidence from ground water extraction, as shown by Minderhoud (2019; 2020). Ignoring land subsidence means that areas that could potentially be flooded in the future are still considered as suitable land in the future projection scenarios of the SSP, even though they may not be accessible as they might be flooded. The SSP are used in planning for areas, therefore it is not only of scientific relevance to make the SSP scenarios as accurate as possible but also relevant for society.

Because the Mekong Delta is heavily affected by land subsidence (Minderhoud, 2019), it is an excellent example for a case study on the underestimation of pressure from land subsidence on delta areas, as its results can be applied to other deltas around the world. Minderhoud (2019) has extensively analysed and quantified subsidence rates of the Mekong delta, and has created a model capable of estimating the subsidence rate based on groundwater extraction in the Mekong delta. Therefore, the Mekong delta has been chosen as the study area for this research.

1.3 Objective

The aim of this research is to improve the current SSP scenarios at the regional (c.q. delta) scale by (1) downscaling SSP scenarios to the Mekong delta, and (2) quantifying the feedback from land subsidence onto SSP projections. This provides recommendations to the modelling groups creating SSP integrated assessment models whether this regional-scale environmental feedback needs to be incorporated to provide sound estimations of land use in the future. The question this research tried to answer is: what is the impact of land subsidence on the projections of the SSP models for the Mekong delta region and its inhabitants?

This research question was investigated through multiple sub questions:

1. What is the projection of the land use and population density of the Mekong delta for each SSP?
2. What are the projections of relative sea level rise for each SSP?
3. How does the expected *relative* sea level rise alter the land use opportunities in the Mekong delta?
4. What is the estimated elevation for the projected population and land use when the effects of relative sea level rise are taken into account?
5. To what extent is there a mismatch between the SSP *projections* of land use and population and *feasible* land use and population density, when taking the effects of *relative* sea level change into account?

It is hypothesized that ignoring the regional-scale environmental feedback from land subsidence in the Mekong delta will lead to an underestimation of the pressure caused by climate change in the future. Thus, causing an overestimation of the opportunities for land use in the area.

2. Study area and method

The area of research is the Mekong delta. With its high population density, intensive agriculture, subsidence rate, and low elevation (Minderhoud et al., 2019 & Delta alliance, 2020) it is an ideal case study to show the impact of local environmental feedback on a global model.

This research used the IMAGE 3.0 model (PBL, 2019) to provide projected land use and population for SSP 1, 2, 3, and 5. The population data was produced by *Jones and O'Neill (2016)* and is an input for IMAGE to provide projections. These projections were made for several time slices in ten-year time slices in the upcoming century. Furthermore, for these SSP scenarios the relative sea level rise (RSLR) was determined and compared with the projections from IMAGE. This showed the impact of local environmental feedback on these projections and what this meant for the projected land use and population of each SSP.

2.1 The Mekong delta

The Mekong delta holds roughly 20 million inhabitants and spans an area of 94,000 square kilometres (Delta Alliance, 2020). The delta area is densely populated and intensively used for agriculture and aquaculture (*Figure 5*; Scarrot et al., 2005). A large area of the delta is below or just above sea level, up to roughly 1 metre (*Figure 6*; Minderhoud et al., 2019). Thus, the area is extremely vulnerable to sea level rise. Furthermore, there is a high rate of subsidence from ground water extraction (*Figure 7;* Minderhoud et al., 2017). For example, in the south-eastern coastal area there has been up to 35 centimetres of total land subsidence, with a subsidence rate of 2.5 centimetres per year (Minderhoud et al., 2017). This further increases the vulnerability to sea level rise.

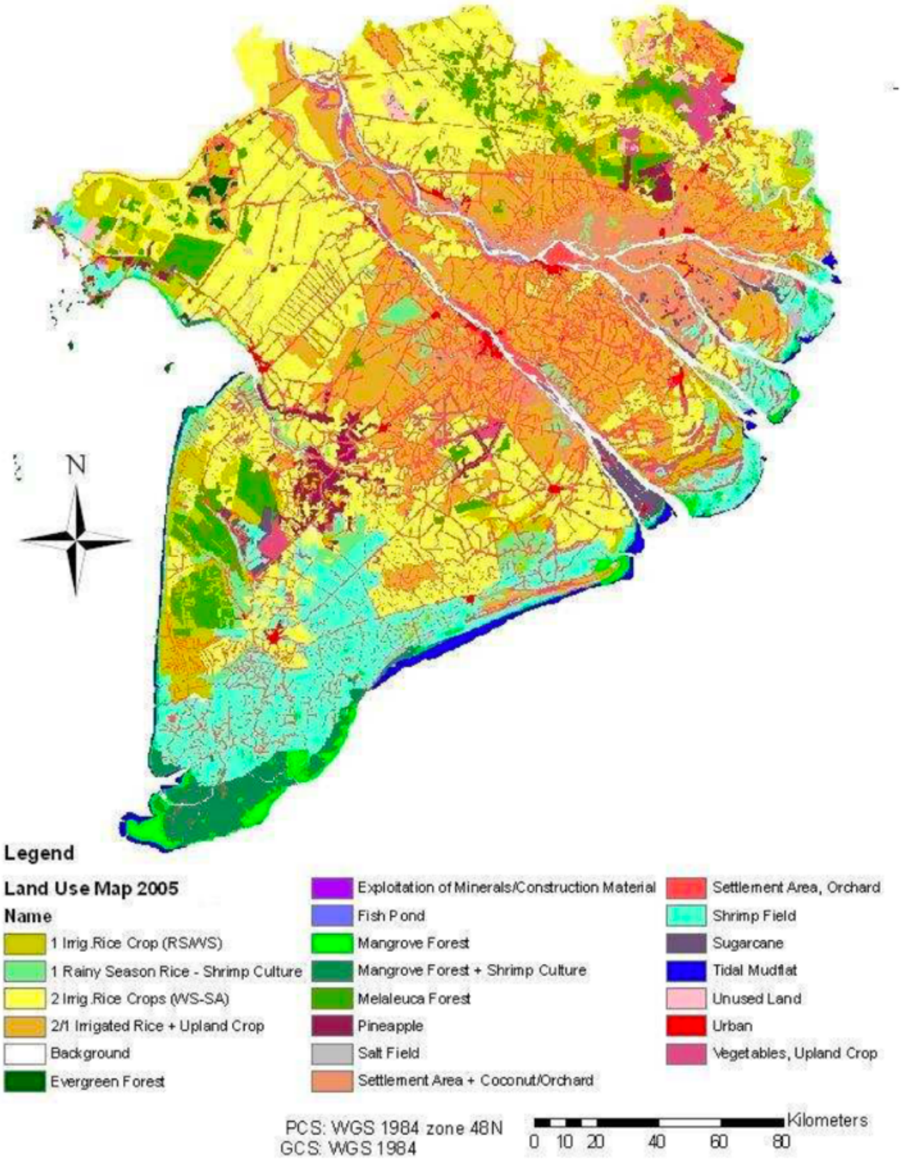


Figure 5. Mekong delta land-use map 2005 (Scarrott, 2009)

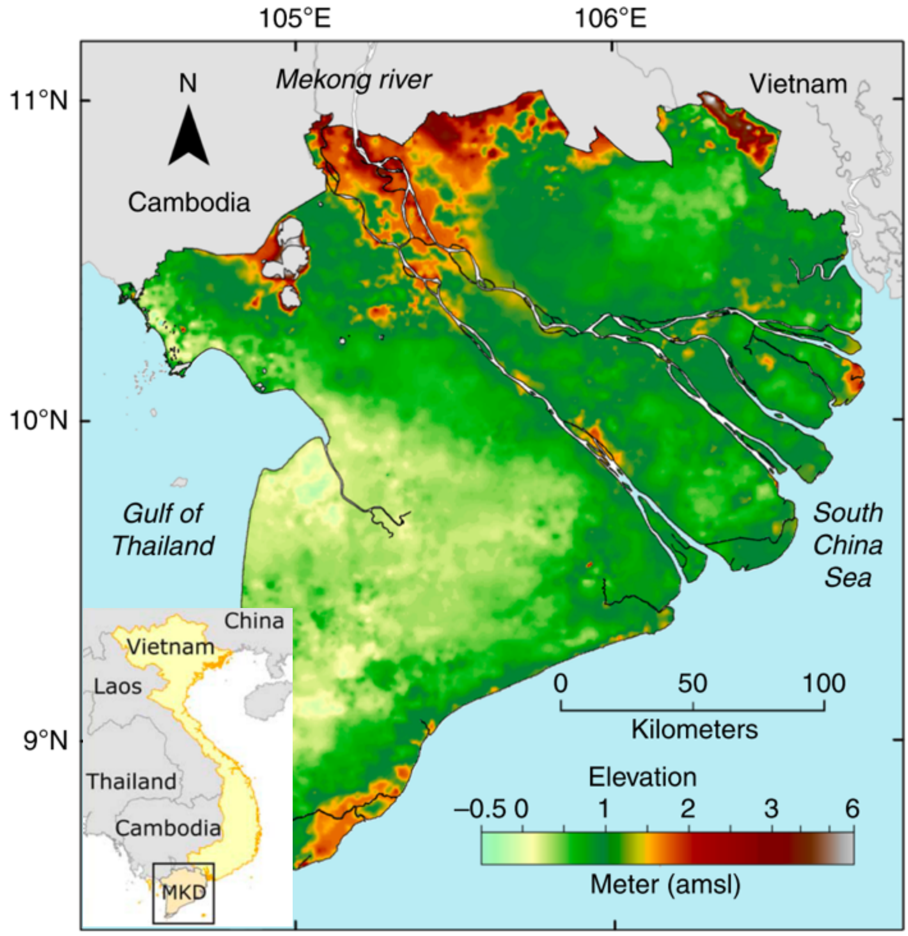


Figure 6. Elevation map of the Mekong delta (Minderhoud et al., 2019) and location of the Mekong delta (MKD) (Minderhoud et al., 2020)

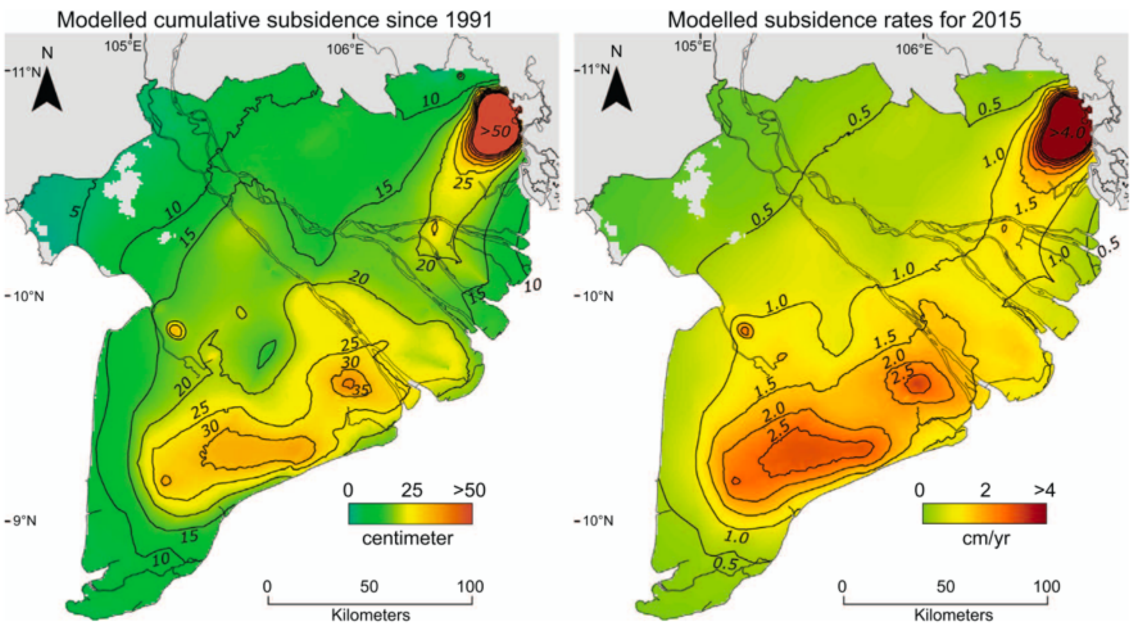


Figure 7. Modelled cumulative land subsidence from 1996 to 2016 and subsidence rates for 2015 of the Mekong delta (Minderhoud et al., 2017)

2.2 Scenarios for the Mekong delta

For this research, four already existing scenarios were considered, SSP 1, 2, 3, and 5. SSP 4 is not utilised, as the scenario would be very similar to SSP 3 for the Mekong delta. So, it has no added value to this research. Firstly, the projections of the SSP for land use and population came from IMAGE. Secondly, the sea level rise was derived from the RCP scenarios of the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC, 2019). Thirdly, the subsidence rates and elevation were obtained from simulation results of Minderhoud et al. (2020). Finally, these were integrated in ARCGIS (10.6.1, Esri).

2.2.1 SSP projections of land use and population from IMAGE

Projections for land use and population were retrieved from IMAGE, to be mapped to the Mekong delta, which results in a digital land use and population density map. IMAGE is a globally integrated projection model for the SSP scenarios, with a grid size of 5 x 5 arcminutes, corresponding to 10 x 10 kilometres at the equator, for land use projections. The projections for population have a grid size of 7.5 x 7.5 arcminutes, corresponding to 15 x 15 kilometres at the equator. The projections are based on socio-economic assumptions and cover greenhouse gas emissions. In the process of calculating these emissions, IMAGE provides projections on trends in population development, land use, energy demand, industry, etc. (PBL, 2019). Moreove*r*, the resulting coarse-scale SSP map IMAGE were compared to the current hi-res land use and population density map from Minderhoud.

One aspect of IMAGE that needs to be taken into account is that it is a global model, so the expected data for emissions, land use, etc. per SSP scenario is projected on a global scale. Therefore, it is possible that local or regional results might vary from the global narrative.

2.2.2 Sea level rise (SLR) from the RCP scenarios

The SSP scenarios were linked to the RCP scenarios that are associated to the emissions resulting from the SSP's. The RCP scenarios provide a projection of climate change and sea level rise based on radiative forcing. Since, the sea level rise is directly derived from the RCP scenarios. Here, three of the RCP scenarios were considered: RCP 2.6 - a best-case scenario with maximum mitigation of emissions, RC P4.5 as middle of the road with moderate greenhouse gas emission mitigation, and RCP 8.5, a worst-case business-as-usual scenario.

This creates the possibility for these RCP scenarios to be linked with the SSP scenarios. SSP 1 is the scenario of a sustainable society, which would result in the lowest greenhouse gas emissions. Therefore, the RCP scenario that would best fit SSP1 is RCP 2.6, where the carbon emissions are drastically cut, as this would fit a best-case situation from a sustainability point of view. The 'middle of the road' scenario SSP 2 with medium levels of wealth in the world, was connected to the moderate emission scenario RCP 4.5. Although under the SSP 3 scenario sustainability is not a priority, economic development is moderate as well. There too RCP 4.5 was considered to match best. In SSP 5 there are extreme levels of carbon emissions because of high levels in economic development and a disregard of sustainability. RCP 8.5 best represents the effects of these extreme carbon emissions.

2.2.3 Land subsidence scenarios from Minderhoud

The subsidence rates came from research of Minderhoud et al. (2020). These scenarios were made consistent with the SSP. The subsidence scenarios were obtained using a combined subsurface geology-hydrological model for six pathways of groundwater extraction: two non-mitigation scenarios and four mitigation scenarios (*Figure 8; Table 2)*. Scenarios B1 and B2 show an increase in groundwater extraction; scenario M1 is a scenario constant with the current ground water extraction rate; and scenario M2, M3, and M4 show a decrease in groundwater extraction. The subsidence model has a cell size of 1 x 1 kilometre, and the base elevation map has a cell size of 0.5 x 0.5 kilometres (Minderhoud et al., 2019; 2020). This model only uses ground water extraction as the driver for land subsidence, instead of adding anthropologic and environmental land subsidence. Because, ground water extraction is the main driver for land subsidence and can be mitigated. (Minderhoud, 2019)

Moreover, Philip Minderhoud created a supplemental scenario specifically for this research: scenario B1.5. This scenario has an annual increase in ground water extraction of 3%, which would fit SSP 5 better. Since B1 would not show the environmental impact of the SSP and B2 would be too extreme.

The SSP scenarios were linked to the subsidence scenarios. SSP 1 reflects the best-case scenario: society has become extremely sustainable and has the means to achieve this level of sustainability. This is reflected in subsidence scenario M3, where the total ground water extraction is reduced by 75%. The SSP 2 reflects a development that would continue on the current socio-economic pathway. Accordingly, subsidence scenario M1 extrapolating current groundwater extractions into the future, with only moderate reduction in extraction rates fits best here. The less sustainable SSP 3 was connected to subsidence scenario B1. As local impact from ground water extraction is not important, so the extraction increases annually by 2%. In SSP 5 with high economic development and a lot of wealth, ground water extractions will continue to occur. To represent the economic development under this SSP, subsidence scenario B1.5 was adopted. The ground water extraction increases annually with 3% to provide for the demand in this scenario.

Table 2. Modelled scenarios of ground water extraction scenarios from 2018 until 2100 (Minderhoud et al. 2020)

Scenario		Extraction pathways
Non-mitigation	B2 : Extreme extraction increase	Steady annual increase: 4% *of the 2018 volume*
	B1 : Moderate extraction increase	Steady annual increase: *2% of the 2018 volume*
Mitigation	M1 : Stable extraction	Stabilizing extraction, no increase after 2020: 2019: 1.5%*; 2020:* 0.5%*; after* 2020: *stable extraction*
	M2 : Stable groundwater levels	Gradual reduction of extracted volume by 50% of the 2018 volume: *2018–2028: Annual reduction of* 5%. *After* 2028: *Stable extraction*
	M3 : Recovery of groundwater levels	Gradual reduction of extracted volume by 75% of the 2018 volume: 2018–2033: *Annual reduction of* 5%. *After* 2033*: stable*
	M4 : Full extraction stop	Complete stop of all extraction after 2018

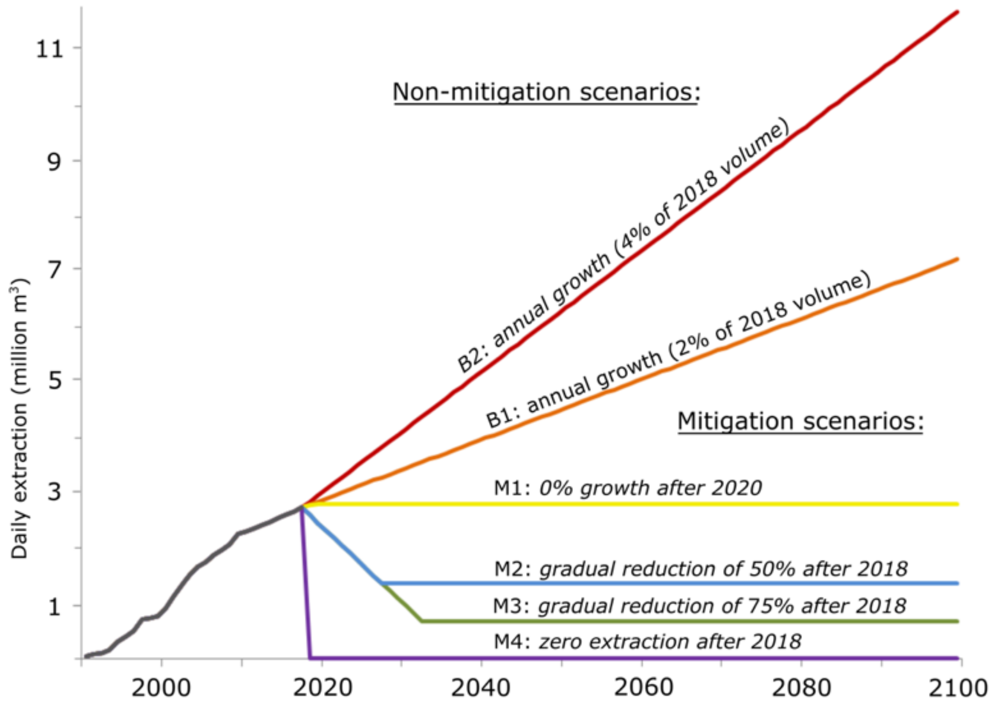


Figure 8. Total modelled daily ground water extraction from 1991 to 2100 in the Mekong delta for each subsidence scenario after 2018 following the non- and mitigation scenarios (Minderhoud et al. 2020)

2.2.4 The Mekong delta Socio-economic Pathway (MSP) scenarios

A combination of the SSP projections from IMAGE, the RCP scenarios, and the subsidence scenarios would result in multiple large complex systems. However, there is common ground between the three scenarios. For example, a green SSP scenario leads to a low radiative forcing from low greenhouse gas emissions and a low subsidence rate from low rates of ground water extraction. Therefore, the SSP, RCP and Subsidence scenarios were connected in coherent sets of MSP (Mekong delta Socio-economic Pathway) scenarios, based on the common drivers behind the three scenario components (*Table 3*).

MSP 1 reflects the 'best-case' pathway: society has become extremely sustainable and has the means to achieve this level of sustainability. Emissions are low, following the RCP 2.6 pathway, generating the associated sea level rise. This sustainable pathway also results in a substantial reduction in groundwater extraction by 75%, resulting in subsidence scenario M3.

MSP 2 reflects the 'middle of the road' pathway, when the Mekong delta develops as it has been done in the recent past. Accordingly, with moderate greenhouse gas emission levels following RCP 4.5 there is a moderate sea level rise, whereas groundwater extractions remain at current levels, resulting in subsidence scenario M1.

MSP 3 is a more negative scenario; sustainability is not a priority and there is little economic growth. Emissions are moderate, following the RCP 4.5 pathway and according sea level rise. The unsustainable practices result in an annual increase in groundwater extraction of 2%, resulting in subsidence scenario B1.

In MSP 5 there are high levels of economic development with no regard for sustainability. Accordingly, with high greenhouse gas emissions levels following RCP 8.5. The economic growth results in an annual increase in groundwater extraction of 3%, resulting in subsidence scenario B1.5.

Table 3. Overview of the MSP framework linking the SSP with the RCP and the Subsidence scenarios from Minderhoud et al 2020.

MSP	SSP	RCP	Subsidence scenario
1	1. Sustainability	2.6	M3 *75% total extraction reduction*
2	2. Middle of the Road	4.5	M1 *Stable extraction*
3	3. Regional Rivalry	4.5	B1 *2% annual extraction increase*
5	5. Fossil-Fuel Development	8.5	B1.5 *3% annual extraction increase*

2.3 Analysis of environmental feedback

The MSP framework was used for the environmental feedback analysis. By combining the three scenarios it is possible to provide a projection of the environmental feedback in the Mekong delta for the upcoming century.

For each MSP, the corresponding SSP future land use and population density map from the IMAGE model were digitally overlain with the appropriate land subsidence map in ARC-GIS. This shows which areas submerge below sea level, and at which point in time this happens. To determine critical elevation for land use and population a high detail map of current land use types (Minderhoud et al., 2017) was overlain to the present-day elevation data (Minderhoud et al., 2019). From this overlay the elevation ranges for which different land uses are feasible were determined. This relationship was used to analyse at which locations and at what future moment the land use and population according to the SSP scenario is affected by land subsidence feedback, and thus lead to local adaptation of the SSP projections.

The land use types analysed are agriculture (rice) and urban area, and population settlements (urban and rural). The area rice is given as a fraction per grid cell, so if the value 0.5 is given then 50% of the cell's land use has been allocated to rice, which means that in the grid cell there is 50 square kilometres of land allocated to rice. Population is given as an absolute number of inhabitants living within a grid cell. In the analysis: land use, population and elevation were compared at ten-year time intervals, for the years: 2040, 2060, 2080, and 2100, to display the future trend for each MSP. Results were calculated as total land use or population per time slice for each MSP covering the entire delta, as well as maps indicating the effects of sea level rise and relative sea level rise on the projections of land use and population.

For these analyses the following steps were taken: Firstly, the future relative sea level rise (RSLR) was determined. This was done by combining the land subsidence with the RCP-SLR in ARC-GIS. For the local sea level rise according to the RCP scenarios in IMAGE, data points were taken along the coast of the Mekong delta, and from these an average value was determined. From the result, the extend of potential flooding was determined as area below sea level, assuming that there is no flood defence or embankment.

Secondly, the estimations of population and land use were projected on the Mekong delta, for comparison to the relative sea level rise. The overlay of the IMAGE maps with the relative sea level rise was performed for one IMAGE cell at a time, because there is a very high resolution for the elevation map and a lower resolution for the global models and these need to be combined. This was then analysed with the critical boundary values for land use and population to demonstrate where additional measures could be required and therefore the accuracy from the SSP projections. Elevation is the variable in this analyses, not other parameters such as distance to a main road etc. or else it would become too complicated.

Finally, the projections for population and other land use were estimated according to the land available when relative sea level rise is taken into account. To achieve this assessment of the IMAGE data, the cell size of the elevation data was transformed to the cell size of IMAGE. When 50% of the elevation of an IMAGE grid cell is below sea level it is assumed that the entire grid cell is below sea level. So, if 49% of the grid cell is below sea level it is assumed that the entire grid cell is above sea level. For this research it is not necessary to show where the cities or rice will be placed, instead it is important to show the amount of available land for a certain land use. This shows the accuracy of IMAGE.

2.3.1 Evaluation of the difference between the results from the MSP and SSP

Final evaluation of this research was to compare the results from the MSP with the original results for the SSP scenarios produced by IMAGE in the Mekong delta. These MSP results indicate which areas are too wet for its allocated land use. This observation was performed for the entire delta. The results then provide an indication to what extent the projections by IMAGE for each SSP are not valid for the Mekong delta, due to ignoring environmental feedback of land subsidence resulting from these SSP projections. This demonstrates the importance of the impact for local environmental feedback in IMAGE land use and population projections at the regional scale.

3. Results

This section of the research first describes the projections of land use, e.g. rice, and population for different MSPs. Secondly, it shows the projections of relative sea level rise and the impact from relative sea level rise on the land use opportunities in the Mekong Delta. Thirdly, the impact from relative sea level rise on the population and its resources is demonstrated, indicating the extent of the mismatch between the SSP projections of land use and population compared to the feasible land use and population density, when taking the effects of relative sea level rise into account. This mismatch will be further elaborated upon in the discussion section.

3.1 Projection of land use and population

The projections by IMAGE for the population and cultivation of rice for each MSP are shown in *Figure 9*, until the end of this century. The results for rice are quite similar throughout the years and between the different MSP's, there is a difference of 3.4% between the maximum and minimum values (*Figure 10*, *Table 4*). Furthermore, there is little to none change in spatial distribution of the rice throughout the delta for each MSP (*Figure 9*). This means that according to IMAGE the Mekong delta is saturated when it comes to available land for rice cultivation. Thus, if it is not possible to use the area designated by IMAGE for rice cultivation then this will have a large impact as it is not possible to relocate the rice to another area in the delta, since the delta is saturated when it comes to rice cultivation. The incapability of doing so will provide pressure on other regions, as the demand for rice is still there. Therefore, IMAGE will force land use to change elsewhere to compensate for the shortage in rice, ensuring overall rice accounting in the region surrounding the Mekong delta will add up (PBL, 2019).

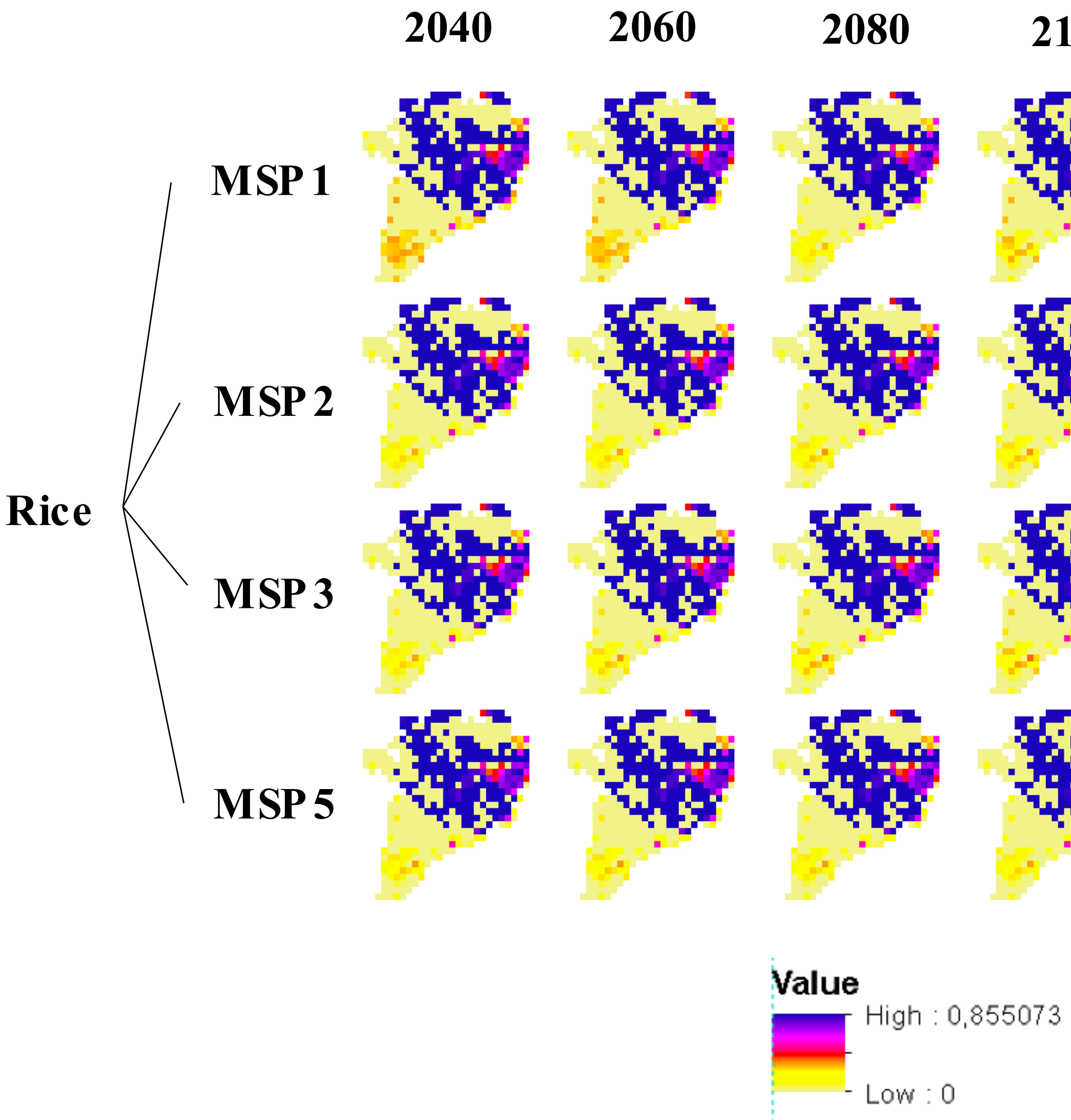


Figure 9. Projection of rice (in fraction) in the Mekong delta by IMAGE for each MSP and time slice

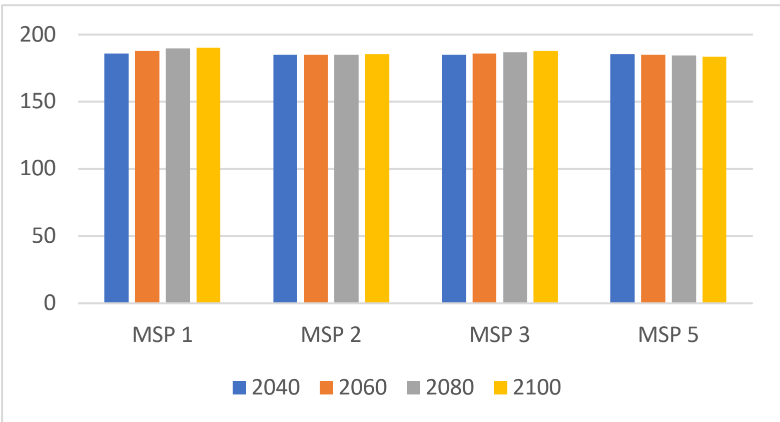


Figure 10. Total surface of projected Rice (in 10^4 m^2) for each MSP and time slice

Table 4. Total surface of projected Rice (in 10^4 m^2) for each MSP and time slice

Rice	*2040*	*2060*	*2080*	*2100*
MSP 1	186	188	190	190
MSP 2	185	185	185	185
MSP 3	185	186	187	188
MSP 5	185	185	184	184

The results of the projection for population by IMAGE are more distinctive for each MSP. The narrative of each MSP can be observed in the population data from IMAGE, and is shown in *Figure 11, 12,* and *Table 5* in a similar manner as the rice data is shown.

MSP 1 starts out similarly to the current situation, with a population of roughly 20 million inhabitants for the delta in 2040, then the number is almost cut in halve to 11 million inhabitants in 2100. What can be clearly observed is the migration to the urban areas (*Figure 11)*. This is similar to the global narrative of MSP 1, where a decrease of population together with high levels of urbanisation is expected.

MSP 2 shows a less dramatic trend for population than MSP 1. The population decreases to 15 million inhabitants, and the urbanisation rate is lower. Furthermore, there is a steep drop in rural and overall population (*Figure 11,12*; *Table 5*).

MSP 3 is a different story: The number of inhabitants in the Mekong delta stays roughly the same in all time slices (*Figure 11,12; Table 5*). Contrary to the other MSPs, there is a large rural population for MSP 3.

MSP 5 is very similar to MSP 1 (*Figure 11, 12; Table 5*). It follows the same trend for overall population and rate of urbanisation, the decline of overall population. This fits the narrative that MSP 5 has a very similar future projection for population as MSP 1.

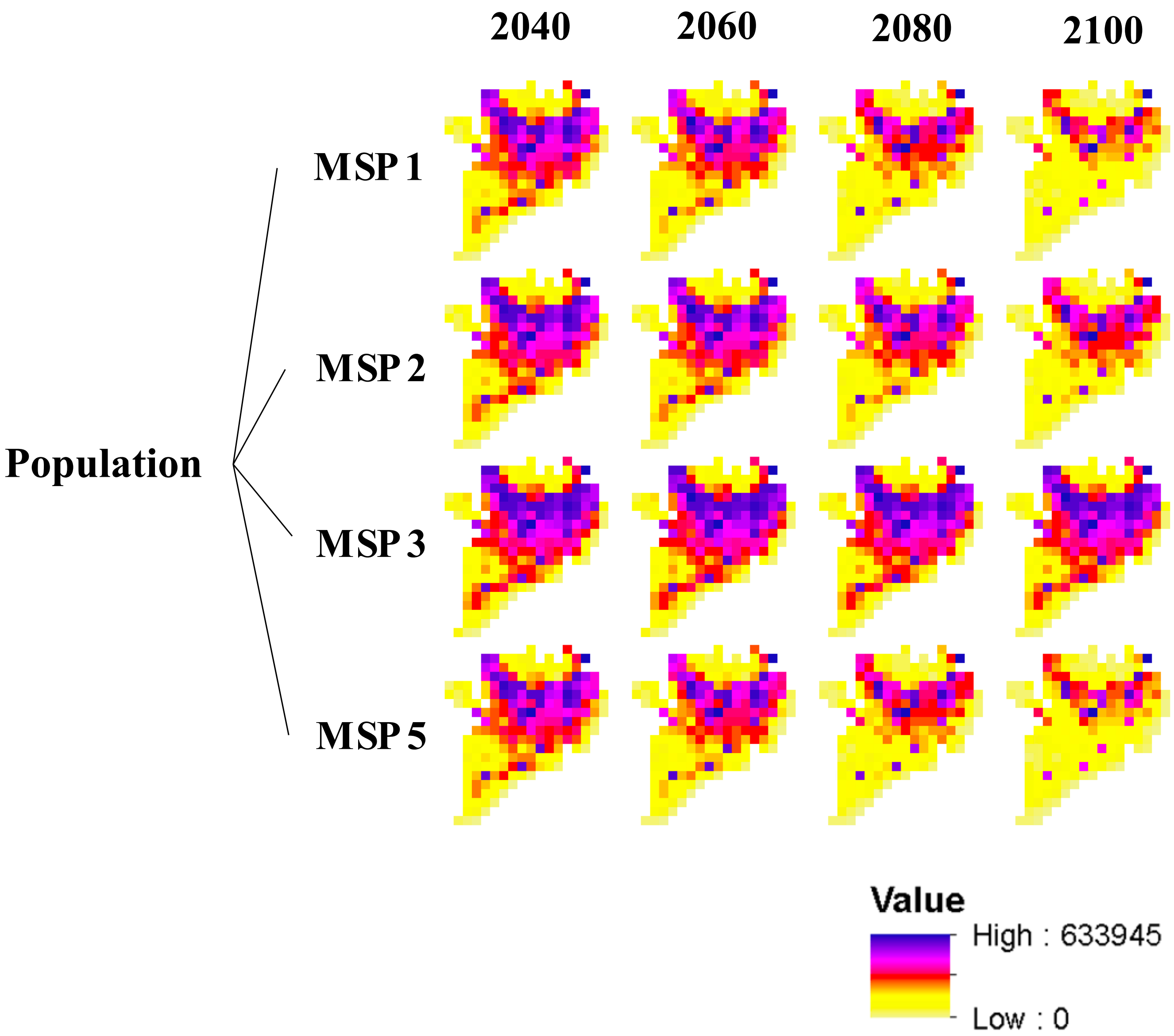


Figure 11. Projection of the population in the Mekong delta by IMAGE for each MSP and time slice, given in number of inhabitants

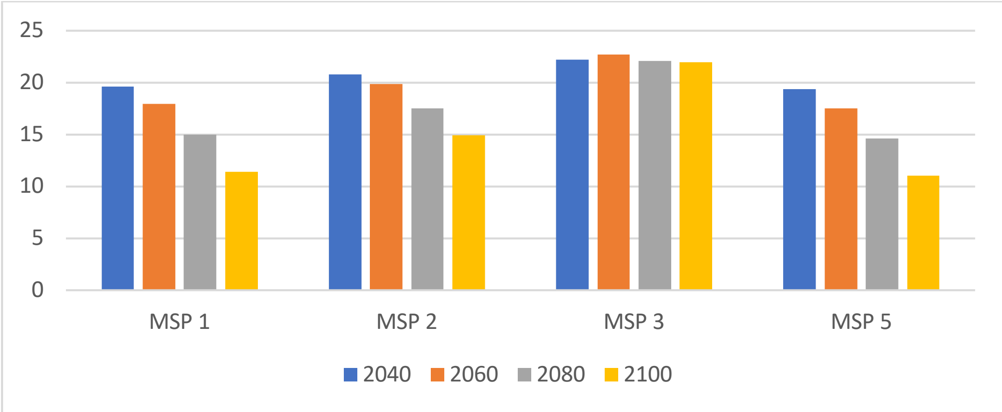


Figure 12. Total projected population (in millions) for each MSP and time slice

Table 5. Total projected population (in millions) for each MSP and time slice

Population	*2040*	*2060*	*2080*	*2100*
MSP 1	19.6	17.9	15.0	11.4
MSP 2	20.8	19.9	17.5	14.9
MSP 3	22.2	22.7	22.1	21.9
MSP 5	19.4	17.5	14.6	11.0

3.2 Projection of relative sea level rise

This section will discuss the projection of relative sea level rise for each MSP by first showing the current elevation, then showing the sea level rise from IMAGE, and finally adding the land subsidence from Minderhoud for the relative sea level rise.

Currently, 0,76% of the delta is located under sea level. More than 90% of the delta has an elevation lower than 2 metres (*Figure 13)*, making the delta vulnerable to relative sea level rise. *Table 6* shows the sea level rise for each RCP scenario. RCP 2.6 corresponds with MSP 1, RCP 4.5 corresponds with MSP 2 and 3, and RCP 8.5 corresponds with MSP 5.

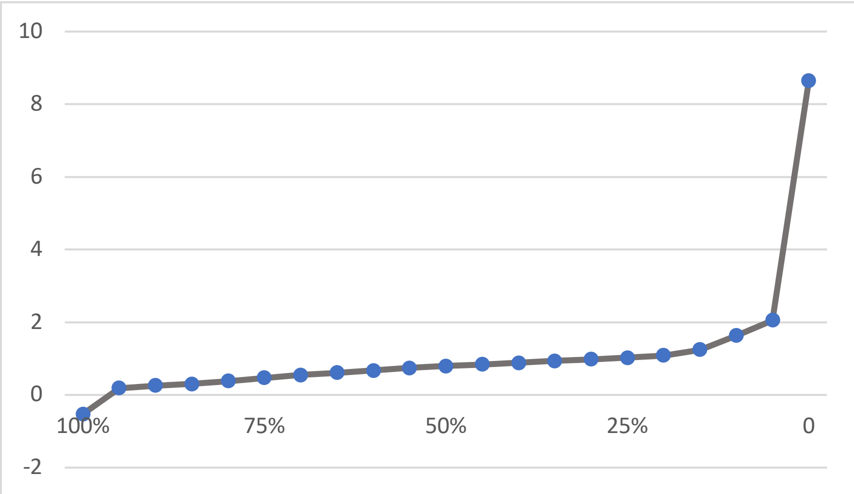


Figure 13. Percentile of original elevation in the Mekong delta in metres

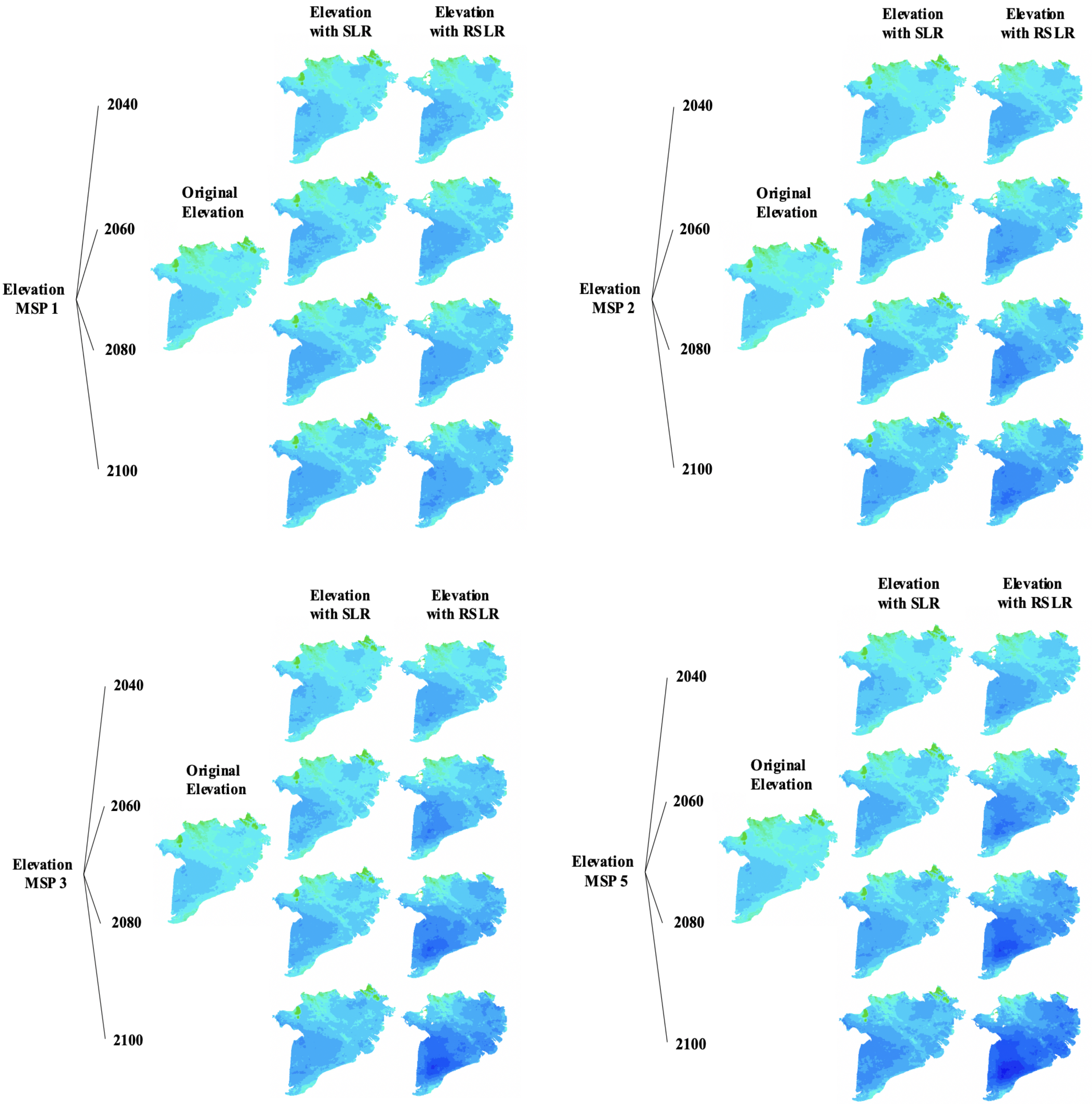
Table 6. Average sea level rise of the Mekong Delta for each RCP scenario in metres.

RCP	**2040**	**2060**	**2080**	**2100**
2.6	0.15	0.26	0.35	0.44
4.5	0.16	0.28	0.41	0.56
8.5	0.20	0.35	0.57	0.83

Figure 14 shows the evolution for the elevation of sea level rise and relative sea level rise throughout the different time slices for each MSP, comparing the elevation for each time slice between the current elevation and the elevation with sea level rise and relative sea level rise taken into account. MSP 1 already shows some change in elevation, and as expected for every MSP the change in elevation becomes larger. Whereas for MSP 1 there is little impact by land subsidence, this becomes more prominent in MSP 2, and very clear in MSP 3 and 5. In the latter it is extremely clear that the land subsidence has a large impact.

To compare the changes in elevation for each MSP and the added impact from land subsidence, *Figure 15* shows the percentile of elevation of each MSP for sea level rise and relative sea level rise. The 95% in this graph means that 95% of the Mekong delta at a certain time slice is located at an elevation higher than the value of the graph at that point. Because, the minimum and maximum values (0% and 100%) are outliers, and the trend of the impact on the delta is more accurately shown in this manner.

Figure 14 adds to the narrative as shown by the maps *Figure 9* and *Figure 11* for the MSP's. *Figure 15* shows that for the 95th percentile in MSP 1 there is some decrease of elevation with sea level rise, almost half a metre, and with relative sea level rise there is a decrease of roughly half a metre, so slightly more. For MSP 2 there is roughly half a metre of change considering the sea level rise, while there is almost a full metre of change caused by relative sea level rise, indicating a large contribution due to land subsidence. In MSP 3 the change becomes more extreme for the relative sea level rise, with roughly 1.5 metres of change. While the sea level rise change is the same as in MSP 2, since they share the same RCP scenario. The most dramatic change of elevation takes place in MSP 5: with roughly ¾ of a metre change caused by sea level rise and roughly 2 metres of change by relative sea level rise. For the other percentiles the impact from sea level rise and relative sea level rise is less pronounced.



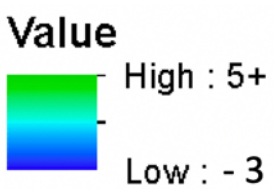


Figure 14. Evolution for the elevation (in metres) of SLR and RSLR throughout the different time slices for each MSP

Figure 15. Percentile of elevation (in metres) for each MSP for SLR and RSLR

3.3 Impact from relative sea level rise on the land use opportunities in the Mekong Delta

This section shows how the expected relative sea level rise alters the land use opportunities in the Mekong delta. *Figure 16* shows the impact of sea level rise and relative sea level rise on the rice cultivation in the Mekong Delta and *Figure 17* shows the impact of sea level rise and relative sea level rise on the population in the Mekong Delta. Remarkably, even in the most sustainable scenario MSP 1 land use and population are heavily affected by relative sea level rise in 2100. *Figure 18* and *Table 7* show that 28% of the projected rice and 31% of the projected population are located below sea level when relative sea level rise is taken into account. For MSP 2 59% of the rice and 60% of the population are located below sea level when relative sea level rise is taken into account. For MSP 3 this number goes to 73% for rice and 72% for the population. While the most dramatic number is for MSP 5, with 84% of rice below sea level and 80% of population below sea level when relative sea level rise is considered.

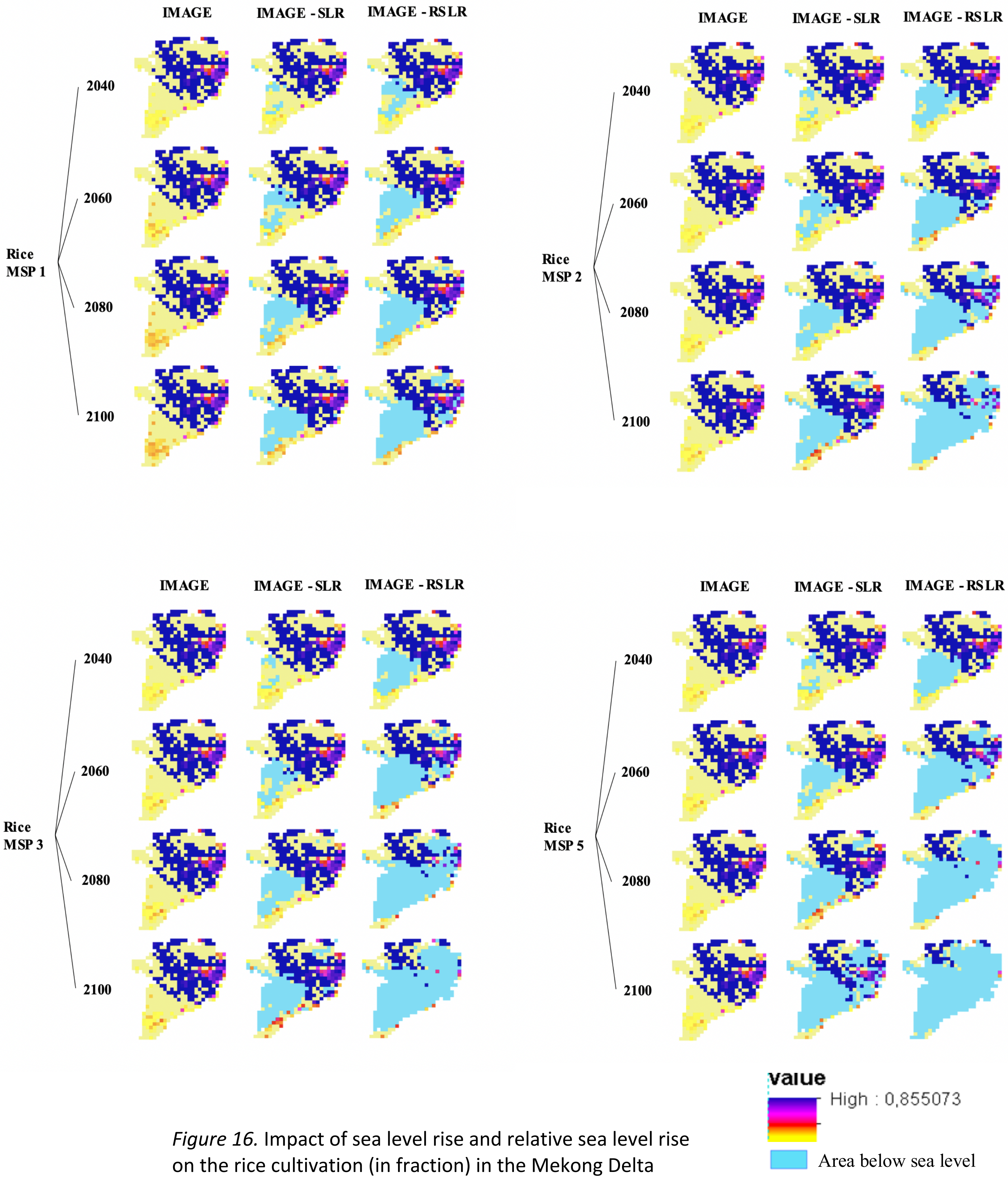


Figure 16. Impact of sea level rise and relative sea level rise on the rice cultivation (in fraction) in the Mekong Delta

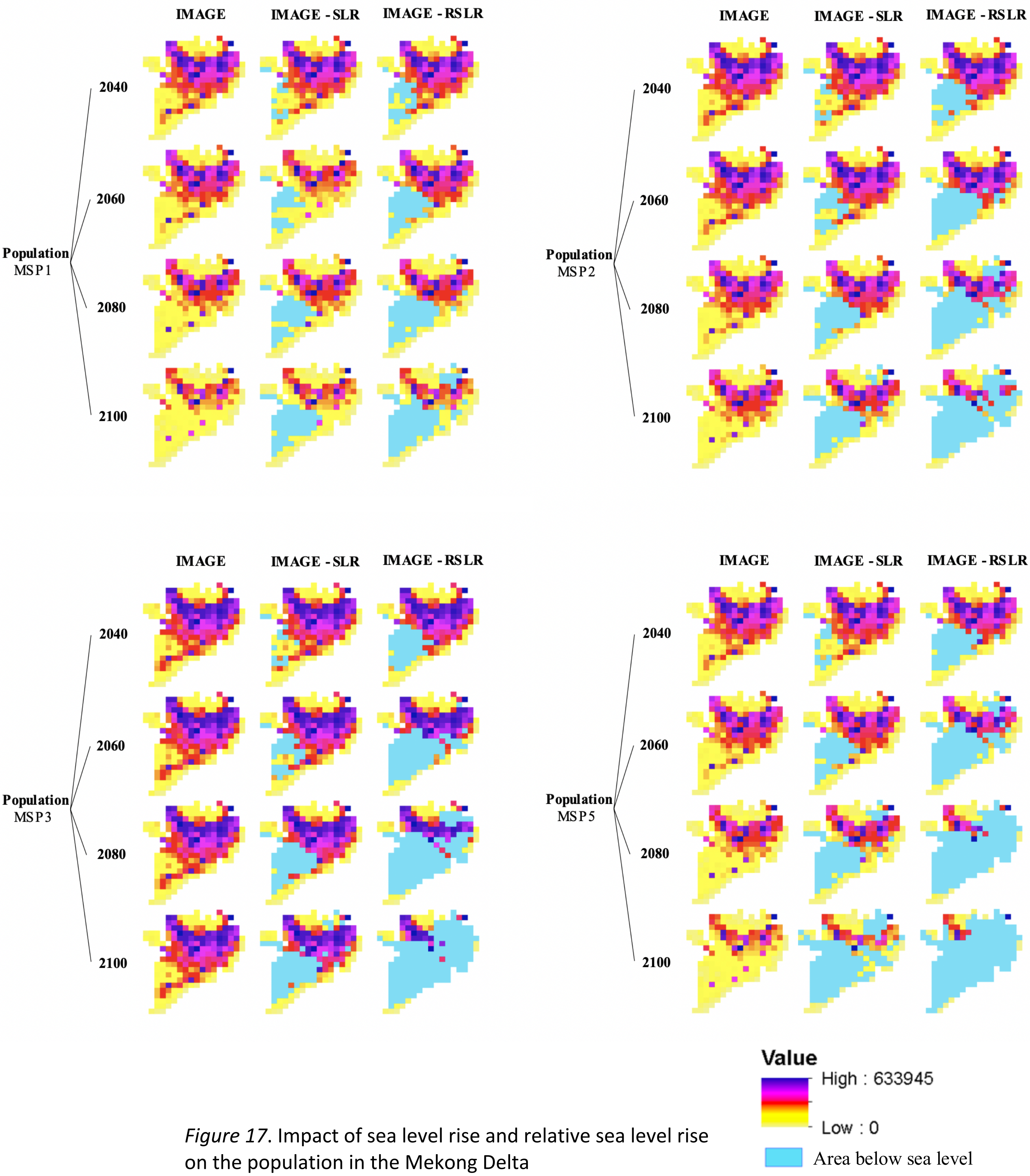


Figure 17. Impact of sea level rise and relative sea level rise on the population in the Mekong Delta

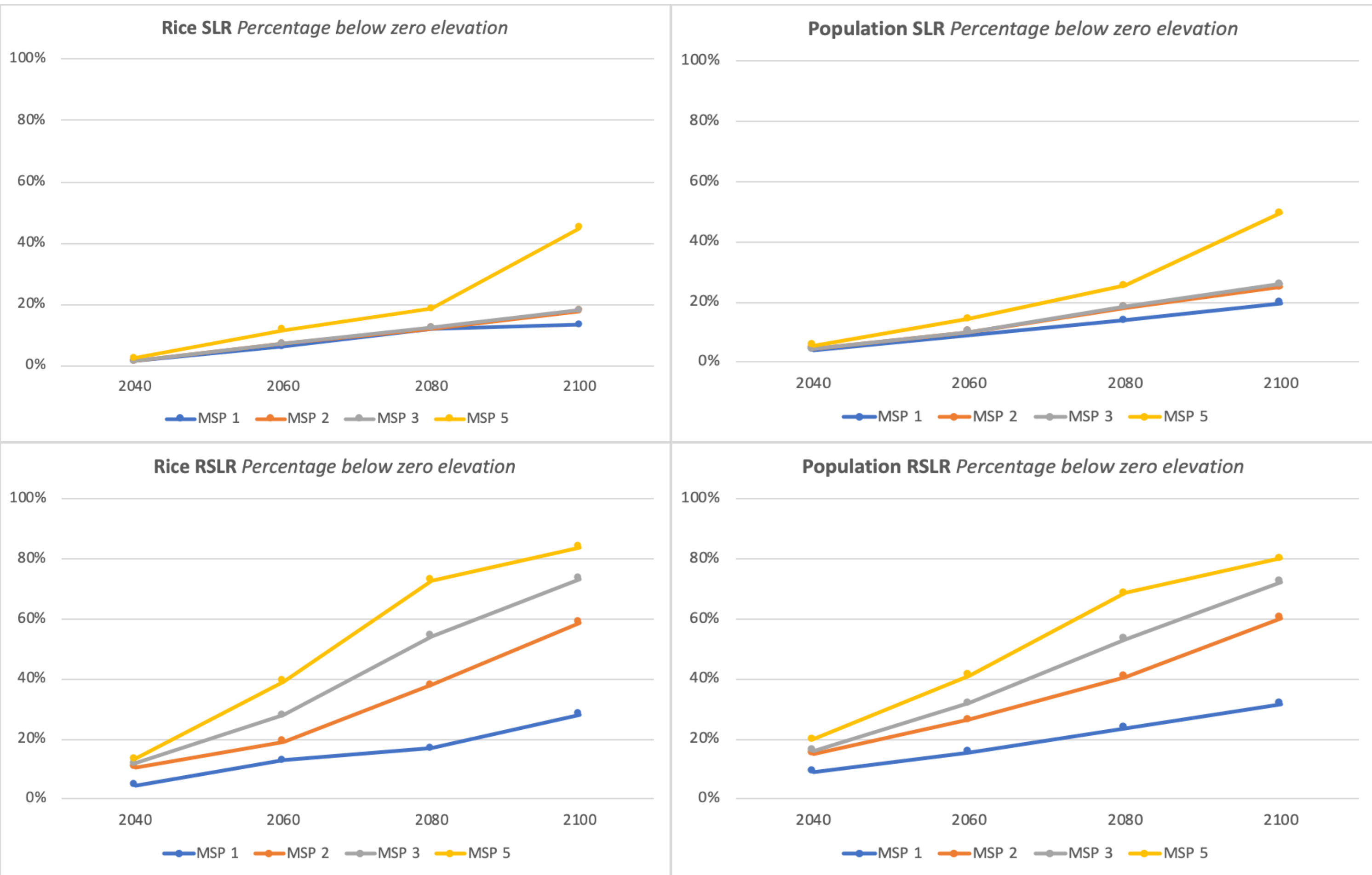


Figure 18. Percentages of Rice and Population below zero elevation for different MSP scenarios due to SLR and RSLR, and for different time slice

Table 7. Percentage below zero elevation for the Rice SLR, Rice RSLR, Population SLR, and Population RSLR for each MSP and time slice

Rice SLR Percentage below zero elevation

	2040	2060	2080	2100
MSP 1	1,49%	6,28%	12,08%	13,27%
MSP 2	1,46%	7,14%	12,25%	17,83%
MSP 3	1,47%	7,24%	12,47%	18,10%
MSP 5	2,41%	11,55%	18,62%	44,96%

Population SLR Percentage below zero elevation

	2040	2060	2080	2100
MSP 1	4,12%	8,99%	13,84%	19,61%
MSP 2	4,44%	9,99%	18,07%	25,00%
MSP 3	4,41%	10,15%	18,35%	25,83%
MSP 5	5,45%	14,33%	25,32%	49,49%

Rice RSLR Percentage below zero elevation

	2040	2060	2080	2100
MSP 1	4,62%	12,80%	16,92%	28,06%
MSP 2	10,61%	19,00%	37,99%	58,76%
MSP 3	11,82%	27,88%	54,18%	73,27%
MSP 5	13,28%	39,22%	72,85%	84,04%

Population RSLR Percentage below zero elevation

	2040	2060	2080	2100
MSP 1	9,13%	15,67%	23,68%	31,66%
MSP 2	15,20%	26,33%	40,82%	60,35%
MSP 3	16,16%	31,89%	53,26%	72,26%
MSP 5	19,86%	41,30%	68,69%	80,26%

3.4 Estimated elevation for projected population and land use

To determine the critical height for when populations and rice are affected by future relative sea level rise, current extents of these projections were compared to elevation above sea level. However, it was not possible to statistically find a critical height above sea level for rice or population by combining the elevation data with the land use data from IMAGE and applying zonal statistics, as the minimum elevation for rice and population was approximately 0. Therefore, elevation at sea level was used as critical elevation, where I assume that flooded land is not appropriate to use without measures in place. However, it is possible that there is a critical height for the category population or rice, as nearing the sea level means an increased risk for flooding and salinization and other factors (Wassmann et al., 2004 & Paik et al., 2020). Thus, this chapter will classify the elevation of the rice and population projection of IMAGE for each MSP, in intervals of 0.5 metres. This classification is shown in *Figure 19, 20, 21,* and *22*. Furthermore, the classification of elevation allows to observe the effort required to protect the delta from flooding or other impacts from (relative) sea level rise, as a lower elevation requires more effort to be protected than a higher elevation. A classification value of - 1 means that the projected rice or population is located between an elevation of - 1 to - 0.5 metres. So, a classification value of 0 means that the projected rice or population is located between an elevation of 0 to 0.5 metres, and so forth.

The stacked graphs below support the previously discussed narratives of the MSPs and provide an overview of the impact from relative sea level rise on the population and its resources. The extents of rice only vary slightly among the different MSPs and time slices, by roughly 3% between the highest and the lowest value. Therefore, the results are expressed in percentages. For the population data this is not the case, there are large differences between the different projections. Therefore, population data is expressed in number of inhabitants.

The trend for the estimated elevation of projected population is similar to the trend observed in the section covering the impact from relative sea level rise on the land use opportunities in the Mekong Delta. The estimated elevation for the projected population and land use when affected relative sea level rise is dramatically lower compared to the estimated elevation when affected by only the sea level rise. This trend is less pronounced in MSP 1; however, it can clearly be observed in MSP 2 and 3; in MSP 5 this trend is even more pronounced than in MSP 2 and 3 (*Figure 19, 20, 21,* and *22*).

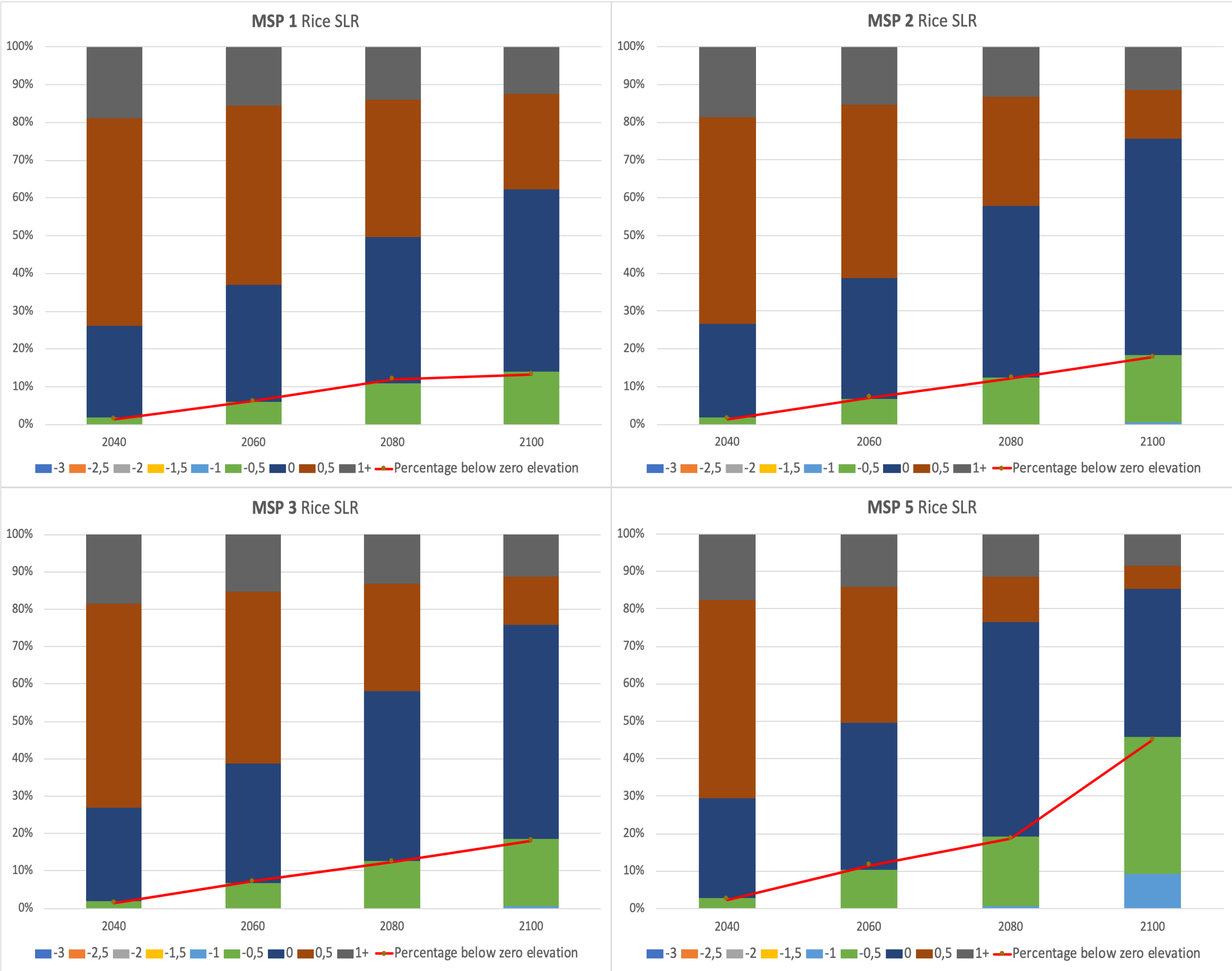


Figure 19. Classification elevation distribution (in %) of rice relative to sea level for each MSP and time slice

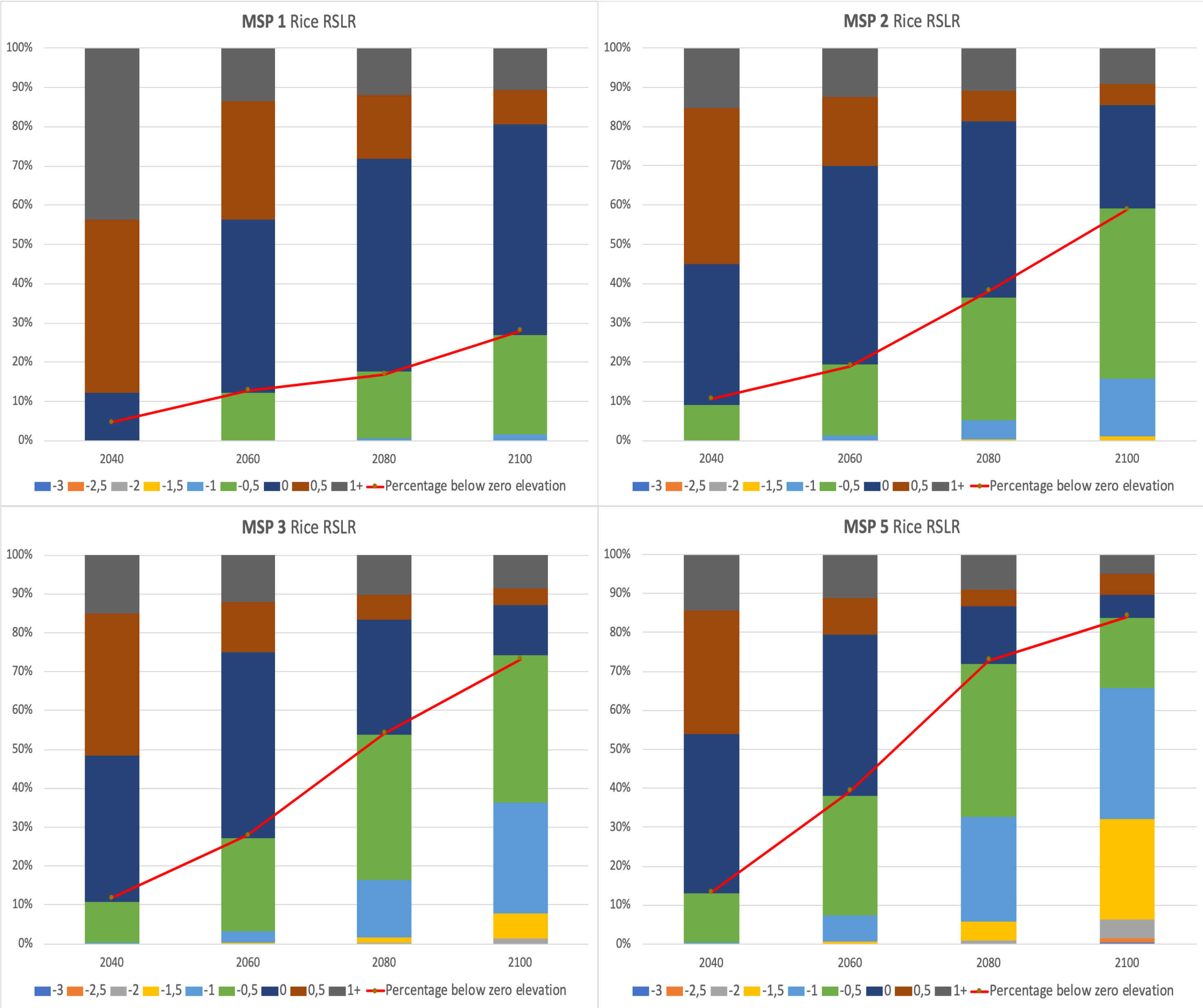


Figure 20. Classification elevation distribution (in %) of rice relative to sea level for each MSP and time slice

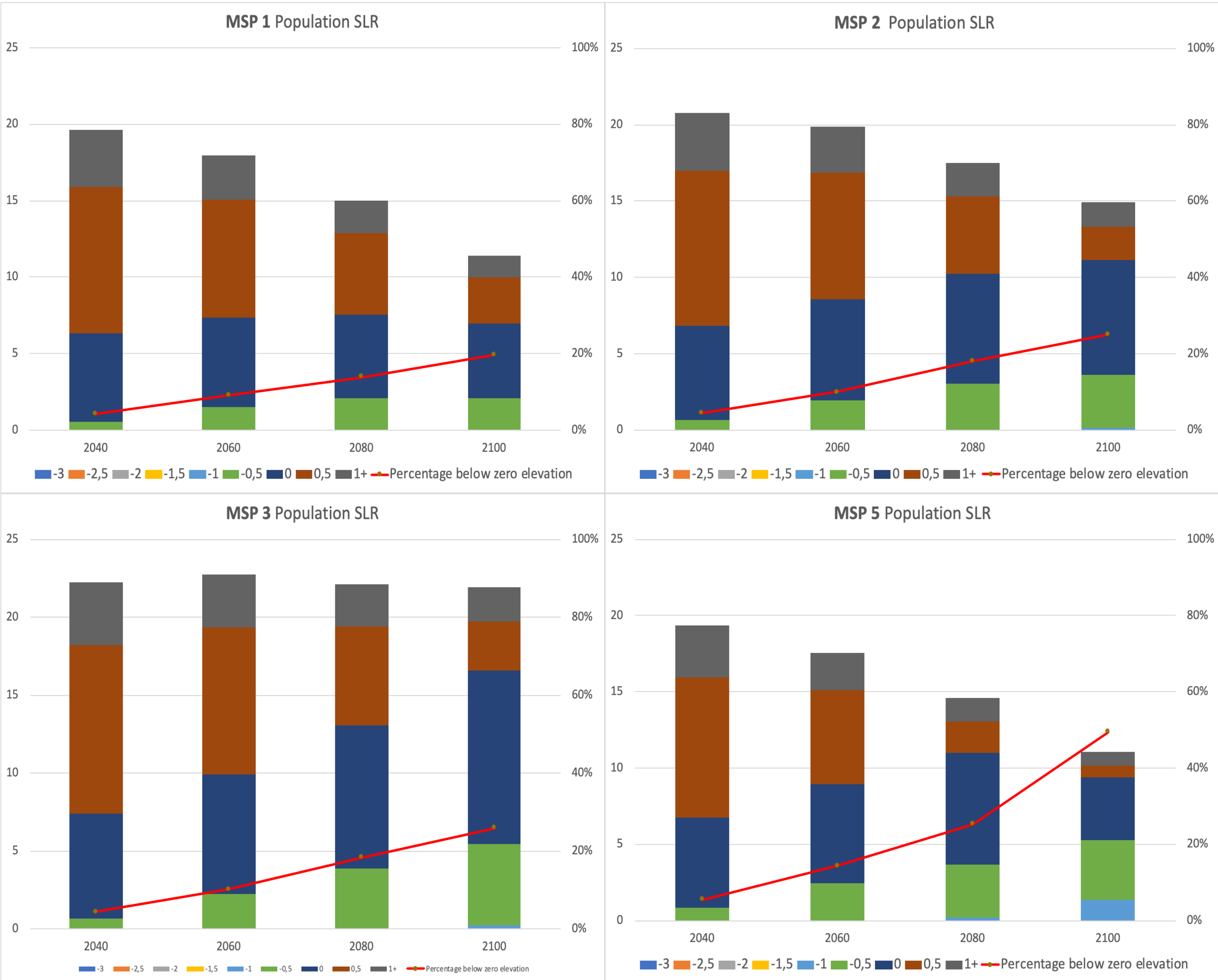


Figure 21. Classification elevation distribution (in millions) of population relative to sea level for each MSP and time slice

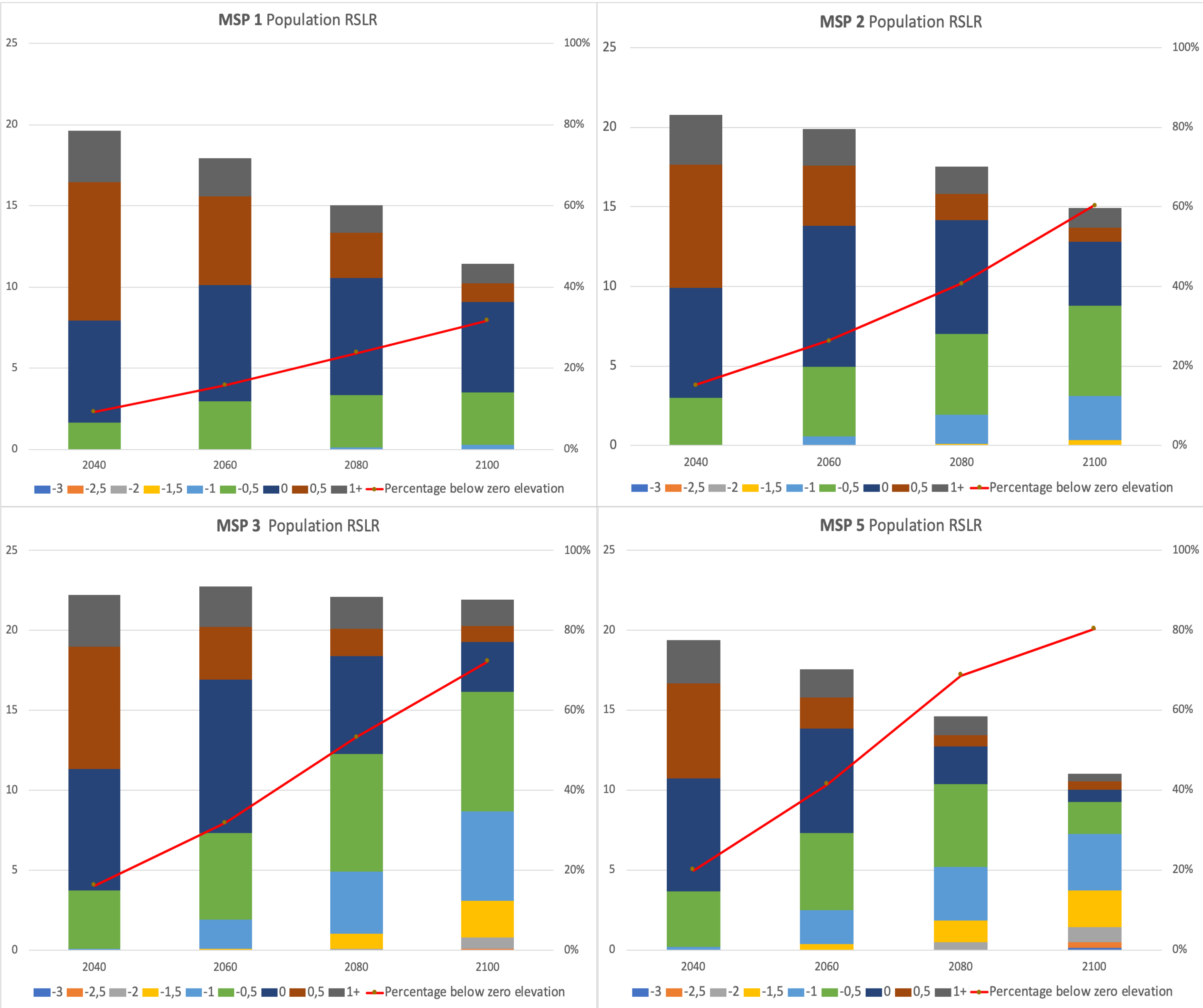


Figure 22. Classification elevation distribution (in millions) of population relative to sea level for each MSP and time slice

4. Discussion

The discussion chapter will cover the limitations of this research. It will answer the research question and the sub questions. Furthermore, it will explore if the hypothesis still holds. Moreover, this chapter will briefly cover possible (local) mitigation and adaptation: to manage pressures caused by the impact from relative sea level rise on the Mekong delta and display management and policy implications. Finally, the scientific implications of this research are shown and suggestions for future research are provided.

4.1 Limitations of this research

Most of the assumptions and limitations of this research have already been mentioned throughout. However, these will be covered in more detail in this section.

Firstly, the “bathtub” model for the sea level rise. It is assumed that the Mekong delta will fill up uniformly when the sea level rises. We assume one constant average per time slice for each MSP. Even though this is not the case in reality, as shown by the RCP sea level rise data: along the coast of the Mekong delta variations in sea level rise are displayed. For this research the ‘bathtub’ model is accurate enough. It helps to create an understanding of the importance of local environmental feedback.

Secondly, to achieve an assessment of the IMAGE data the cell size of elevation data had to be transformed to the cell size of IMAGE. When 50% of the elevation of an IMAGE grid cell is projected to be below sea level, then it is assumed that the entire grid cell is below sea level. So, if 49% of the grid cell is below sea level it is assumed that the entire grid cell is above sea level and for 51% of the grid cell below sea level it is assumed that the grid cell is completely below sea level. Thus, 51% and 80% have the same impact in this research, even though in reality this is not the case. Other methods would be to apply cubic convolution, bilinear interpolation, or use the nearest neighbour method. These methods would have decreased the accuracy of the research and are not suited for the increasing the cell size of the elevation projections to the cell size used in IMAGE.

Thirdly, the subsidence model is driven by ground water extraction. The model only uses ground water extraction as the driver for land subsidence, instead of adding anthropologic and environmental subsidence. Because ground water extraction is the main driver for land subsidence and can be mitigated (Minderhoud, 2019).

These limitations are all within the constraints set by IMAGE. The aim of this research is to improve the current SSP scenarios at the regional (c.q. delta) scale by downscaling SSP scenarios to the Mekong delta, and quantifying the feedback from land subsidence to SSP projections. This should provide recommendations to the modelling groups creating SSP-implementations whether this regional-scale environmental feedback needs to be incorporated to provide sound estimations of land use in the future. Thus, the results of this research are reliable enough to provide an answer to the research questions.

4.2 Discussion of the research question and sub questions

The projections for rice cultivation are quite similar throughout the different MSP's and time slices. There is more variation between the different scenarios for the population distribution and numbers, which is covered in the results section. The projections for relative sea level rise increase as expected throughout the years and become increasingly higher from MSP 1 to 5. This narrative is examined in the results section.

The land use opportunities in the Mekong delta are negatively impacted by the expected relative sea level rise. Large parts of the Mekong delta are likely to become flooded in the future, even for the most sustainable scenario MSP 1: 28% of the projected rice and 32% of the projected population are estimated to be located in areas with an elevation beneath sea level in 2100. This means that 3.6 million inhabitants will likely require protection or will have to migrate to higher elevated areas, and roughly 5.3 thousand square kilometres of rice land are likely to be located under sea level. Furthermore, in MSP 2, 59% of the projected rice and 60% of the projected population are estimated to be located below sea level in 2100. Thus, almost 10.9 thousand square kilometres of rice land and 9.0 million inhabitants are likely to be located in these areas. Moreover, in MSP 3, the opportunities decline further: 73% of the projected rice and 72% of the projected population are estimated to be located in areas with an elevation below sea level in 2100. This means that 15.9 million inhabitants and 13.7 thousand square kilometres of rice land are likely to be located in areas below sea level. On top of this, the estimation for the land use opportunities in MSP 5 is estimated to drop further to 84% of the projected rice and 80% of the projected population. So, 15.4 square kilometres of rice land and 8.9 million inhabitants are likely located in these sub-zero elevation areas.

Additionally, a trend is observed between the percentages of land use located beneath sea level for the projections of rice and population. At first, there is a larger percentage of projected population located in a sub sea level area than there is for projected rice. However, with relative sea level rise in MSP 3 and 5 for the time slices 2080 and 2100 there is a higher percentage of projected rice located in sub sea level areas. Because the projected population is for one part located in areas with a relatively low elevation in the more southern part of the delta and for the other part in the northern areas with a relatively high elevation. While projected rice is relatively more distributed across the delta when compared to the projected population.

The population and its resources are likely to be affected heavily by the relative sea level rise throughout the different MSP's. As mentioned above, large areas of the Mekong delta are likely to be located beneath sea level. However, this does not entirely display the impact from relative sea level rise, as it does not show to what extent the area is beneath sea level or how vulnerable the area above sea level is to relative sea level rise. Therefore, the estimated elevation for the projected land use and population was calculated. This setup allows for observation of multiple elevations of land use in the Mekong delta. Thus, showing the impact of relative sea level rise on the population and its resources, e.g. projected rice.

The estimated elevation for projected land use and population after relative sea level rise follows the same trend as the expected impact by relative sea level rise on land use opportunities. Moreover, it shows the extent of this impact further. As expected, there is relatively more effect by relative sea level rise on the population and its resources as the relative sea level rise increases from MSP 1 to 5. The total extent of this effect is shown in Figure 19, 20, 21, 22.

Combined, these results display a clear mismatch between the SSP projections of land use and population and the projections by the MSP's for land use and population estimations. As mentioned above, in the future large areas of the delta are likely to be located in areas with an elevation below sea level. Since local environmental feedback is not taken into account in IMAGE, relative sea level rise is not included in future projections of the Mekong delta. Therefore, there is a large mismatch between what land uses are likely feasible in the future for each MSP. Thus, the performance of IMAGE in a delta is not accurate enough to use for decision making, as up to 84% of the projected rice and 80% of the projected population are below sea level in 2100. Even in the most sustainable scenario MSP 1, it is estimated that 28% of the projected rice and 32% of the projected population are below sea level in 2100.

When projecting land use the projections of IMAGE are not accurate enough for policy making in delta areas. First of all, the distribution of land use will be unreliable and the total number of population and amount of rice cultivation in the delta incorrect: there will be a severe overestimation of the projected rice and population. Since, the impact from migration, because a large number of inhabitants would have to move to inhabitable areas if they are not protected, and a shortage of rice, as the Mekong delta is saturated when it comes to rice cultivation, are neglected in the projections from IMAGE. Therefore, it is not reliable to use IMAGE for regional projections of land use and population. Because, IMAGE and other Integrated Assessment Models are designed to model policy impacts globally: they do not to take into account (local) environmental feedback, e.g. land subsidence in delta regions. This limits their reliability to allocate land use or population in globally significant regions such as the Mekong delta.

4.3 (Local) Mitigation and adaptation measures

The aim of this research was to improve the current SSP scenarios at the regional (c.q. delta) scale by determination of environmental feedback effects on the SSP land use and population projections by IMAGE for deltas, using the Mekong delta as an example. The strong elevation feedback that emerged in my analyses also demonstrate that these results can be used for management and policy making, as they provide a better picture of the expected relative sea level rise and land use opportunities in the Mekong delta. Some suggestions will be given in this section by going over possible (local) mitigation and adaptation measures.

Mitigation for sea level rise can only be achieved on a global level, as it is caused by global carbon emissions and the Mekong delta or the country of Vietnam cannot solve this problem individually. This makes it difficult for local authorities to mitigate sea level rise, as it requires global cooperation and management and this is difficult for one, relatively small when compared to China and the United States of America, country, let alone delta region, to reach. Still, it is possible to lobby in the IPCC. However, the effectiveness of this mitigation method is likely to be relatively low. Furthermore, sea level rise has less impact in the delta region than land subsidence, as can be observed in the results section. The main driver in relative sea level rise is the land subsidence, fortunately this driver can be locally mitigated.

It is possible for the authorities to reduce the amount of ground water extraction in the Mekong delta, decreasing the rate of subsidence. An example of this would be to make sure that in MSP 5 the subsidence scenario B1.5, a gradual increase in ground water extraction of 3% per year, would be replaced by subsidence scenario in MSP 1: subsidence scenario M3, where the ground water extraction is reduced by 75%.

The percentage of projected rice under sea level would go from 84% to 75% and for projected population it would go from 80% to 71%. But the clearest impact of this measure can be observed in *Figure 23.* and *24.* The elevation values for the percentiles would increase, especially in 2100, where the elevation is more than a metre higher with the M3 subsidence scenario (*Figure 23*). The impact from relative sea level rise on the population and its resources would diminish dramatically (*Figure 24)*. The impact on rice and population might seem similar but there is a difference between them (*Figure 24*).

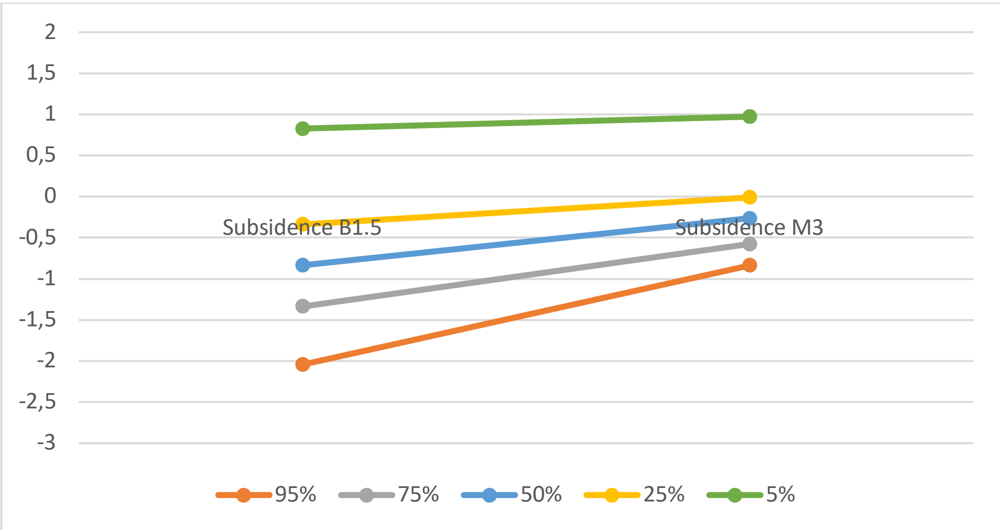


Figure 23. Effect of subsidence scenario M3 on the percentile of MSP 5 with the original subsidence scenario B1.5 in 2100 in metres

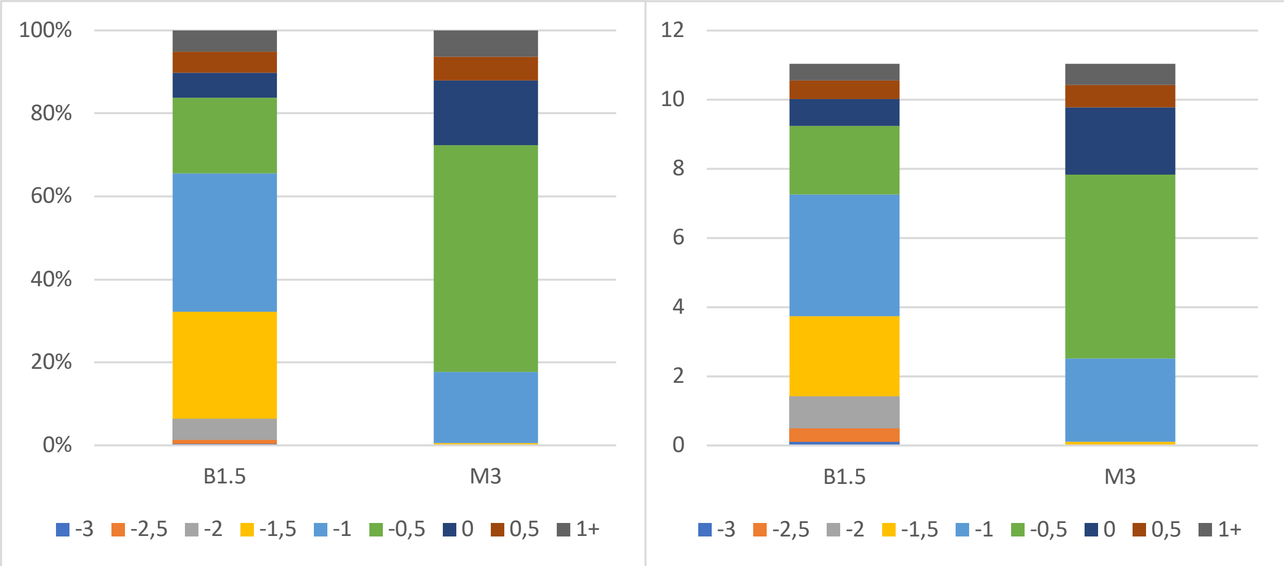


Figure 24. Classification Elevation distribution of rice (in %) and population (in millions) relative to sea level for different subsidence scenarios in MSP 5 for the year 2100

In the above scenario the mitigation effect on the projections for rice and population, caused by a reduction in ground water extraction, is not as large as the impact on the elevation. However, applying the same mitigation to MSP 3, replacing the B1 subsidence scenario with scenario M3, provides a different narrative: the percentage of projected rice under sea level would go from 73% to 39% and for projected population it would go from 72% to 42%, a much more dramatic change compared to the land subsidence mitigation in MSP 5. Because, in MSP 5 there is a larger impact from the sea level rise on the projections by IMAGE than in MSP 3.

The impact of this local mitigation on the elevation can be observed in *Figure 25* and *26*, the impact on elevation is not as large as in MSP 5 (*Figure 23*). However, there is still significant impact: in 2100 the elevation is almost a metre higher with the M3 subsidence scenario (*Figure 25*). Furthermore, the impact from relative sea level rise on the population and its resources is reduced by the decrease in ground water extraction (*Figure 26*).

Thus, this would not have an immediate impact on the percentage of projected rice and projected population. However, there are indeed significant benefits from this mitigation measure (*Figure 23, 24*). Furthermore, this mitigation measure reduces the impact on the projections from IMAGE by relative sea level rise more in MSP 3. Nonetheless, the impact on elevation and depth of projections are not affected as much as they would be in MSP 5 (*Figure 25, 26*). The land subsidence for MSP 5 is roughly twice as large as in MSP 3, so there is more impact on the elevation in MSP 5 by reducing the ground water extraction to the levels in subsidence scenario M3.

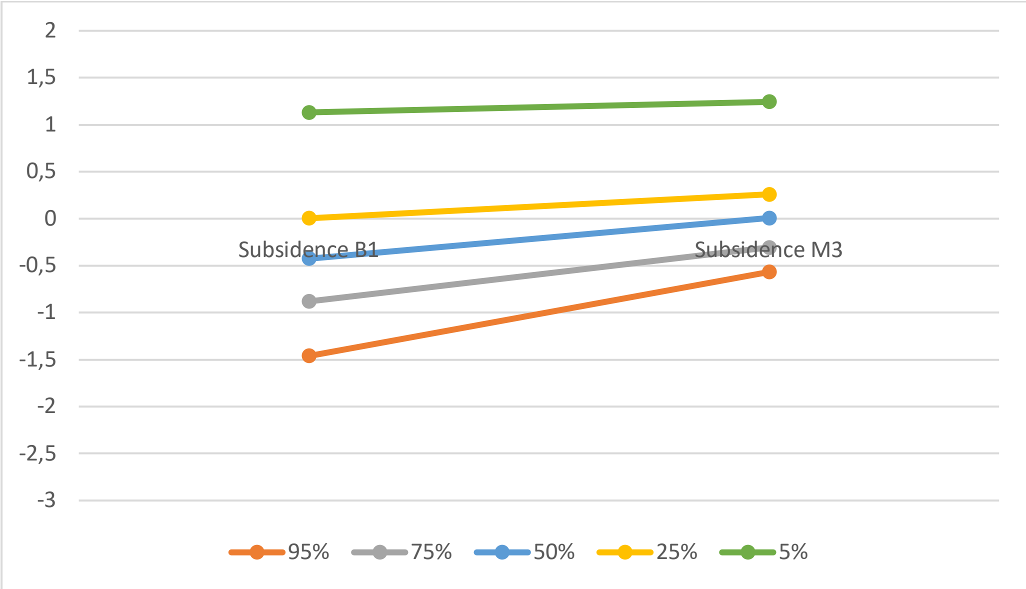


Figure 25. Effect of subsidence scenario M3 on the percentile of MSP 3 with the original subsidence scenario B1 in 2100 in metres

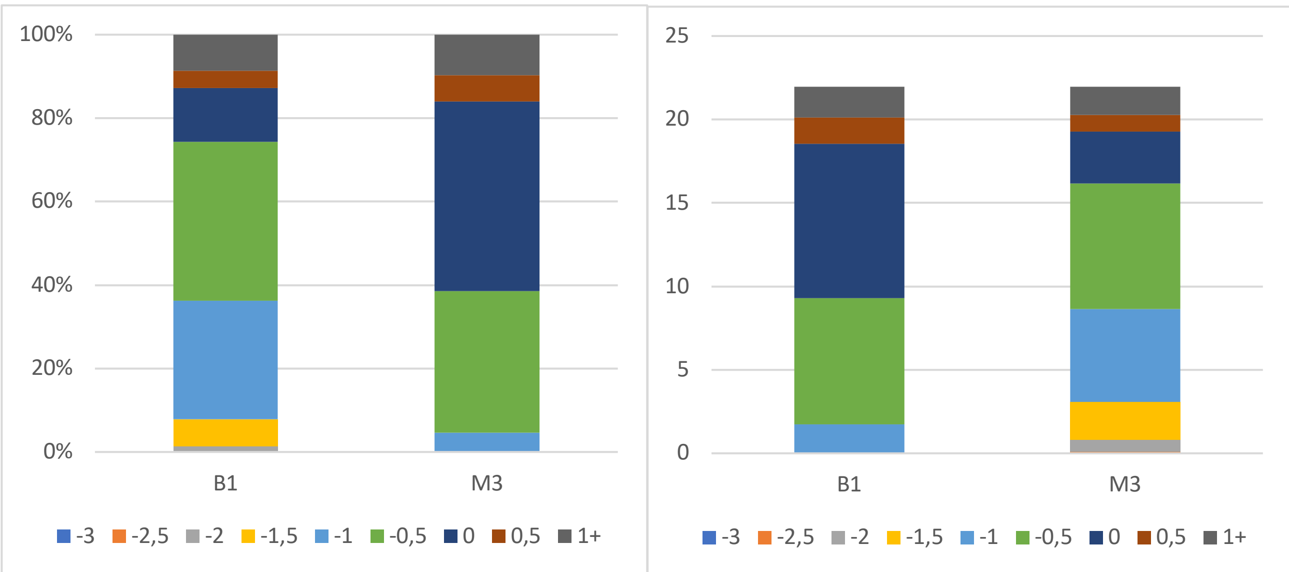


Figure 26. Classification Elevation distribution of rice (in %) and population (in millions) relative to sea level for different subsidence scenarios in MSP 3 for the year 2100

Another possibility would be to reduce the potentially adverse effects of relative sea level rise. For the projected population this is relatively easier than for the projected rice. Inhabitants of the Mekong delta can migrate to areas at higher elevations, or into urban areas where it is easier and more cost effective to protect high numbers of population as there is a higher population density. Each MSP would require a different migration pattern, for example MSP 1 is much more urbanised than MSP 3. This migration will have a large impact on the area that the inhabitants migrate, causing an array of new pressures regarding housing, food security etc.

Because the Mekong delta is 'saturated' when it comes to rice production, as shown by IMAGE, there is no option to relocate rice production to other parts of the delta. Therefore, IMAGE would have to force land use change elsewhere in the surrounding region to ensure overall rice accounting in the region when it cannot allocate rice to a grid cell in the Mekong delta, generating pressure somewhere else. Furthermore, it would be extremely expensive and difficult to dike the rice areas, since these are large and cannot be densified in a similar manner as the population can. Moreover, dikes will not protect the rice from salinization which negatively affects the yield (Wassmann et al. 2004 & Paik et al., 2020) and solving these problems would be very costly. An alternative solution would be to utilise salt resistance rice strains, however this bio-technology has not yet been perfected enough to be utilised on the scale required in the Mekong delta (Paik et al., 2020)

4.4 Scientific implications and further research

The scientific implications of this research are that this study shows the inaccuracy of IMAGE in delta areas, significant regions even on a global scale. Showing that IMAGE is potentially less reliable in projecting land use and population data down to delta regions for future SSP scenarios. This suggests that global integration assessment models, such as IMAGE, might be inappropriate for detailed local delta analysis, as it is not possible to downscale global SSP scenarios from IAM's one to one to regional delta areas. What could be incorporated into the integrated assessment models are global digital elevation models and sea level rise projections, increasing the reliability of the projections made by these models; integrating land subsidence on a global scale is considerably more complex. Thus, integrated assessment models can only be used on the global scale they were designed for. Projecting land use and population for (delta) regions requires separate downscale projections, as performed in this study and in Nicholls et al. (2016) for the Ganges-Brahmaputra-Meghna delta, Bangladesh.

There are several ways in which this research could be expanded further upon. First of all, the cost-effectiveness of the (local) mitigation and adaptation measures can be researched to show the impact and feasibility of these measures. Furthermore, the adaptation would have to be tailor made to the Mekong delta and the local factors on a municipal level, not on the level IMAGE is working on. Furthermore, it was not possible to find a critical height from the elevation and land use data above zero elevation. However, there is research that suggest there is a critical height above zero elevation for rice (Wassmann et al., 2004). The estimation for elevation of the projected land use and population allows for further research to apply their own critical height to the data in this research.

5. Conclusion

This research studied the environmental feedback effect of land subsidence for the projections of the SSP models in the Mekong delta region and for its inhabitants. By integrating the SSP scenarios, RCP scenarios, and land subsidence scenarios it was possible to provide consistent regional scenarios: the MSP's. The MSP's showed how land use projections and population projections spatially overlap with sea level rise and land subsidence in the Mekong delta. This allows the research questions to be answered: firstly, the MSP's provide projections for the land use, population density, and relative sea level rise in the Mekong delta for each SSP; secondly, they show how the relative sea level rise alters the land use opportunities in the Mekong delta; thirdly, they provide the estimated elevation for projected population and land use, when taking the effects of *relative* sea level rise into account; fourthly, they show to what extent there is a mismatch between the SSP *projections* of land use and population and *feasible* land use and population density, when taking the effects of *relative* sea level change into account.

This allows the research question to be answered, as these sub questions display the narrative; explaining the impact of land subsidence on the projections for the SSP model in the Mekong delta region and its inhabitants. The MSP's show that the impact from relative sea level rise is significant and is mostly driven by land subsidence. Fortunately, land subsidence can be locally mitigated by decreasing the ground water extraction.

In the beginning of this research it has been hypothesized that the exclusion of the small-scale environmental feedback from land subsidence in the Mekong delta, will lead to an underestimation of the pressure caused by climate change in the future and therefore an overestimation of the opportunities for land use in the area. The results of this research have shown that the exclusion of environmental feedback by IMAGE has led to an underestimation of the impact on opportunities for land use in the area, affecting the reliability of IMAGE in the Mekong delta. Thus, global SSP scenarios from integrated assessment models, such as IMAGE, cannot be downscaled one to one to the regional (c.q. delta) scale, they can only be used on the global scale they were designed for. Unless, they are adapted to include local environmental feedback

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