Participatory approaches and geospatial
modeling for increased resilience to climate change at the local level

PCLM Guidebook

Participatory coastal land-use management

Ministry of the Environment
IGES Institute for Global Environmental Strategies

Participatory Coastal Land-Use Management (PCLM) Guidebook: Participatory approaches and geospatial modeling for increased resilience to climate change at the local level

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Concept and objectives of this PCLM Guidebook
This guidebook is intended to provide an overview of how to conduct climate change and land-use change impact assessments at the local level, so that the local impacts on water, biodiversity, and health can be better understood. A key aspect of the guidebook is the tutorials provided for conducting climate change/land-use change scenario analysis and impact assessment using free software. The methodology presented (PCLM) and training materials provided can help local governments with their climate change adaptation and land-use planning, and is designed to complement/support countries' official planning processes. Using these training materials as a basis, more intensive in-person (or online) trainings can also be conducted to provide more specialized or location-specific trainings in priority sites.

Table of Contents

Chapter 1: Introduction to Participatory Coastal Land-use Management (PCLM) approach

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Overview

This guidebook introduces several concepts and methodologies for evaluating and building resilience to climate change and land-use change in coastal areas, focusing on the local level (e.g. the municipal or provincial level). Specifically, it presents a framework that we developed, called "Participatory Coastal Land-use Management" (PCLM), which utilizes various participatory approaches and geospatial modeling techniques to quantitatively evaluate the potential impacts of climate change and land-use changes, and to develop suitable local countermeasures.

The target of the PCLM approach is to help the local governments located in coastal areas work together to quantify climate change/ land-use change impacts and develop more resilient development plans, so that future generations can be protected from climate-related hazards and continue enjoying the benefits provided by nature. This guidebook is intended for technical experts (environmental scientists, hydrologists, GIS experts, etc.) and managers/policymakers working at the local level.

In this chapter, you will:

- Learn how climate change and land-use change can affect coastal communities' resilience at a local scale.
- Be introduced to the steps involved in the Participatory Coastal Land-use Management (PCLM) approach, which will be covered in detail in subsequent chapters.

Main concepts

Coastal areas are some of the most dynamic areas on our planet. They are constantly shaped and reshaped by the winds and waves, and frequently affected by climate-related hazards including typhoons and coastal floods. Global climate change is expected to raise the sea level and increase typhoon frequency and/or intensity in many parts of the world, which may further exacerbate coastal hazards (IPCC 2019). Despite their high exposure to climate hazards, coastal areas are home to many of the world's megacities and vast infrastructure (e.g. large ports, power plants, and roads/railways), owing to the economic benefits associated with access to the ocean. Coastal areas are also home to important land, estuarine, and marine ecosystems that are rich in biodiversity. As a melting pot of diverse stakeholder interests, coastal areas often undergo rapid land-use changes, serving different commercial and recreational purposes. These land-use changes can lead to loss or degradation of coastal ecosystems.

Mangroves, coral reefs, sea grasses, and other coastal ecosystems provide a wide range of ecosystem services to coastal communities, including food provisioning, natural shoreline stabilization, and protection against storms and floods. As one example, mangroves' (which are naturally found in many regions affected by typhoons) dense aerial root systems trap sediments floating in the water and build up the soil over time, forming a natural "buffer" which protects inland areas from coastal flooding and sea-level rise (Figure 1.1.). In the context of climate change, coastal ecosystems can help to reduce several negative impacts, including: increasing storm frequency/intensity, sea-level rise, sea surface temperature rise, and ocean acidification (UNEP 2016). However, coastal ecosystem are often not prioritized in coastal land-use planning and development processes because it is difficult to visualize and quantify their various benefits.

Figure 1.1. Soil accretion in mangrove ecosystems. The dense root system traps sediments and builds-up the soil, protecting further inland areas from sea-level rise, storm surge, and other coastal hazards. Source: Authors.

Coastal EbA option	Sea surface temperature rise	Sea level rise	Ocean acidification	Increased intensity of storms and hurricanes
Coral reef restoration and conservation	Reducing non-climate pressures (e.g. pollution) and encouraging temperature tolerant species may reduce incidence of coral bleaching and increase the resilience of services provided by reefs (e.g. habitat for fish, tourism) to temperature increases.	Reefs can attenuate (reduce the height and power of) waves. Reducing the height of waves reaching the shore can decrease wave inundation (to a certain extent). When corals grow as sea level rises this attenuation service can be maintained.	Reducing non-climate pressures (e.g. high nutrient pollution and overfishing of herbivorous fish) increases the resilience of reefs to climate change impacts. Services provided by reefs are more likely to be maintained if other threats are effectively managed.	Wave attenuation by reefs can reduce the power of storm waves reaching the shore and thereby reduce coastal flooding and erosion.
Mangrove restoration and conservation	Reducing non-climate pressures (e.g. pollution) and encouraging temperature tolerant tree species may increase the resilience of services provided by mangroves (e.g. habitat for fish) to temperature increases.	Mangroves can attenuate waves and so reduce wave inundation (to a certain extent). They also capture sediment and so help counteract coastal erosion. Where mangroves accrete (vertically build up soil) as sea level rises these coastal protection services can be maintained (up to certain thresholds).	Reducing non-climate pressures increase the resilience of services provided by mangroves to acidification. Mangroves have also been found to act as a refuge for corals from ocean acidification. Therefore, protecting a mosaic of habitats (e.g. mangroves near coral reefs) could provide resilience benefits.	Mangrove forests attenuate waves and slow storm surge water flows if mangroves areas are wide enough.
Seagrass restoration and conservation	Reducing non-climate pressures (e.g. pollution) and encouraging temperature tolerant tree species may increase the resilience of services provided by mangroves (e.g. habitat for fish) to temperature increases.	Seagrasses can reduce current velocity, dissipate wave energy and stabilize the sediment, most reliably in shallow waters. Reducing the height of waves reaching the shore can decrease wave inundation (to a certain extent). Stabilizing sediment can help seagrasses accrete with sea level rise under certain sedimentation and accretion rates.	Seagrass meadows have been shown in some locations to have a buffering effect on pH, modifying it through photosynthetic activity. As a result, healthy seagrass beds may provide a refuge for calcifying organisms. In addition, seagrass biomass is increased by ocean acidification leading to increased carbon sequestration.	Seagrass can reduce current velocity, dissipate wave energy and stabilize the sediment most reliably in shallow waters and low wave energy environments.
Dune and beach restoration and conservation (dune stabilization)		Reducing non-climate pressures (e.g. clearing and trampling) and encouraging dune plant development increases the resilience of services provided by dunes and beaches. Dunes can act as a physical buffer to waves and so provide some barrier to wave inundation as sea levels rise.		Dunes can act as a buffer to waves and storm surges. Their porous structure absorbs and dissipates wave energy, protecting inland structures from flooding and damage. Dunes also provide additional material which re-enters the marine system and forms a new beach profile after erosion events.
Coastal wetland conservation and restoration	Reducing non-climate pressures (e.g. pollution) and encouraging temperature tolerant species may increase the resilience of services provided by wetlands (e.g. habitat for fish) to temperature increases.	Depending on the type, wetlands can help attenuate waves and so reduce wave inundation. They may also act as a water store during times of high water, reducing flooding of coastal areas. Wetlands, including salt marshes, can trap sediment and so may vertically build up soil as sea level rises. Coastal wetlands can also help manage the hydrology of the area providing a freshwater source necessary to maintain other habitats such as salt marsh and mangroves that then provide some protection against sea level rise.		
Managed realignment/ coastal setbacks		Redefining the location of the coastline and maintaining buffer ecosystems (such as saltmarshes) can help to reduce the impact of sea level rise on communities.		Redefining the location of the coastline and maintaining buffer ecosystems can help protect communities against storm surges.
Livelihoods diversification and protection of ecosystem based livelihoods	Supporting communities to protect and diversify their livelihoods can help reduce their reliance on livelihoods which may be at risk from sea surface temperature rises (e.g. fishing of a particular species).	Supporting communities to protect and diversify their livelihoods can help reduce their reliance on livelihoods which may be at risk from sea level rise.	Supporting communities to protect and diversify their livelihoods can help reduce their reliance on livelihoods which may be at risk from acidification (e.g. harvesting of a particular crustacean or mussels may become unsustainable in the face of acidification).	Supporting communities to protect and diversify their livelihoods can help reduce their reliance on livelihoods which may be at risk from storms and support them in recovering after storm events.
Marine protected areas (MPAs) and other area- based management measures	MPA management, through helping to reduce non- climate pressures, can help to increase the resilience of ecosystems (and the services they provide) to temperature rise.	Where MPAs protect ecosystems that help to attenuate waves and can accrete, they can help reduce wave inundations as sea levels rise.	MPA management, through helping to reduce non- climate pressures, can help to increase the resilience to acidification of ecosystems and the services they provide.	Where MPAs protect ecosystems that help to attenuate storm waves, they can help reduce associated coastal flooding and erosion.
Sustainable fisheries management plans or Ecosystem approach to fisheries (EAF)	Where such plans take into account the impact of temperatures on shifting species distributions and abundances, they can help to manage the impacts.		Where such plans take into account the impact of acidification on shifting abundances and reproduction/growth patterns, they can help to manage the impacts.	

Table 1.1. Benefits of different ecosystem-based adaptation (EbA) meausures. Source: (UNEP 2016)

From the above, it is clear that climate change and land-use change can have significant impacts on people's exposure to climate-related hazards in coastal areas. In some cases, these hazards may result in "disasters", i.e. major economic damage, injuries, and/or loss of lives. Local disaster risks associated with climate hazards are typically thought of as being related to three factors:

1. The frequency and level of extremity of the climate-related hazards experienced in the locality;
2. The level of exposure to these climate-related hazards, e.g. the number of people and properties located in the impacted areas; and
3. The level of vulnerability of the people/infrastructure/environment in the areas exposed to the climate-related hazards

Figure 1.2 shows how all three factors (i.e. hazards, exposure, and vulnerability) interact to determine disaster risk.

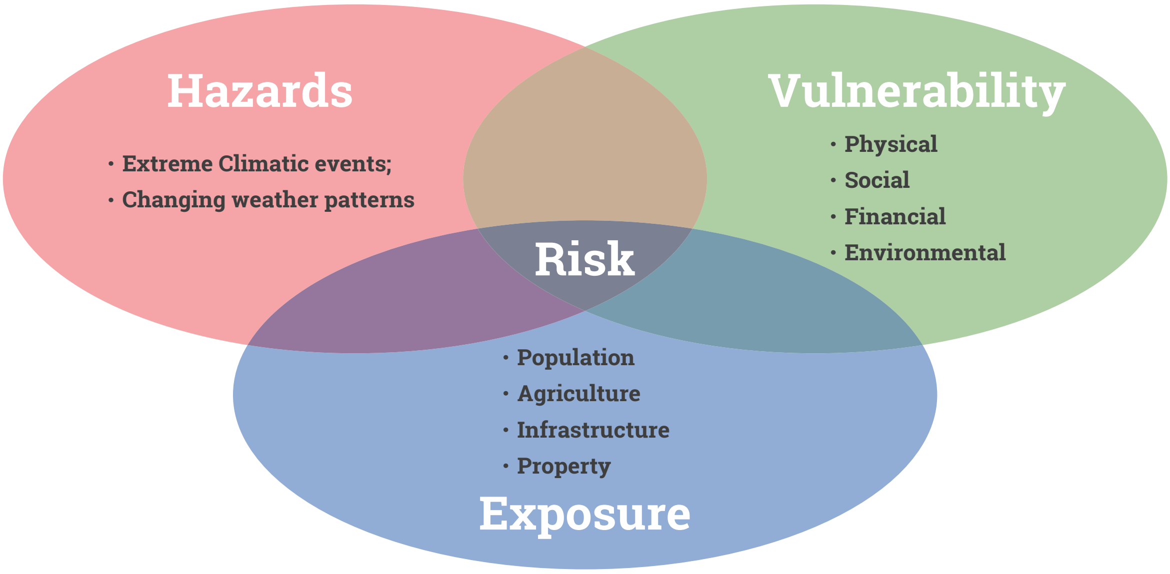

Figure 1.1. Concepts of hazard, exposure, vulnerability, and risk.

Aside from their impacts on disaster risk, climate change and land-use change can have a variety of other local impacts. For example, loss/degradation of coastal mangrove ecosystems due to changing climate conditions or land-use conversions (e.g. conversion to fishponds) may result in the loss of biodiversity and deterioration of water quality (because the mangrove areas help trap sediments that run-off from upstream areas), among other things. To help visualize how these types of changes in climate and/or land-use can impact the environment and society, one interesting tool is called the "impact chain" (https://www.pik-potsdam.de/cigrasp-2/ic/ic.html).

The impact chain is basically a graphical representation of how a specific climate or land-use modification (i.e. a "stimulus") directly and indirectly affects a location of interest. The impact chain can be developed utilizing scientific models, local knowledge, or other relevant information. One example of an impact chain is shown in Figure 1.3 to demonstrate the approach. From this example, we can see that climate change (sea-level rise), urban land expansion, and agricultural land expansion can have many interlinked direct and indirect impacts. In cases like this where more than one stimulus is found to lead to the same impact, we can understand that this impact is highly significant, and efforts should be made to mitigate the problem.

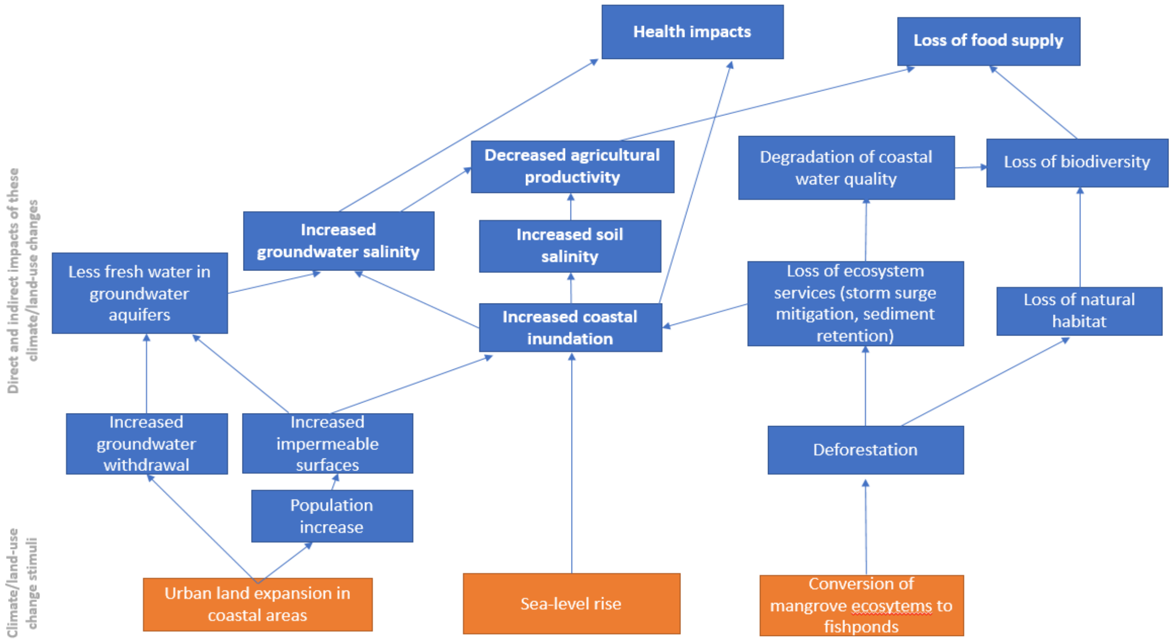

Figure 1.3. Impact chain considering three stimuli: urban land expansion in coastal areas, sea-level rise, and conversion of mangrove ecosystems to fishponds.

Participatory Coastal Land-use Management (PCLM) approach

To estimate how climate change and land-use change will affect a coastal area, planners and policymakers first need to have an understanding of how the climate and the land-use are likely to change in the future (e.g. over the next 10, 20, or 50 years). Once future climate and land-use scenarios are identified, they can serve as input data for different types of computer simulation models to estimate the impacts of these changes, e.g. on flood hazard, water quality, or biodiversity. The "Participatory Coastal Land-use Management" (PCLM) approach presented in this guidebook is intended to help with this process. The PCLM approach can help complement traditional approaches like the impact chain (Figure 1.3.) by helping to quantify the potential impacts of future climate change and/or land-use change.

In the PCLM approach, future climate and land-use scenarios are generated, the impacts of these changes are estimated using free software/computer models, local governments identify countermeasures to reduce these impacts, and finally the local governments adopt these countermeasures in local plans and policies to increase their resilience to climate change. If some of the identified countermeasures require external funding from national or international sources to implement (e.g. large ecosystem restoration or infrastructure building projects), they can be used as a basis to develop proposals for climate change adaptation funding from sources like the Green Climate Fund (https://www.greenclimate.fund/). We hope that by using the PCLM approach, local governments and other stakeholders can better understand the potential impacts of climate change and land-use change in coastal areas, so that more effective policies, plans, and infrastructure can be put in place.

The PCLM approach utilizes a combination of participatory processes and geospatial modeling techniques for this impact assessment and policy development, and consists of four main steps:

1. **Scenario development:** Future scenarios of land-use change and climate change are identified ;
2. **Impact assessment:** Impacts of the future land-use change/climate change scenario(s) are analyzed using different computer models and software;
3. **Countermeasure identification:** Local governments within the coastal study site identify countermeasures based on the risk assessments, and try to agree upon some priority countermeasures relevant for all local governments in the area (e.g. transboundary ecosystem-based or infrastructure measures);
4. **Climate resilient land-use planning and implementation:** Local governments use the identified countermeasures to improve their land-use plans, and for development of climate change adaptation actions and policies. The identified countermeasures can also be used to develop project proposals for domestic or international sources of climate change adaptation funding (e.g. through the Green Climate Fund: https://www.greenclimate.fund/).

Figure 1.4. provides an overview of these four steps, and the processes and software/tools required for each step. All of these processes are described in more detail in the subsequent chapters, and you will learn how to apply them yourselves through a series of hands-on tutorials.

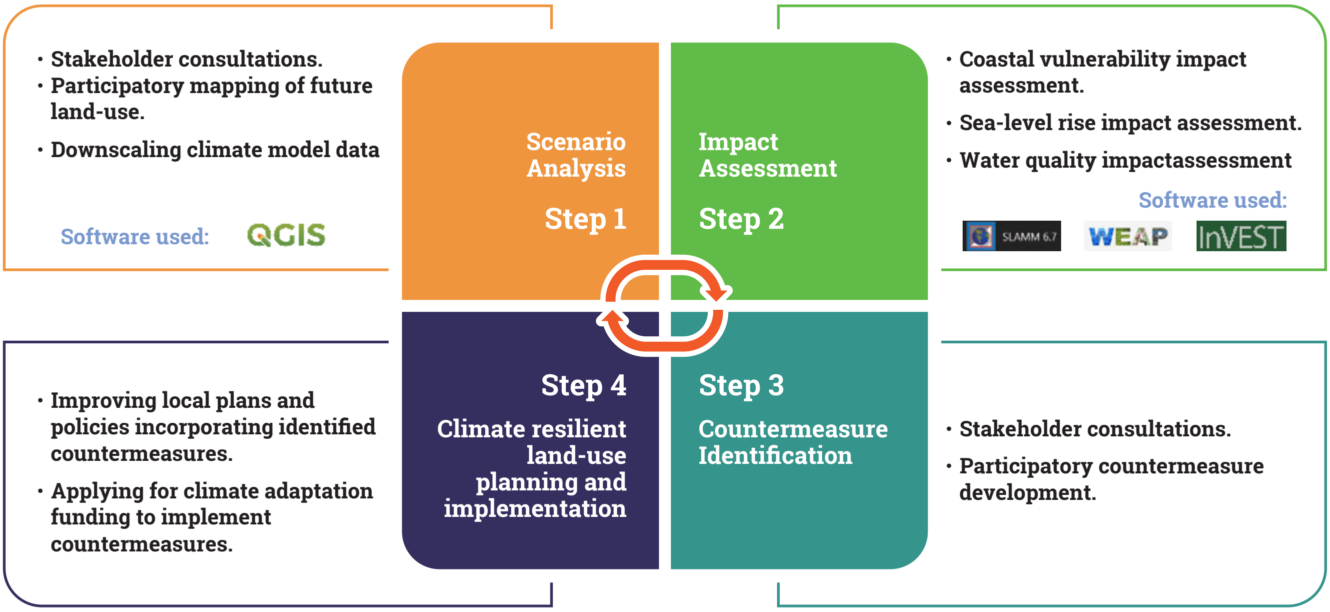

Figure 1.4. Four steps of the PCLM approach, and the different processes and software/tools required in each step.

Step 1: Scenario Development (covered in Chapters 2 and 3)

In the first step of PCLM, future scenarios of land-use change and climate change are developed through participatory mapping (for land-use scenarios) and downscaling of climate model projections (for climate change scenarios).

Land-use scenario development

To understand the likely future land-use changes of a coastal area, a participatory mapping approach is used. For this, a stakeholder consultation workshop should be organized, wherein representatives from each local government within a coastal study site share their land-use and development plans. A map of the future land-use is created through a participatory mapping activity. Local government officials sketch their planned future land-use conversions (e.g. based on their land-use plan, or their knowledge of planned land acquisitions/development) onto a printed map using markers and tracing paper (see Figure 1.5 for some examples). Each local government then presents its future land-use plans to the other neighboring local governments, so that all have a better understanding of the future land-use conditions of the coastline. Later, the sketched maps are digitized and georeferenced using the free Geographic Information Systems (GIS) software "QGIS". Chapter 2 of this guidebook provides a step-by-step tutorial on how to perform this land-use scenario development.

Climate change scenario development

To understand the future climate changes of a coastal study area, projections from General Circulation Models (GCMs, a.k.a. Global Climate Models) or Regional Circulation Models (RCMs, a.k.a. Regional Climate Models) are used. GCMs/RCMs are computer models of the future climate, assuming different levels of future greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) has estimated these future levels of emissions under different socioeconomic scenarios known as Relative Concentration Pathways (RCPs). Due to the high level of uncertainty of these future climate change estimates, multiple scenarios should be used to show a range of possible futures. For higher accuracy, the climate model data should also be downscaled and bias-corrected using local climate observations. Chapter 3 of this guidebook covers the basics of GCMs, how to acquire the GCM data, and how to visualize it in QGIS software.

Figure 1.5. Participatory future land-use mapping activity.

Main outputs of Step 1	Software used in Step 1
1. Current land-use map	QGIS: https://www.qgis.org/en/site/
2. Future land-use map	
3. Downscaled climate data (current and future daily/monthly data)	

Step 2: Impact Assessment (Chapters 4, 5, and 6)

In the second step of PCLM, impact assessment, computer modeling software is used to estimate various impacts of the future land-use and climate changes. For the PCLM approach to be open to as many as possible, in this guidebook we have demonstrated how to conduct all of the impact assessments using freely available GIS and modeling software.

Chapter 4 of this guidebook shows you how to perform coastal vulnerability impact assessment using InVEST software, based on tutorial data from a case study site in the Philippines. Chapter 5 shows you how to perform sea-level rise impact assessment in the same study site using SLAMM software. Chapter 6 shows you how to perform coastal water quality impact assessment in this site using the Water Evaluation and Planning (WEAP) tool. Through these tutorials, you will learn the basics of how to apply the PCLM models in your own coastal area.

Main outputs of Step 2	Software used in Step 2
Water quality parameters (current and future)	QGIS: https://www.qgis.org/en/site/
Flood hazard maps (current and future)	SLAMM：https://coast.noaa.gov/digitalcoast/tools/slamm.html
Habitat quality maps (current and future)	Water Evaluation and Planning (WEAP): https://www.weap21.org/
	InVEST: https://naturalcapitalproject.stanford.edu/software/invest

Step 3: Countermeasure Identification (Chapter 7)

In the third step of PCLM, countermeasures to reduce the negative impacts of future land-use changes and climate change are identified using a participatory process. For this, the results of the impact assessments from Step 2 are presented to all of the local governments within the coastal area, and the local government officials are asked to think of potential countermeasures and write them down (e.g. using markers and adhesive notecards, as shown in Figure 1.6.). Each local government presents their identified countermeasures, and finally, some common/priority countermeasures are discussed and identified.

Figure 1.6. Stakeholder consultations to develop countermeasures for reducing the impacts of future land-use changes and climate change.

Main outputs of Step 3	Software used in Step 3
List of countermeasures identified by each local government in the watershed List of priority countermeasures for watershed as a whole	No specific software needed

Step 4: Climate resilient land-use planning and implementation (Chapter 7)

In the final step of PCLM, the priority countermeasures identified from Step 3 are used as a basis for developing more climate resilient land-use plans and other policies, as well as for implementing climate change adaptation actions and infrastructure. This is probably the most important step of PCLM, as the goal of this step is to translate the scientific information generated through PCLM into concrete actions.

Some countermeasures identified through PCLM may be possible for local governments to implement on their own (e.g. changing zoning regulations or building codes), while some measures may be too costly for the local governments to implement without external aid. In case external aid is necessary, the identified countermeasures can be proposed as projects for funding by the Green Climate Fund or other national/international climate adaptation funds. Examples of the types of adaptation projects funded by the Green Climate Fund can be found at https://www.greenclimate.fund/projects?f[]=field_theme:235. The Green Climate Fund and other types of adaptation funds typically require a climate change impact assessment to be conducted prior to applying for project funding (to justify why the funds are needed, and to estimate the benefits of the proposed project). The impact assessments from step 2 of PCLM provide the basis for this assessment.

In Chapter 7 of this guidebook, we show some specific examples of the types of actions that could be taken in step 4 of PCLM, based on the results of a case study conducted in the Philippines.

Main outputs of Step 4	Software used in Step 4
1. More climate resilient local policies and plans	No specific software needed
2. Project proposals for climate change adaptation-related funds (to help implement any identified countermeasures that require external funding)	

References

PCC. 2019. "Summary for Policymakers." In IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Cambridge, United Kingdom and New York, NY, USA.

UNEP. 2016. "Options for Ecosystem-Based Adaptation (EBA) in Coastal Environments: A Guide for Environmental Managers and Planners." UNEP, Nairobi (June 2019): 110. https://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/380/original/Options_for_Ecosystem_based_Adaptation_in_Coastal_Environments_low-res.pdf?1462462607.

Chapter 2: Land-use change scenario analysis

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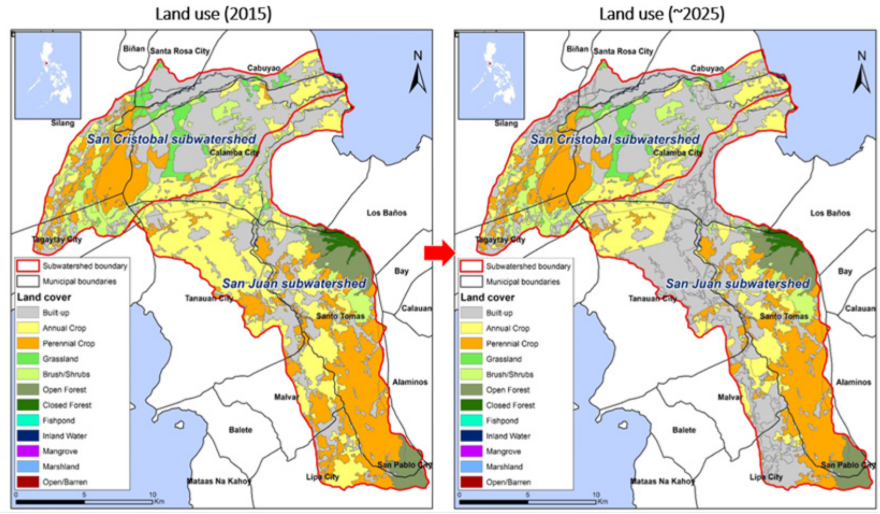


Overview of this chapter

Land-use changes can have a significant impact on the biodiversity, water quality, and damage caused by extreme weather events in coastal areas. This chapter gives an overview of the impacts of land-use changes, and demonstrates how to perform land-use change scenario analysis. In the chapter, you will learn how to create your own maps of the current and future land-use of a study site using free Geographic Information Systems (GIS) software. This represents the land-use change scenario development component of PCLM Step 1 ("Scenario Analysis"). These maps will serve as the basis for conducting land-use change impact assessments in PCLM Step 2 ("Impact Assessment"), which are explained in Chapters 4-6.

After completing the chapter, you will be able to:

- Perform basic GIS operations in QGIS software (https://qgis.org/en/site/);
- Generate your own land-use maps showing the current and future (planned) land-use.

Main concepts

Land-use change and climate-related hazards in coastal areas

As introduced in Chapter 1, land-use is a major factor that affects a community's resilience to climate change and climate-related hazards. Conserving and restoring coastal mangroves, forests, wetlands, and other natural ecosystems can reduce the cause of climate change ($CO2$ emissions) as well as the potential impacts like increased coastal inundation and salt water intrusion. In contrast, converting natural coastal ecosystems into urban or agricultural/aquacultural areas can have the opposite effect, resulting in the release of $CO2$ emissions from deforestation/forest degradation as well as increased climate-related hazards like coastal flooding (due to reduced protection of the coastline from sea-level-rise and storm surge).

Land-use changes associated with urbanization can have also have major impact on the biodiversity and water quality in coastal areas, among other things. Coastal ecosystems serve as habitat and nursing grounds to a range of aquatic animals, many of which have high economic and livelihood importance to the local communities. On the other hand, urban development and population growth in areas near the coast can lead to increased groundwater withdrawals for household and commercial/industrial use, which subsequently causes increased salt-water intrusion (as salt water flows into the depleted fresh water aquifers). This can make the groundwater unsuitable for drinking and irrigation.

Of course, many different factors must be considered for land-use planning in coastal areas, such as demand for urban, agricultural, and recreational land to meet the needs of growing populations and economies.

Data and software for land-use change mapping/analysis

In this chapter, we will provide you with training in some of the tools/software that can help to better understand and manage the potential impacts of future land-use changes. The first step of this land-use change impact assessment process is to identify or create the needed land-use maps; including:

i. a map of the current (or nearly up-to-date) land-use; and
ii. a map of the planned (or potential) land-use for a desired date in the future. Municipal land-use plans could be a basis for this future land-use map.

It is important to note that the quality and quantity of available land-use data may vary significantly from one location to another, so identifying the appropriate land-use map(s) to use for impact assessment is not always a simple process. If an accurate and up-to-date local land-use map is already available for your city/town (e.g. a land-use map produced by/regularly updated by your local government), this will probably be the best data to use for an impact assessment. If a local land-use map is not available, you can check online for other existing global-, regional-, or national-level land-use maps to determine if they meet the level of detail (e.g. high enough spatial resolution, and a sufficient number of land-use classes mapped) and accuracy that you require. Finally, in case you need a more accurate/up-to-date/detailed land-use map than what is available, you can always create your own by carefully digitizing land-use polygons over a satellite image base map using GIS software. (this digitizing process will be explained later in the chapter). Figure 2.1. shows the general decision process for identifying appropriate land-use maps for impact assessments.

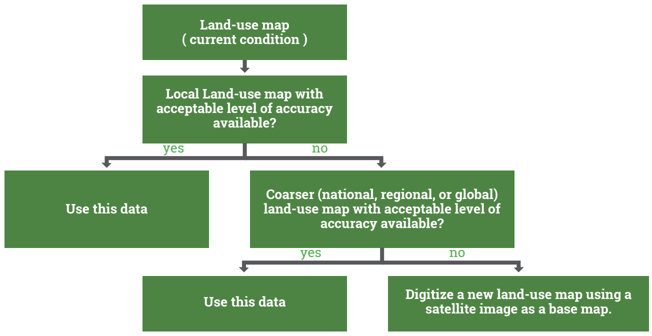


Figure 2.1. Process for identifying sources of current and future land-use data to use for impact assessments.

A similar decision process can be used to identify the appropriate source of future land-use data (Figure 2.1.). Future land-use maps are often produced through participatory mapping activities, e.g. by sketching future land-use changes on paper or digitizing them directly using GIS software (Endo et al., 2017). Alternatively, they can be generated by computer simulation modeling by overlaying historical maps of land-use changes with other geo-spatial and demographic information, identifying drivers of land-use change, and simulating future changes based on the predicted changes of these drivers (e.g. population growth estimates) (Iizuka et al., 2017) (Figure 2.2.). A comparison of current and future land-use maps can be used to calculate the change in area of each land-use class, and visualize their spatial distribution (Figure 2.3.).

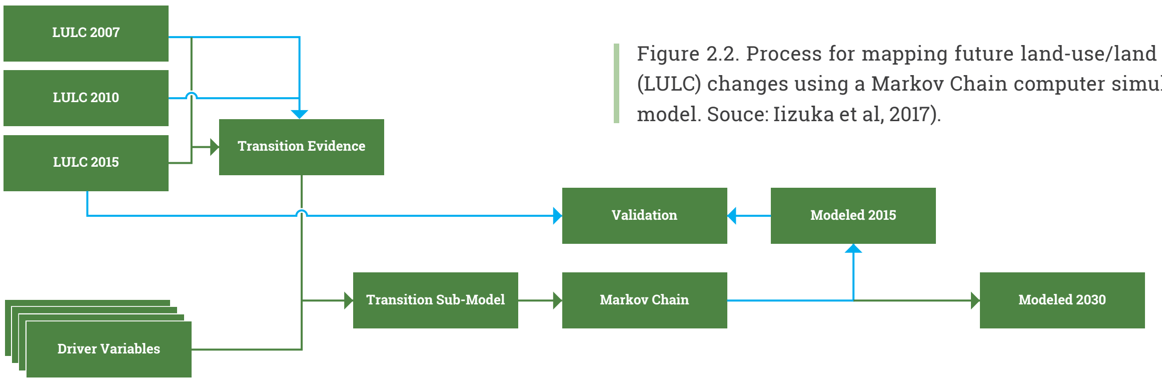


Figure 2.2. Process for mapping future land-use/land cover (LULC) changes using a Markov Chain computer simulation model. Souce: Iizuka et al, 2017).

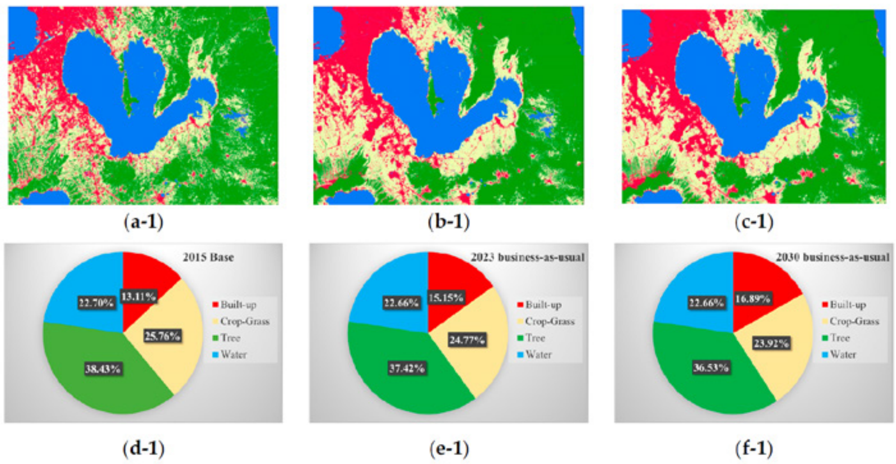


Figure 2.2. Process for mapping future land-use/land cover (LULC) changes using a Markov Chain computer simulation model. Souce: Iizuka et al, 2017).

The remainder of this chapter is a tutorial for digitizing land-use polygons using a free GIS software package called QGIS. QGIS has a relatively simple user interface, and runs on Windows, Mac, Linux, and Android operating systems. You can downloaded the latest version of the software from https://www.qgis.org/en/site/.

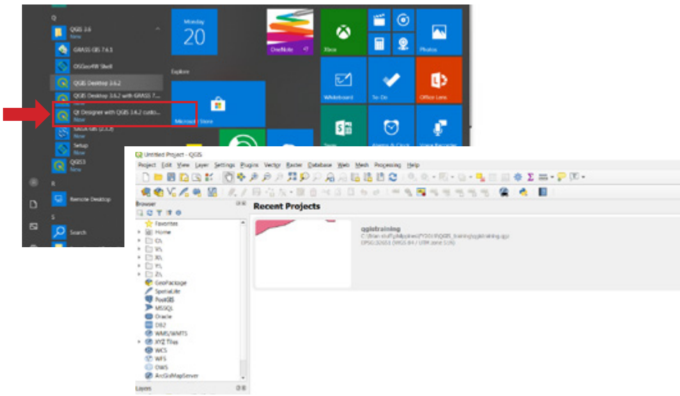
Tutorial

This tutorial focuses on the process for preparing current and future land-use maps of a case study site, using free GIS software. We have provided all of the data for this tutorial in the folder entitled "QGIS training".

Step 1. Downloading and running QGIS

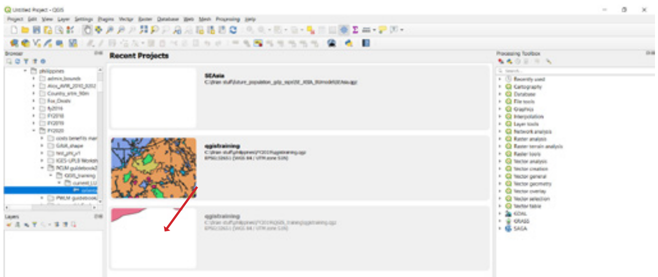
For the sake of this tutorial, we have already downloaded QGIS and provided it to you with this training package. Let's install it.

b Open "QGIS Desktop" using the Windows Start menu. After QGIS opens, you will see a browser menu on the left, and recent projects in the main window.

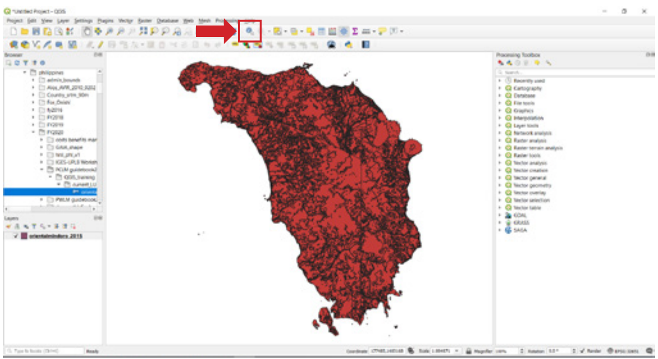


Step 2. Loading GIS data of the current land-use of the sample study site (Mindoro Island, Philippines).

a Load the "mindoro_2015.shp" file in the "Current_LU" folder by dragging the file to the from the "Browser" menu in QGIS to the "Layers" window.

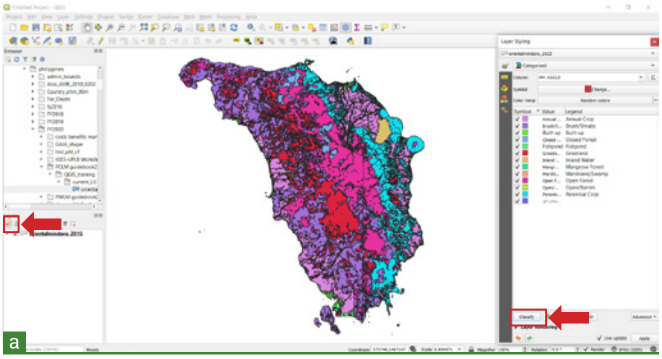


Step 3. Inspecting the data and modifying the layer style



a You will see a map of the land-use of Mindoro Island in 2015. Check the details of the added file by clicking on the "Identify features" icon in QGIS. You can also check by right-clicking on "mindoro_2015" in the Layers menu, and selecting "Open attribute table". The "NAME" row shows the name of the watershed that the polygon contains, and the other rows show the size, area, and average population density of the watershed.

Step 4. Visualizing each land-use class as a different color.

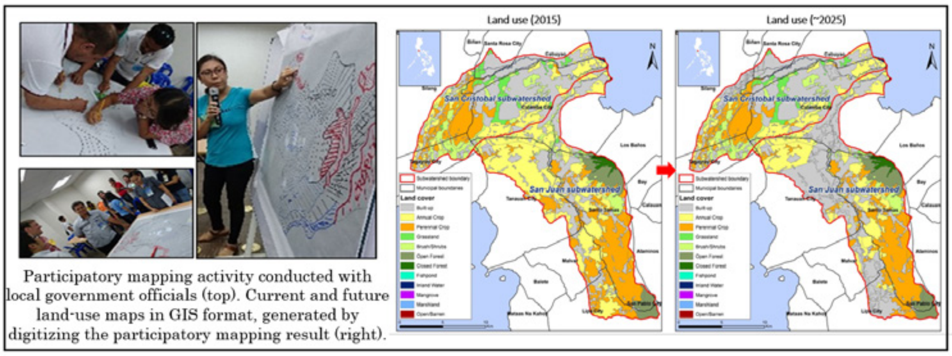


a For easier visualization, you will assign a unique color to the polygons representing each land-use class. To do this, click on the "mindoro_2015" map layer in the Layers window to highlight this layer, and then click the Layer Styling Panel icon. In the Layer Styling window, change the symbol type from "Single Symbol" to "Categorized", and specify the "AGC12" column as the column containing the land-use information. Finally, click the "Classify" icon. Now, you should see each land-use class displayed as a different color.

b Practice zooming in and out to the study area boundary using the magnifier and "pan" icons above the map window . Practice turning on/off the two map layers by checking on/off the check boxes in the Layers window, and re-ordering the maps by dragging them up and down in the Layers window. Finally, practice changing the colors of each land-use class by clicking the color box next to it in the "Symbol" column of the "Layer styling" window.

Step 5. Create a future land-use map based on the outputs of a participatory mapping activity.

In Step 2, we loaded a GIS shapefile containing the current land-use. For land-use change impact assessments, however, we also need a map showing the potential future land-use. This could be a land-use map based on your municipality's land-use or zoning plan, which may already be in GIS format. If no future land-use/zoning map exists already, a common approach to understand the potential future land-use conditions of a coastal area is to conduct a participatory land-use mapping activity with relevant local government staff (i.e. those involved in land-use planning processes) as well as any other relevant stakeholders. This kind of activity typically involves printing out a large poster-size map of the site, showing the administrative boundaries, the current land-use, the major roads and rivers, and other important geographic features. The local government staff then sketch the planned (or likely) future land-use changes using colored markers. To translate this analog data to digital GIS format, we can finally digitize it using GIS software.

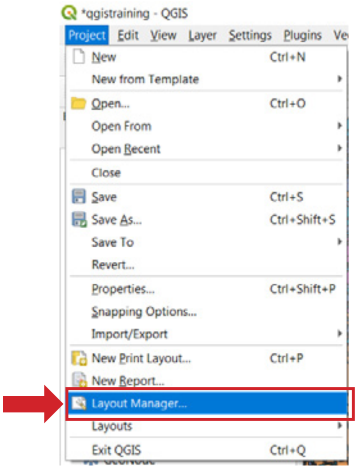


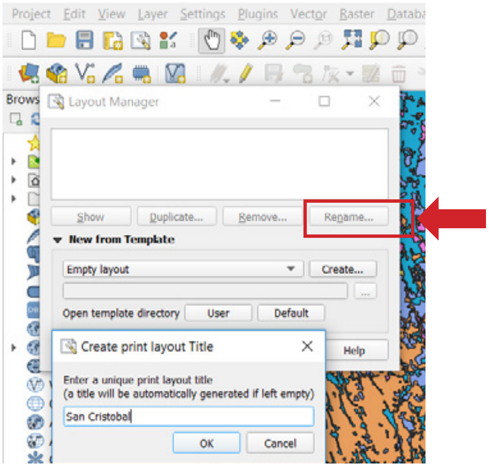
Participatory mapping activity conducted with local government officials (top). Current and future land-use maps in GIS format, generated by digitizing the participatory mapping result (right).

5.1. Creating a current land-use map to use as a basis for participatory mapping activity

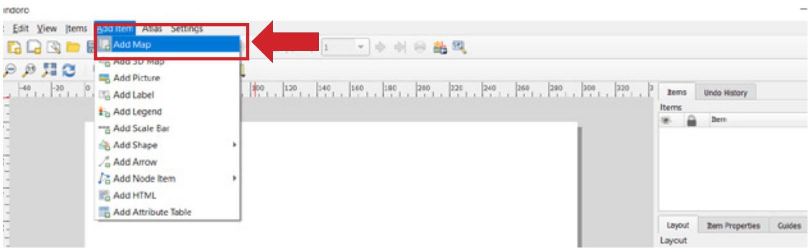
Let’s create a very basic current land-use map that could be printed out and used for a participatory mapping activity.

a Click on the “Project” menu, then click “Layout Manager...” from the dropdown box. A Layout Manager window will appear. Under **New from Template** header in this window, make sure “Empty layout” is selected and click the “Create...” button. In the “Create print layout Title” window that appears, please enter “Mindoro” as the title, and then click “OK”.

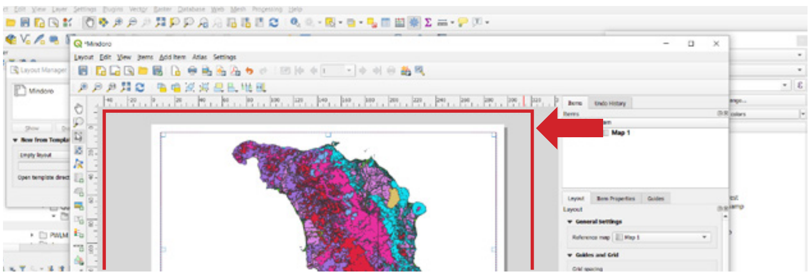




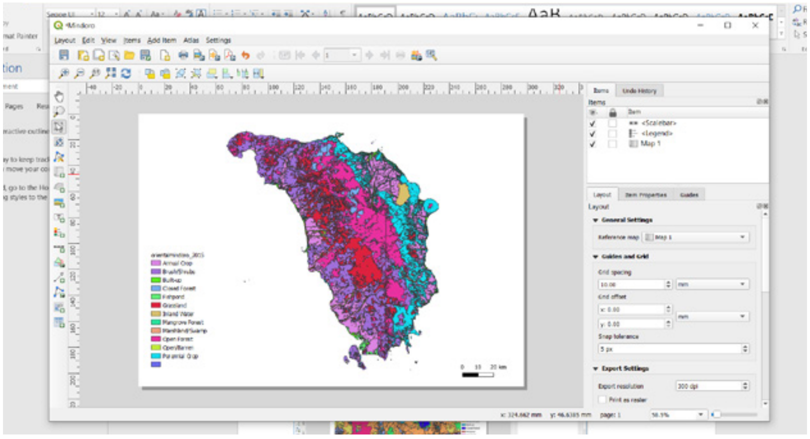
b A new window entitled “Mindoro” will appear. [If you close this window, you can open it again by clicking again on the “Project” menu, and then clicking “Layouts”, and “Mindoro”.] In the next steps, you will create the current land-use map layout for San Cristobal watershed using the tools in this window.



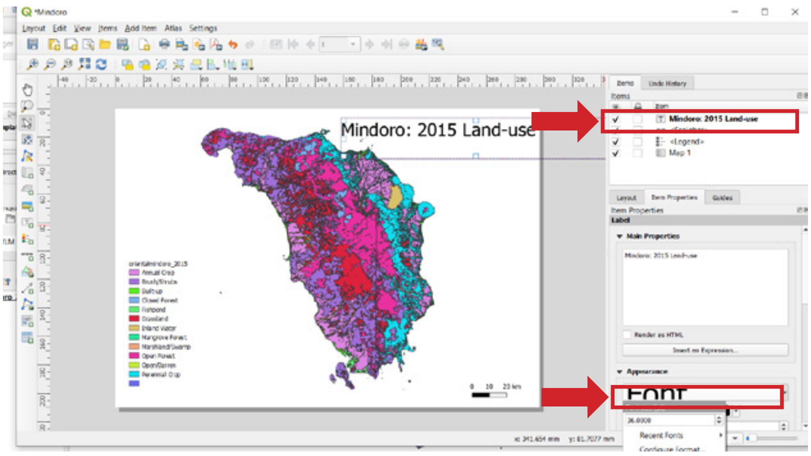
c To add a map to the layout, click on the “Add Item” menu, and click “Add Map” in the dropdown box. A crosshairs will appear for your mouse pointer, and you can click and drag a rectangle that will display the GIS layers in this layout. You can move the map or resize it by dragging or stretching the rectangle.



b Add a map legend by clicking on the "Add item" menu and clicking "Add legend" in the dropdown box. You can draw a rectangle to indicate where you want the legend to go. Usually, map legends go in one of the corners of the map layout, where they will not obstruct the GIS layers shown in the map.



e Add a scale bar to the map by clicking on the "Add item" menu and clicking "Add Scale Bar" in the dropdown box. You can draw a rectangle to indicate where you want the scale bar to go. Usually, scale bars also go in one of the corners of the map layout, where they will not obstruct the GIS layers shown in the map. Your layout window will look something like this after adding the Legend and scale bar:



f Add a title for the map. Click again on the "Add item" menu, and click "Add label" in the dropdown box. Drag a rectangle in the top part of the layout window where the title will go. By default, the title text is "Lorem ipssum". Let's change this title by right-clicking on "Lorem ipsum", and clicking "Item properties" from the dropdown box, and then entering a new title: "Mindoro: Current Land-use". You can make the text larger by clicking on the "Font" menu, and selecting a larger font size (try size 36 font).

g Save the layout by clicking the "Layout" menu, and clicking "Save project". You can also click the disk icon below the Layout menu to save. Save the file to the "QGIS_outputs" folder.

h Finally, save the layout as a .pdf file by clicking the "Layout" menu, and clicking "Export to pdf" in the dropdown box. Name the file "Mindoro 2015 Land-use" and save it in the "QGIS_outputs" folder.

Now you have completed the process of creating an existing land-use map of a coastal study site, which can be printed out and used to conduct a participatory mapping activity! The actual participatory mapping can be done by providing markers of different colors to the participants, and asking them to draw out their planned future land-use changes in different colors. For example, they might digitize new planned urban developments in red, new parks or other green spaces in green, and new agricultural areas in yellow. Once this is completed, this analog data will need to be digitized into a new GIS layer.

Step 5.2. Digitizing the future land-use map created through a participatory mapping activity.

In the next steps, we will practice the digitizing process in QGIS so that you can digitize a future (or current) land-use map using GIS software.

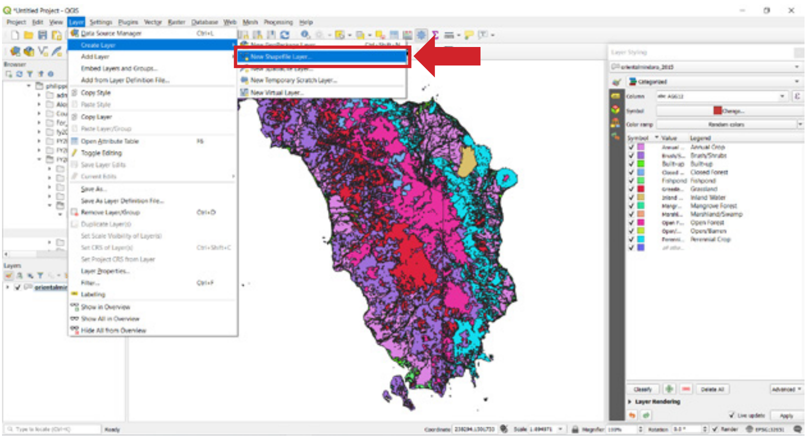
a Open the Layer menu, click "Create Layer", then click "New Shapefile Layer".

b Set the file and file path by clicking the [...] icon. Please name the file "Future_LU.shp", and place it in the "QGIS_outputs" folder.

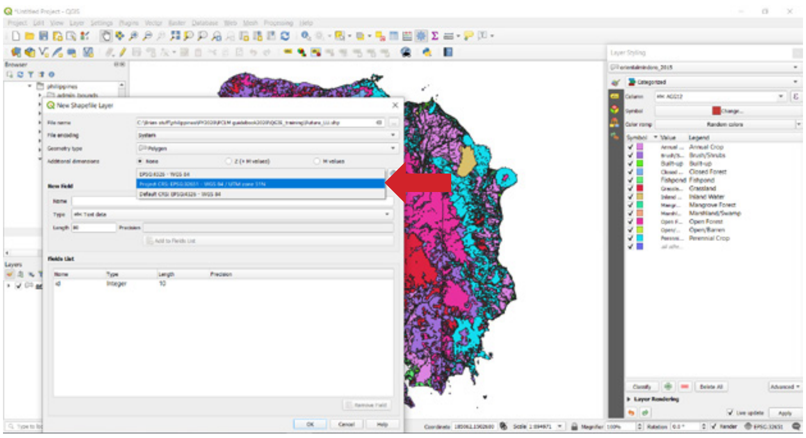
c Change the geometry type from "Point" to "Polygon".

d For additional dimensions, specify "None"

e Set the coordinate system and map projection to match the other GIS datasets (WGS 1984, UTM Zone 51N).

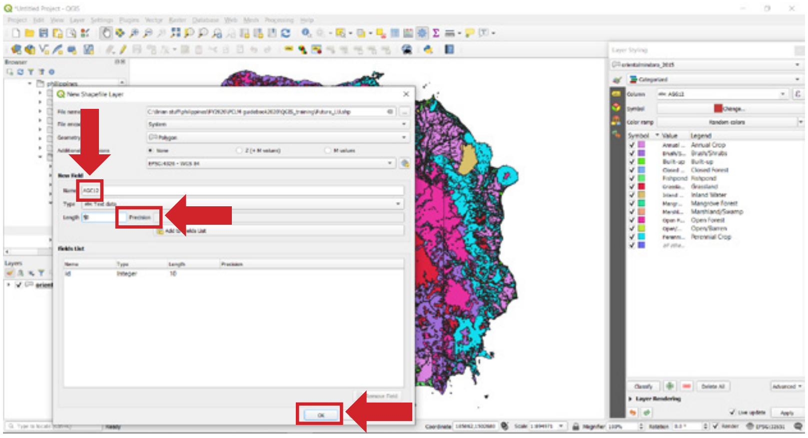


f Add a New Field to the file, called "AGC12". This field will contain the future land-use class information of each polygon that you will digitize. Set the Type to Text data, and the Length to 50. Click the "Add to Fields List" icon.

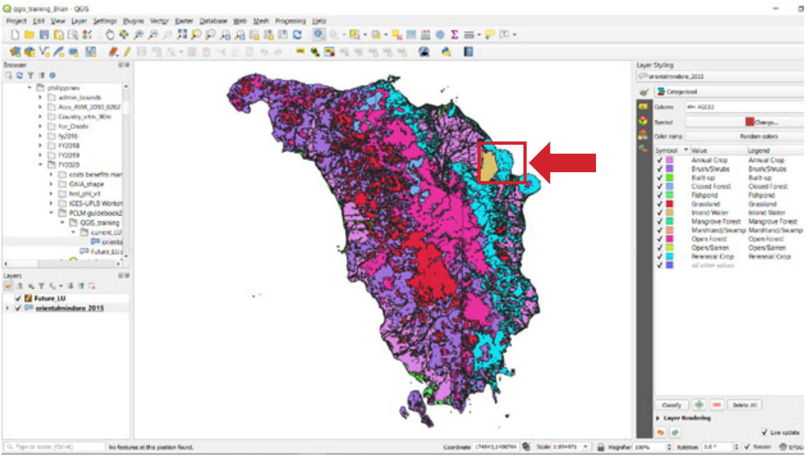


For now, this is just an empty shapefile. As the next step, we need to digitize polygons representing the future land-use of the watershed.

g Make sure everything matches the screenshot below. Then click "OK"

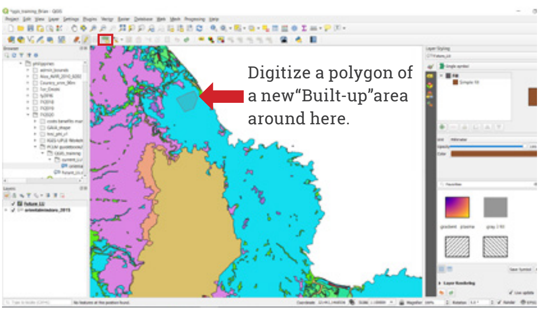


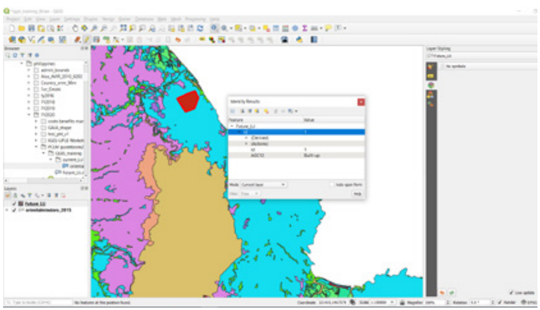
h Highlight the "Future_LU" layer in the Layers window, and click the Toggle Editing icon .



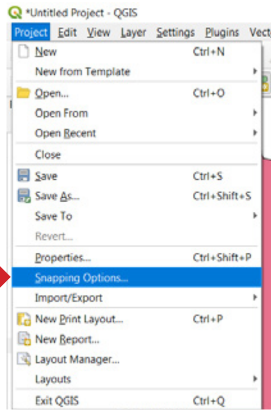
i Now zoom to a location having a current land-use of "Annual Crop". It is light purple in the map we generated, but may appear differently on your screen. To check, you can use the "Identify Features" tool from Step 3a. As one example, you can zoom into the area shown in the screenshot below:

j After zooming in, try digitizing a new polygon representing the "Built-up" land-use class. Click the Add Polygon Feature icon . Left click in the map display at a location where you'd like to start digitizing a polygon feature, then keep left clicking to add vertices (corners) of the polygon. When you've got the shape you want, right click to close the polygon. For this exercise, just try adding 5-6 vertices for the polygon, like the example shown below. (If you aren't happy with the polygon you made, and want to redo it, click the Undo icon). Add a unique ID number (1) and a land-use class (Built-up).

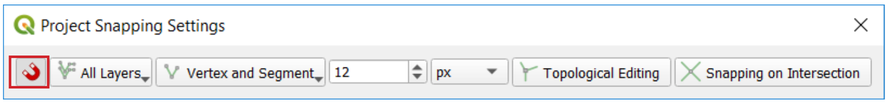




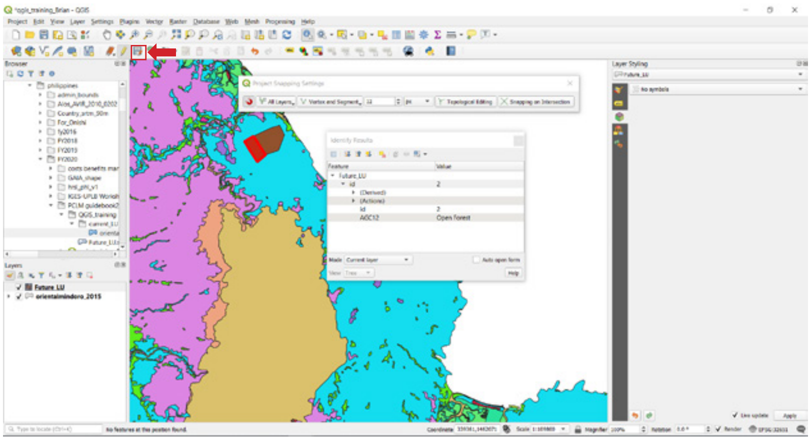
k Turn on “Snapping” to that the digitized polygons snap to one another, to allow for easier mapping. Click the “Project” menu, then “Snapping Options”.



l Click the “Enable Snapping” icon. Choose “Vertex and Segment”. This will ensure that polygons you digitize will snap to the existing polygons, and help avoid topological errors like overlapping polygons or gaps between polygons.



m Digitize another polygon with 4 vertices, this time of an “Open Forest” land-use feature. Digitize it adjacent to the “Built-up” polygon you digitized earlier to practice snapping, and assign it an ID of 2.



n Try digitizing a few more polygons of the other types of land-use features. Assign a different color to each land-use class in this new layer. Go back to Step 4(b) if you need to refresh your memory of how to do this. [Note: In a real situation, you would need to digitize polygons covering your study area of interest, so it may take some time to complete.]

o Finally, save your edits by clicking on the “Save Layer Edits” icon!!!!

Congratulations, you’ve learned the basics of displaying and digitizing land-use data in QGIS!

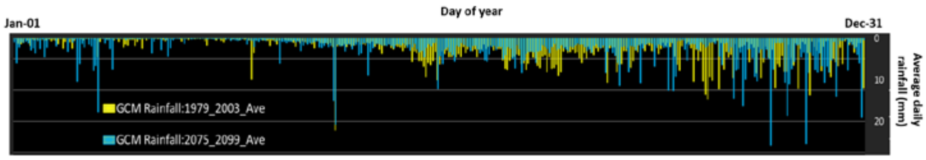
For a longer and more general QGIS tutorial, please also check the QGIS website:
[https://docs.qgis.org/3.4/en/docs/training_manual/create_vector_data/create_new_vector.html.](https://docs.qgis.org/3.4/en/docs/training_manual/create_vector_data/create_new_vector.html)

References

Endo, I., Magcale-Macandog, D. B., Kojima, S., Johnson, B. A., Bragais, M. A., Macandog, P. B. M., & Scheyvens, H. (2017). Participatory land-use approach for integrating climate change adaptation and mitigation into basin-scale local planning. Sustainable cities and society, 35, 47-56.

Iizuka, K., Johnson, B. A., Onishi, A., Magcale-Macandog, D. B., Endo, I., & Bragais, M. (2017). Modeling future urban sprawl and landscape change in the Laguna de Bay Area, Philippines. Land, 6(2), 26.

Chapter 3: Climate change scenario analysis



Pankaj Kumar
Brian A. Johnson

Overview of this chapter

Due to increasing greenhouse gas (GHG) concentrations in the atmosphere, the Earth's climate is changing at the global scale. The main change is increased global temperatures, while the magnitude of the temperature changes varies from location to location. Climate change is affecting the water cycle as well, leading to more rainfall in some regions and less in others, and changing the seasonal rainfall patterns in many places (causing more/less drought or flooding, depending on the geographic region). To better understand local climate changes, projections from global climate models (i.e. general circulation models; GCMs) or regional climate models (RCMs) are typically downscaled using statistical approaches, and then bias-corrected using local climate observation data. These downscaled and bias-corrected climate projections can be extremely useful for estimating the local impacts of climate change and identifying appropriate adaptation actions.

After completing the chapter, you will be able to:

This chapter will introduce you to GCMs and downscaling, and show you how to access downscaled climate data.

- Understand what GCMs are and how they are generated;
- Download GCM data (future precipitation and temperature climate variables); and
- Visualize the climate change projection using QGIS software.

Main concepts

Climate change and its impacts

Climate change is caused by a variety of natural and anthropogenic factors. Some natural factors affecting climate include variations in solar radiation and the occurrence of volcanic eruptions. Human activities like burning of fossil fuels and deforestation, however, are believed to be the main drivers of climate change (due to increased concentrations of greenhouse gasses (GHGs) in the atmosphere).

Global climate change is disrupting the ways that people live and interact with their environment. Some of the impacts of climate change include the alteration of natural ecosystems, interruption of food production and water supply, damage to infrastructure, and human morbidity and mortality (e.g. from increased heat stroke, drought, or climate-induced disasters) (IPCC, 2014). The consequences of climate change are already becoming evident in terms of the changes in the amount, intensity and frequency of precipitation, and temperature in many parts of the world.

The hydrosphere is possibly the most negatively affected component of the Earth system. Considering freshwater as a finite resource, many scientific studies have focused on evaluating the effects of climate change on precipitation patterns and hydrologic regimes (Dore 2005, Kleinn et al. 2005, Abbs et al. 2007). These studies and other similar ones have highlighted the impacts of climate change on regional precipitation trends, which include increased flooding and drought as well as deteriorating water quality in many regions. Developing nations, many of which have inadequate infrastructure and/or water governance systems, are likely to be most significantly affected. Asia, having the highest gap between freshwater supply and demand, is expected to bear the brunt of these global changes.

Climate change projections

It is difficult to precisely predict the future climate at a specific location (e.g. city or town) due to uncertainties from climate models and various other sources. Understanding of the general trend of climate change and variability, however, is important for impact assessment and climate change adaptation. Climate projections are the main tools used to understand the expected impacts of climate change on different sectors of a country. Climate projections consist of a synthetic time-series of climate variables, such as daily or monthly precipitation and temperature. These climate projections are derived from general circulation models (GCMs), also called global climate models. A GCM is a mathematical model of the general circulation of the planet's atmosphere or oceans, and is based on mathematical equations that represent the physical processes described in figure 3.1. GCMs simulate the responses of changes in greenhouse gas concentrations, and provide estimates of climate variables in the future (Mishra and Herath, 2011).

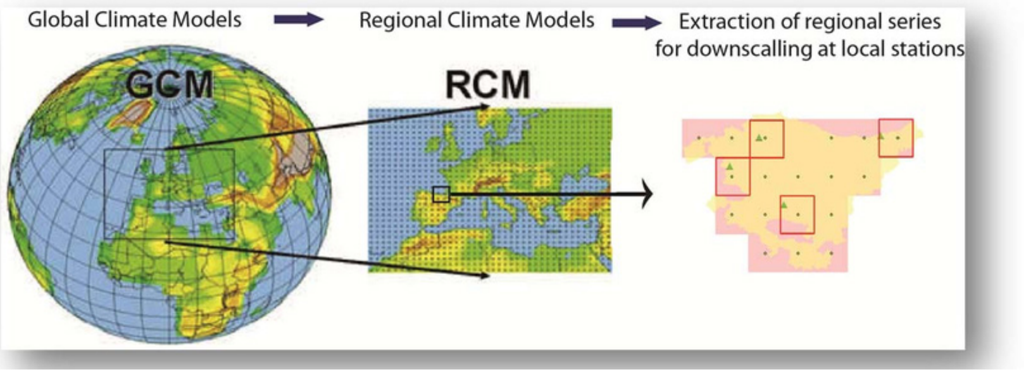


Figure 3.1. Climate model data (adopted from Aparicio and Zucker, 2015)

The GCM outputs are based on coarse resolution information (e.g. orography and elevation) for the generation of climatic variables, and are typically of a coarse spatial resolution (hundreds of km pixel size). However, forcing and circulation that affect local climate generally occur at much finer scale than that of GCM. Therefore, direct use of GCM outputs is not suitable for local climate change impact assessments, and hence spatial downscaling is required. Spatial downscaling is the process of deriving finer resolution (i.e. local) of climate data from the coarse GCM output for the climate change impact studies at local level. There are various downscaling techniques to convert the GCM outputs into locally applicable climate data. Although we will not discuss them in detail here, more information on downscaling methods can be found in Mishra and Herath (2011).

GCMs (and the downscaled data from them) are generated based on estimated future greenhouse gas emissions, which are calculated for different socioeconomic scenarios. The most widely-used of these socioeconomic scenarios are the so-called "representative concentration pathways" (RCPs), including RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (Moss et al. 2010). The RCPs are labeled according to the approximate global radiative-forcing level at 2100, with RCP 2.6 estimating the lowest amount of climate change by the year 2100, and RCP 8.5 estimating the highest amount of climate change by 2100.

Tutorial

Step 1. Downloading GCM data

Although GCM data can be downloaded from various sources, the most common one is from IPCC, as shown below.

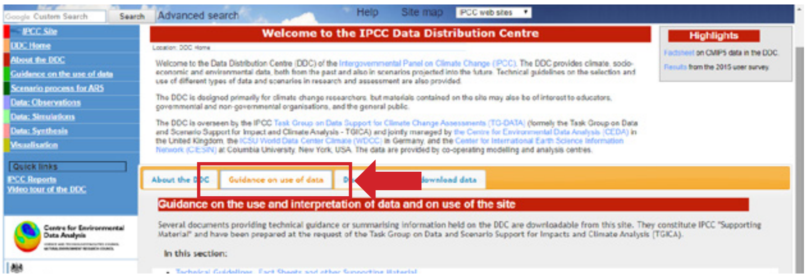
Figure 3.2. GCM data source from IPCC website

Please follow following steps to download GCM data from this site:

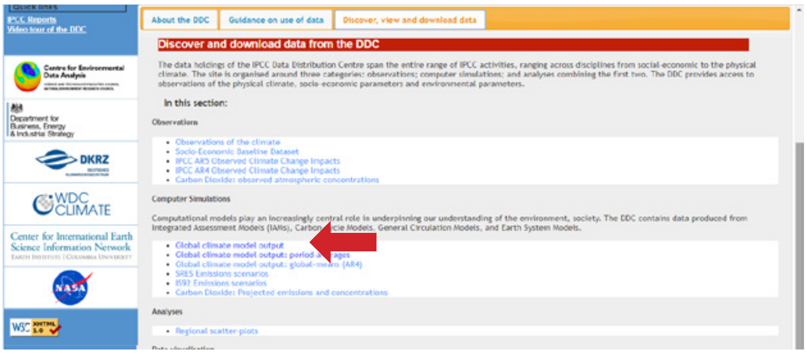
a Go to Intergovernmental Panel on Climate Change (IPCC) data distribution site: https://www.ipcc-data.org/

b Click the tab “guidance” to get different guidelines regarding how to select scenarios, fact sheet and scenario processes for IPCC Assessment Report 5 (AR5). This site has both past climatological data as well as projected data.

c Now click the tab discover, view and download data. This page has all the observed climate data, IPCC Assessment Report 5 (AR5) observed climate change impacts. Most importantly, this page has the global climate model outputs, as shown below.



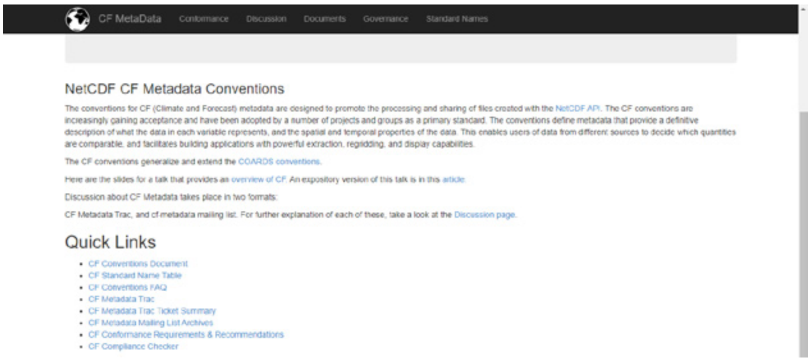
d Click “Global Climate Model Output” link, and following page will open



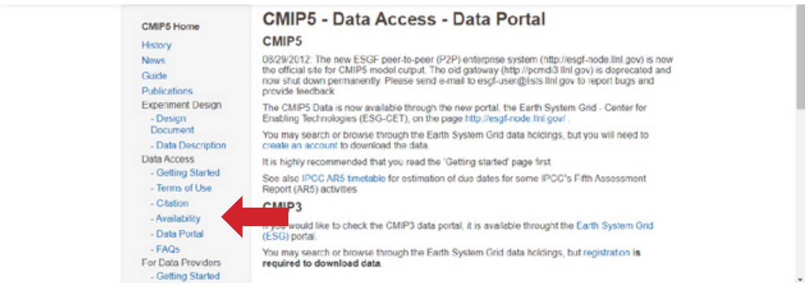
e Click “Results from GCM-Runs for the Fifth Assessment Report (AR5) based on the IPCC-RCP scenarios”, and following page will open.

All the outputs shown here are from The IPCC’s Fifth Assessment Report (AR5), which relies heavily on the Coupled Model Intercomparison Project, Phase 5 (CMIP5), a large climate modelling process coordinated by the World Climate Research Programme (WCRP). The format for GCM output from all the RCP is in NetCDF/CF. NetCDF files can be opened and visualized in QGIS. For more details, please click the link output format NetCDF/CF (an overview is shown in the screenshot below http://cfconventions.org/).

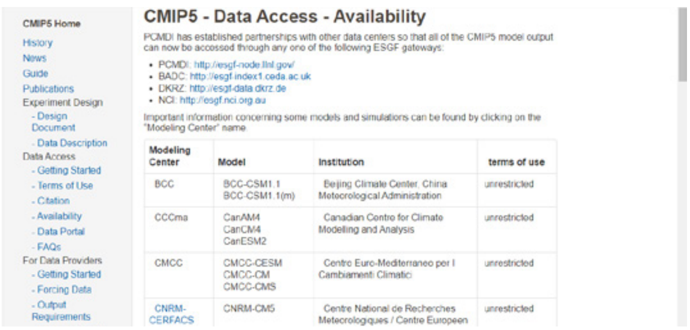
f To get data for a particular location, you need to click on following link: https://pcmdi.llnl.gov/mips/cmip5/data-portal.html., and the page below will open:



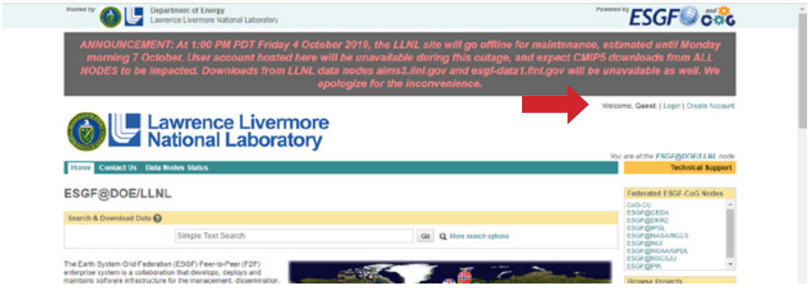
g Click “availability” on the left hand side menu and following page will open. Click the “PCMDI” link to go to the webpage for downloading the climate model data.



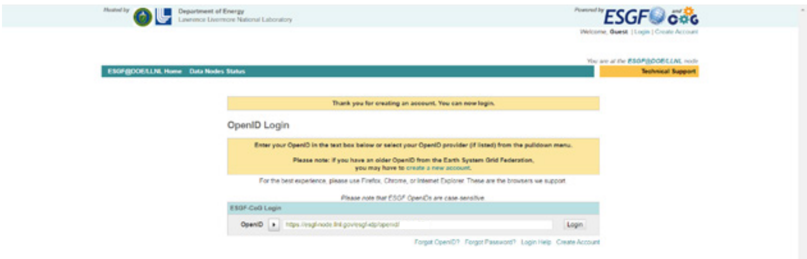
h Before downloading the data, first you need to create account by clicking “Create Account” in top right corner.



i After clicking the link, add the requested information (email address, user name, password, First/Last name, etc.) and you will receive an “OpenID Login”. After inputting this OpenID and clicking the Login button, you can enter your user name and password.

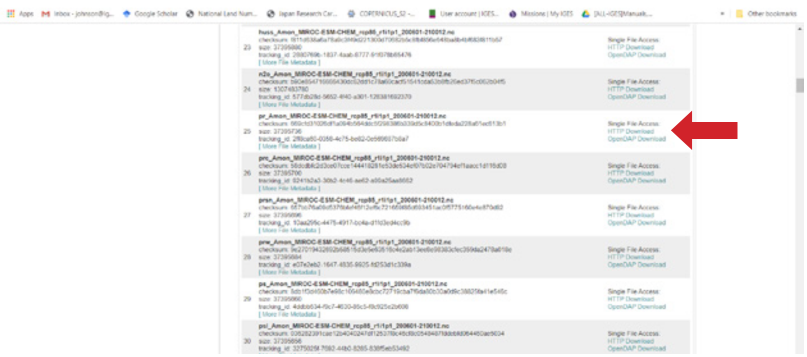


j After logging in, click on the CMIP5 link as shown below.



k The webpage below will open. Now you can choose which climate model and climate variables to download data for. Please click the + icon next to “Project” to expand the list of projects, and check on the box next to “CMIP5”. Next, click the + icon next to “Experiment” and check the box for “rcp85”. Finally, click the + icon next to “Variable Long Name” and check on the boxes next to “Air Temperature” and “Precipitation”. Once all of these model components are selected, click the “Search” box and the available models will be displayed. The first model displayed is MIROC-ESM-CHEM, generated by the University of Tokyo, the National Institute for Environmental Studies, and the Japan Agency for Marine-Earth Science and Technology.

l Click on “List Files” for the first model in the list (“MIROC-ESM-CHEM”)… To download the precipitation climate data (“Precipitation flux”), click the “HTTP Download” link for the variable number 25, “pr_Amon_MR-ROC….”. To download the Precipitation data, click the “HTTP Download” link for the variable “prc_Amon…”



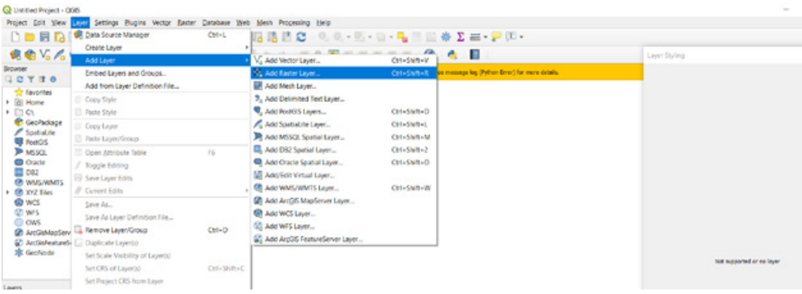
Step 2. Opening the climate model data in QGIS

Although GCM data can be downloaded from various sources, the most common one is from IPCC, as shown below.

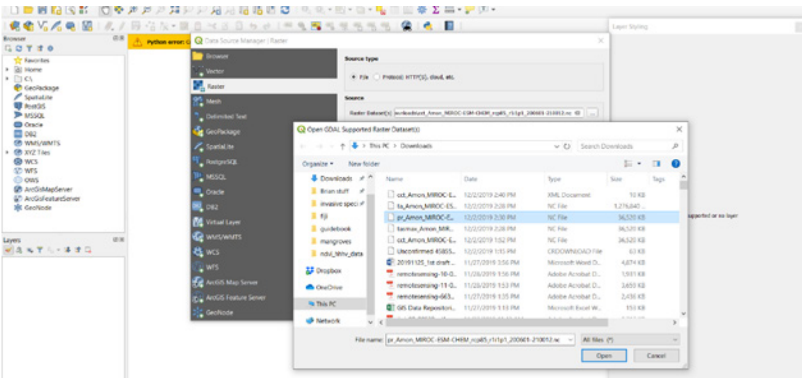
a Open QGIS software (See Chapter 2 if you don't remember how to do this!).

b Click on the "Layer" menu and then click "Add Raster Layer".

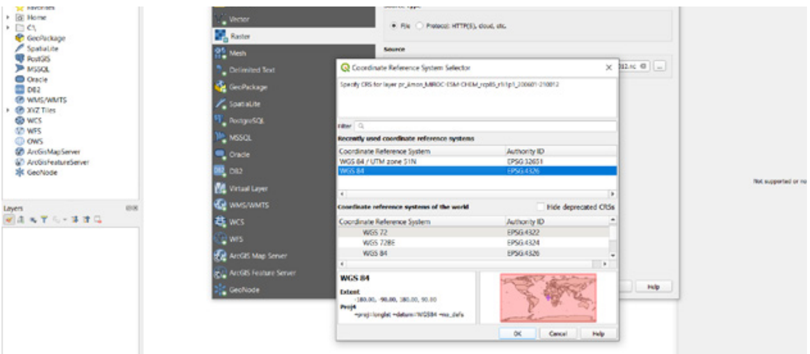
c Select the NetCDF file "pr_Anon...." and click "Open".



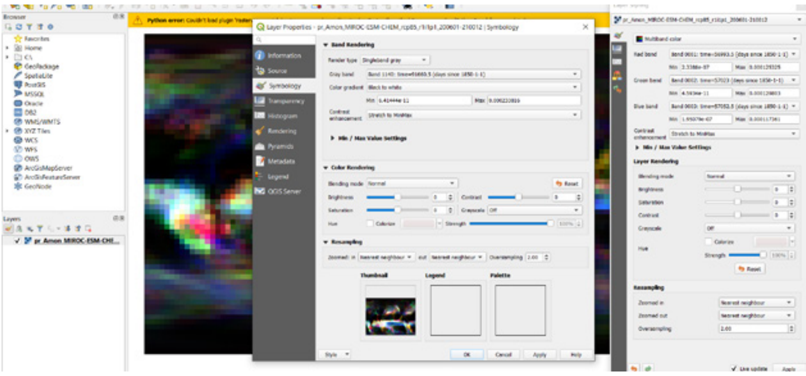
d Then click "Add". Then choose the desired coordinate reference system ("WGS 1984") and click "OK" to add the NetCDF layer in QGIS.



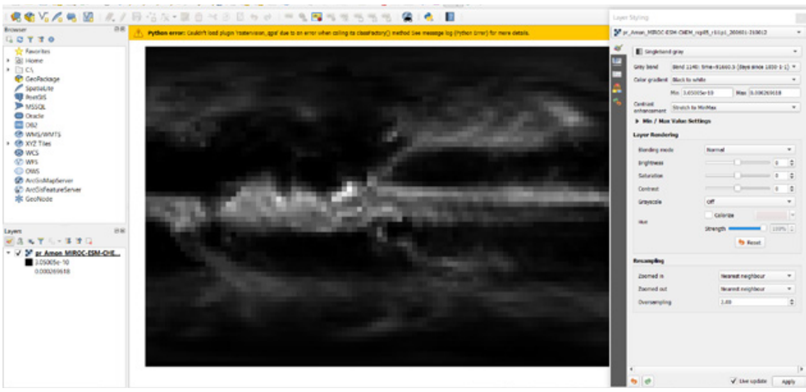
e To understand this layer, click on it in the "Layers" menu. By default, it shows as a "Multiband color" image, with model results for 3 years shown as a color map.



f Change this to “Singleband gray” to visualize the climate model results for a single month. As you can see, the dates are indicated by the number of days since 01/01/1850 (January 01, 1850). Please select Band 1140: time =91660.5 (days since 1850-1-1), this corresponds to the month of December in the year 2100.



g As you can see, the resulting map shows the spatial distribution of precipitation for the month of December in the year 2100. To convert these precipitation flux measurements (in units of kg/m2/s) to average millimeters of precipitation per day, these values would need to be multiplied by 86,400. To convert to monthly precipitation, they would then be multiplied by the number of days in the month of interest (i.e. 31 in the case of December).



h Now try to download and display the data for the average maximum monthly temperature variable (“tasmax” variable)

Congratulations, you’ve learned how to download and visualize climate model data in QGIS!

The global climate model results shown in this Chapter were very coarse in scale (300km x 300km spatial resolution). In practice, they would need to be downscaled to a finer resolution using statistical approaches, and bias corrected. Downscaled climate data for different regions are available from various sources including the Asia-Pacific Climate Change Adaptation Information Platform (AP-PLAT: https://ap-plat.nies.go.jp/). These downscaled data also typically come in NetCDF format, so the methods presented in this tutorial can be used to visualize downscaled data of your study site of interest. We are, however, happy to provide additional trainings for the downscaling and bias correction processes.

References

Aparicio, I.G., Zucker, A. (2015) Meteorological data for RES-E integration studies- State of the art review; EUR 27587; 10.2790/349276.

Chapter 4: Coastal vulnerability impact assessment using InVEST software

Rajarshi Dasgupta
Brian A. Johnson

Overview of this chapter

In this chapter, we will learn how to use the InVEST Coastal Vulnerability Modelling tool. This tool can be used to measure and communicate the vulnerability of the shoreline to coastal flooding and erosion by taking into account the local wind/wave exposure, land elevation, and land-use/land-cover. InVEST is particularly useful for assessing the benefits of ecosystems in terms of shoreline protection, as it can consider different scenarios, e.g. with and without the presence of coastal ecosystems. This chapter will show you how to create your own coastal vulnerability maps, which can help to visualize the threats associated with coastal hazards and the capacity of coastal ecosystems to partially mitigate these threats.

After completing the chapter, you will be able to:

- Perform basic data collection and pre-processing the data
- Estimate current and future vulnerability from wind and waves
- Interpret a coastal vulnerability map for risk sensitive land-use planning

Main concepts

Coastal areas are exposed to hazards coming from the sea (e.g. typhoons, tsunami, sea-level rise) as well as land (e.g. river floods and landslides). Thus, disaster risk reduction and climate change adaptation measures are particularly critical in coastal areas. Because coastal areas are also often biodiversity hotspots, measures which can effectively utilize natural ecosystems to mitigate hazards are highly desirable.

Ecosystem-based Adaptation (EbA) is an approach that uses natural ecosystem services as part of a holistic climate change adaptation strategy (Vignola et al., 2009). Various types of measures can broadly be considered as EbA measures, including the conserving/restoring/sustainable management of ecosystems, if they contribute to increasing the resilience of local communities to climate-related hazards. EbA also ensures a variety of ecological benefits, such as food, fodder, recreation etc. Many researchers also regard EbA as Nature-based Solution (NbS). Nature-based solutions (NbS) broadly aim to use nature in tackling challenges of the climate change, natural disaster and a host of other issues such as food security, and water resource management. For example, studies revealed that mangroves and other coastal ecosystems can provide great resilience to natural hazards, therefore, restoration and conservation of mangroves are often linked with coastal development polices. At the same time, restoration of mangroves can control erosion of muddy coasts, hence, can be considered as EbA measure to combat sea level rise. In the remainder of this Chapter, we will introduce a model that can be used to evaluate the benefits of natural ecosystems in reducing coastal vulnerability to hazards (focusing specfically on storm surge and coastal erosion hazards).

InVEST Model

InVEST stands for integrated valuation of ecosystem services and tradeoffs. This is a suite of spatially-explicit ecosystem services modeling tools developed by the famous Natural Capital Project of Stanford University. InVEST is a set of 28 biophysical models (many others are under development), which run independently, or as script tools in the QGIS/ ArcGIS/ ArcTool Box environment. All of these models are spatially explicit, and thus, use maps as input and generate maps as output. It feeds on spatial information, while the scope of non-spatial information that can be incorporated but more restricted. All of the calculations in InVEST are done at the pixel scale (e.g. a 30 meter x 30 meter grid cell for many commonly used land-use maps). InVEST model is generally requires limited data, and therefore applicable even in data-deficit regions. The spatial resolution of this model is also flexible, allowing users to operate at any scale, ranging from local, regional, to even global. This gives it an advantage over conventional ecosystem service modelling tools, which are generally bounded by scales and require a lot of primary data generation. However, as there is no functionality in InVEST for manipulating or viewing the map inputs/outputs, we need to use other GIS software like QGIS or ArcGIS to prepare the map inputs and view the modelling results. Therefore, to operate InVEST, a basic understanding of GIS software is necessary. You will use some of what you learned in Chapter 2 to view the inputs/outputs of InVEST.

The InVEST Coastal Vulnerability model calculates an exposure index rank in a five point scale for each point along a coastline. The index represents the relative exposure originating from coastal erosion and inundation caused by storm surges. The index takes account of seven bio-geophysical variables, namely, relief, ecological characteristics across the region, the rate of sea-level rise, the local bathymetry, topography, the relative wind, population density and wave forcing associated with storms (see Figure 4.1. for a description of how to set and interpret the exposure values). Values from 1-5 are set for each of these seven variables, and the final result final output of the model is a geospatial dataset showing points spaced at a user-defined interval (e.g. every 100m along the coast), with the average exposure of each point location to coastal hazards (i.e. average value of the seven input variables at that location). These values range from 1 (very low) to 5 (very high) coastal exposure.

	Level of exposure				
Rank	**1 (very low)**	**2 (low)**	**3 (moderate)**	**4 (high)**	**5 (very high)**
Geomorphology	Rocky; high cliffs; fjord; fiard; seawalls	Medium cliff; indented coast; bulkheads and small seawalls	Low cliff; glacial drift; alluvial plain; revetments; rip-rap walls	Cobble beach; estuary; lagoon; bluff	Barrier beach; sand beach; mud flat; delta
Relief	81-100 Percentile	61- 80 Percentile	41 - 60 Percentile	21 - 40 Percentile	0 - 20 Percentile
Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass; kelp	No habitat present
Sea Level Change	0 - 20 Percentile	21 - 40 Percentile	41 - 60 Percentile	61 - 80 Percentile	81 - 100 Percentile
Wave Exposure	0 - 20 Percentile	21 - 40 Percentile	41 - 60 Percentile	61 - 80 Percentile	81 - 100 Percentile
Surge Potential	0 - 20 Percentile	21 - 40 Percentile	41 - 60 Percentile	61 - 80 Percentile	81 - 100 Percentile

Figure 4.1. List of Bio-geophysical variables and exposure ranking system in InVEST Coastal Vulnerability Index. Adapted from Table 4.1 from http://releases.naturalcapitalproject.org/invest-userguide/latest/coastal_vulnerability.html.

Tutorial

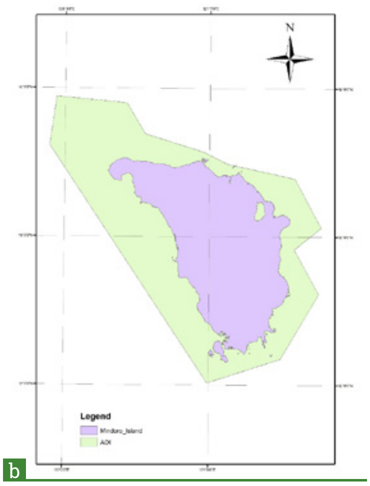
In the following tutorial, you will learn how to run the InVEST Coastal Vulnerability Index model. As with other InVEST components, data preparation is the primary task, and any GIS software can be used for data preparation. The following examples are created using QGIS. For the simulation, we will use a dataset for Mindoro island, Philippines. As mentioned above, CVI requires the following datasets, namely the (1) Area of Interest (shapefile), (2) Landmass (shapefile), (3) WaveWatchIII vector data (grid points as well as wave and wind variables that represent storm conditions at that location), (4) Maximum Fetch Distance, (5) Bathymetry in raster format, (6) Digital Elevation Model (raster), (7) Elevation averaging radius, (8) Continental Shelf Contour, (9) Habitats Table, (10) Population density (optional), and (11) Sea Level rise (Optional).

Step 1: Open QGIS and create/display the AOI file

For InVEST CVI Modelling, the Area of Interest (AOI) file roughly delineates the outer boundary of the study site. The AOI file should be a polygon vector file (i.e. .shp file) having a 'projected' coordinate system, which must be displayed in the units of meters. Generally, the spatial extent covered by the AOI file should be made larger than the actual study area of interest (to make sure no parts of the study area are excluded). Hence, when you digitize an AOI polygon file, make sure all parts of the land area are covered!

a Open QGIS and add the "mindoro_boundary.shp" file, located in the "MINDORO_SIMULATION" folder.

b Digitize a polygon slightly larger than the extent of the "mindoro_boundary.shp" map, similarly to the figure shown here. Make sure you are using the same projected coordinates as the "mindoro_boundary.shp" map (i.e. UTM Zone 51N). If you forgot how to digitize polylgons in QGIS, refer back to Chapter 2 of this guidebook. (Alternatively, you can use the file that we have already prepared, called "AOI.shp".



b

Step 2: Create a Landmass shape file in QGIS

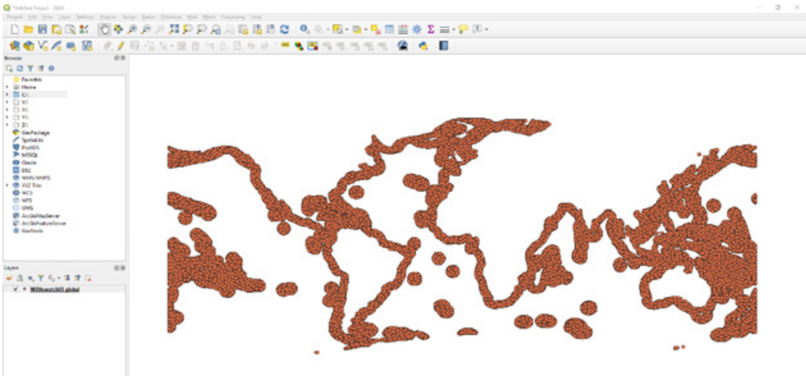
The Landmass polygon input provides the model with a map of all landmasses in the region of interest. A global land mass polygon shape file is provided as default in InVEST , but you may prefer to create one in QGIS. We have already extracted the polygon boundary for Mindoro Island for the sake of this tutorial.

a Add the "landmass_polygon_Mindoro.shp" file in QGIS to visualize it

Step 3: Display the WaveWatchIII vector file in QGIS

This vector contains a grid of points as well as wave and wind variables that represent storm conditions at that location. These variables are used to compute the Wind and Wave Exposure ranking of each shoreline segment. In-VEST model supplies nearly the entire ocean coverage for this type of data.

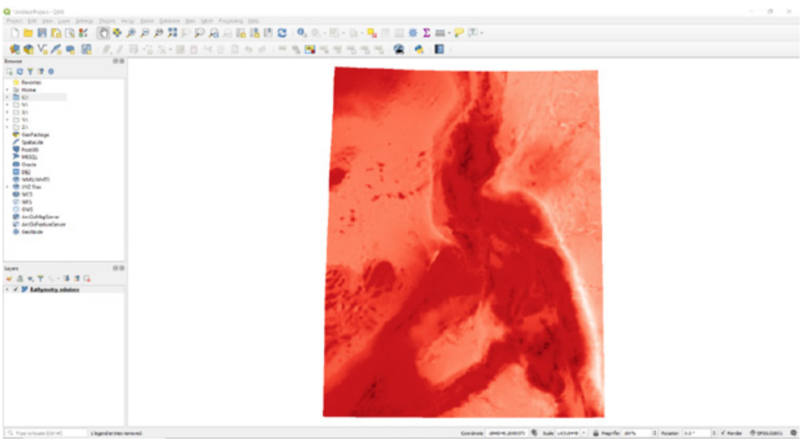
a Please add the "WAVewatchIII_global.shp" file in QGIS. The InVEST model will automatically take the data from the nearest points to the study area, so we do not need to crop and edit this data.



Step 4: Display and Edit the local Bathymetry data

This raster input is used to find average water depths required for wave height and period calculations. Please note that bathymetry values should be negative (in meters below sea-level). The raster should cover the entire offshore area extending beyond the AOI by at least the distance of the Maximum Fetch Distance. All nodata and positive values are masked before calculating the average depth along a fetch ray. So it is okay if this raster also includes onshore elevation data.

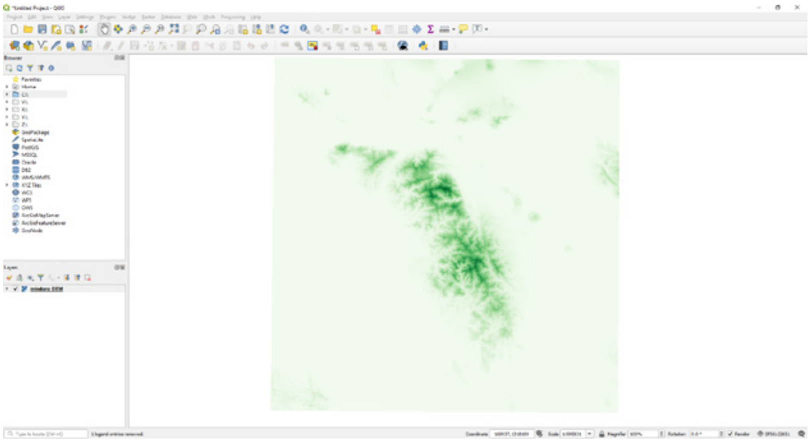
a Add the "Bathymetry_mindoro.tif" file in QGIS. This file contains bathymetry for almost the entire extent of the Philippines. This is the official data downloaded from the geological survey of the country.



Step 5: Display and Edit the Digital Elevation Model

A Digital Elevation Model (DEM) is used to compute the Relief ranking of each shoreline segment. It should provide elevation information covering the entire land polygon and some areas extending beyond the AOI.

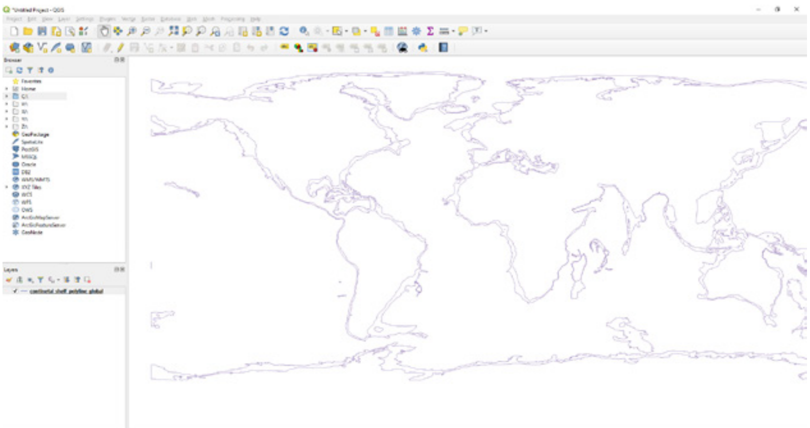
a Add the file entitled Mindoro_DEM.tif in QGIS. Note that the file extends way beyond the Minodoro Island.



Step 6: Display Continental Shelf Contour

This is a polyline input that represents the location of the continental margin or other locally-important bathymetry contour. It must be within 1500 km of the coastline in the area of interest.

a Using QGIS, open the file called continental_shelf_polyline_global.shp.

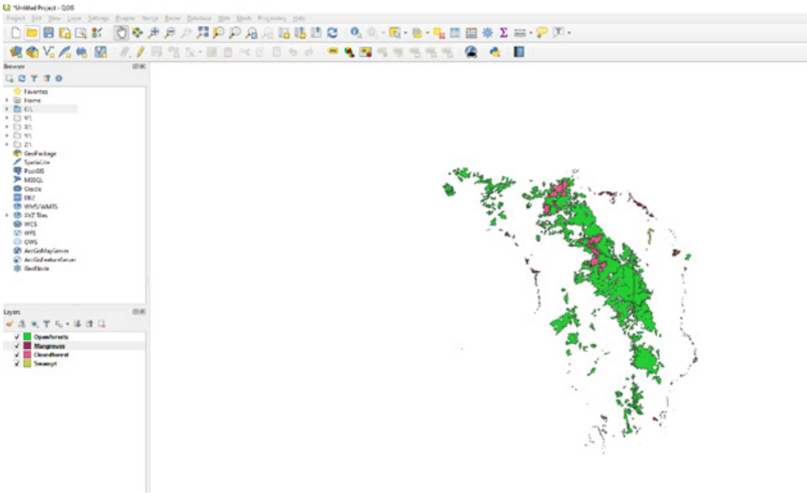


Step 7: Display the Habitat Maps and Tables

In this step, we will load habitat maps of the study site. We will load polygon shapefiles showing mangroves, swamp forests, and inland forests (open and closed forests), all of which have definite roles in protecting the coast from wind and waves. These maps can be easily prepared if you have a detailed land use map of the study area. For the sake of this tutorial, we have already prepared them.

a Load the Mangroves.shp, Swampt.shp, Openforests.shp, and Closedforest.shp files, located inside the "MINDORO_SIMULATION\Mindoro_Habitat" folder.

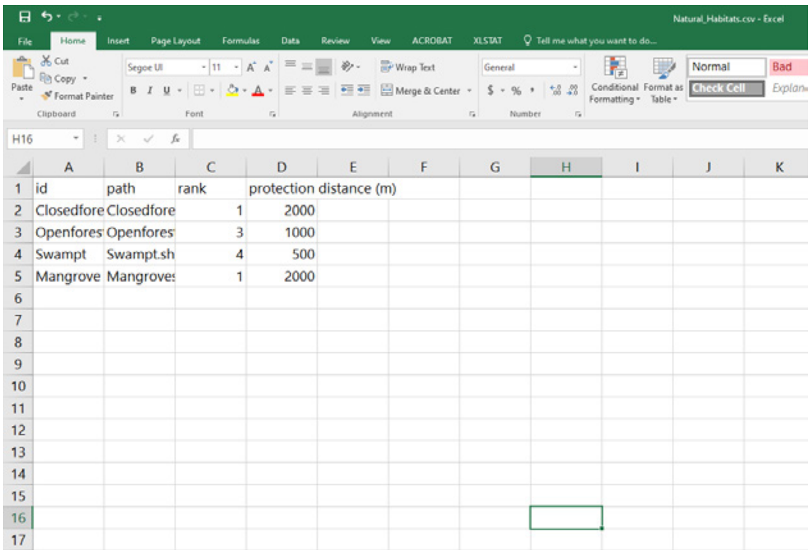
b Assign a different color for each type of habitat (e.g. mangroves as purple, open forests as green, closed forests as pink, and swamps as light green, as in the map below).



The next task is to instruct the InVEST model how to read this shapefile. For this, we need to create a table to instruct the model on habitat layer inputs and parameters.

c Create a new table in MS Excel (or other spreadsheet software). The table must have the headers "id", "path", "rank", "protection distance (m)" in the top row, as shown below. It should contain four columns, i.e. id is a text string (no spaces allowed), path is the location and filename of the habitat GIS layer, rank is an exposure value ranging from 1 to 5 (see Table 4.1. for a description of the values for each habitat type), and protection distance (m) is the distance in meters beyond which this habitat will provide no protection to the coastline.

d Assign the rank and protection distance values as shown in the image below. Once done, please save the file as Natural_Habitat.csv. Please make sure to save it as .csv file (not an .xls file!).



id	path	rank	protection distance (m)
Closedfore	Closedfore	1	2000
Openfores	Openfores	3	1000
Swampt	Swampt.sh	4	500
Mangrove	Mangroves	1	2000

Step 8: Geomorphology /Population (Optional modules)

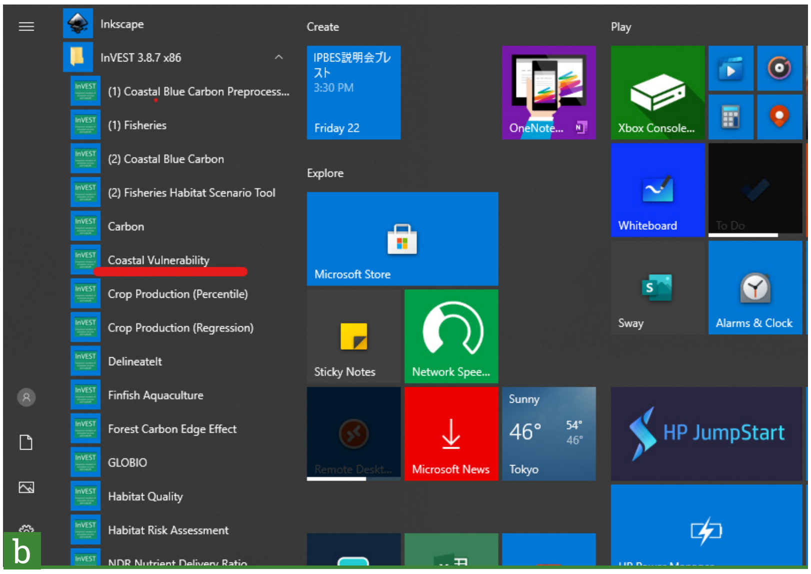
You can also add the regional geomorphology and population information, however, the model can run without these information. For the time being, we will skip these two modules.

Step 9: Open InVEST Coastal Vulnerability Model

Once you are done with data preparation, we will now start the modelling

a Download and install InVEST from the following website: https://naturalcapitalproject.stanford.edu/software/invest. Alternatively, you can find the installation file (InVEST_3.9.0_x64_Setup.exe) inside the MINDORO_SIMULATION folder. Run through the installation process.

b Go to the start menu and open InVEST. Please note once you click InVEST, there would be display of all the available models. Please click on the coastal vulnerability model.



Step 10: Model interface and data input

Once the model interface is displayed, please assign the path to the different data set you prepared in the last steps. For your convenience, the folder titled MINDORO_SIMULATION contains all the required files to run the simulation. Please follow the below mentioned instructions

a For Workspace, create a folder by the name of coastal_vilnerability_workspace under my documents where all your intermediate and results files will be stored. It is recommended to create a new directory for each run of the model. In case you do not define, the model will arbitrarily create one folder under my documents.

b For Area of Interest (vector), select the AOI.shp file from the MINDORO_SIMULATION folder.

c Set the model resolution (meters) parameter to 1000. This value determines the spacing between shore points and expressed in the units of meters. A larger value will yield fewer shore points but a faster computation time. It is recommended to keep it to 1000 unless the extent of study area is not excessively small. You may go for higher resolution in that case. Please note for higher resolution, the model will run for longer time, sometimes in hours.

d For Landmass, select the landmass_polygon_Mindoro.shp from the MINDORO_SIMULATION folder.

e For maximum fetch distance, use the default value of 10000. A numeric value in meters should be used for this, which will determine the degree to which shore points are exposed to oceanic waves. A shore point is only exposed to oceanic wave energy if, in some direction around the point, no landmass is intersected when casting a ray the length of this max fetch distance.

f For Bathymetry, please add the bathymetry_mindoro.tif file from the MINDORO_SIMULATION folder.

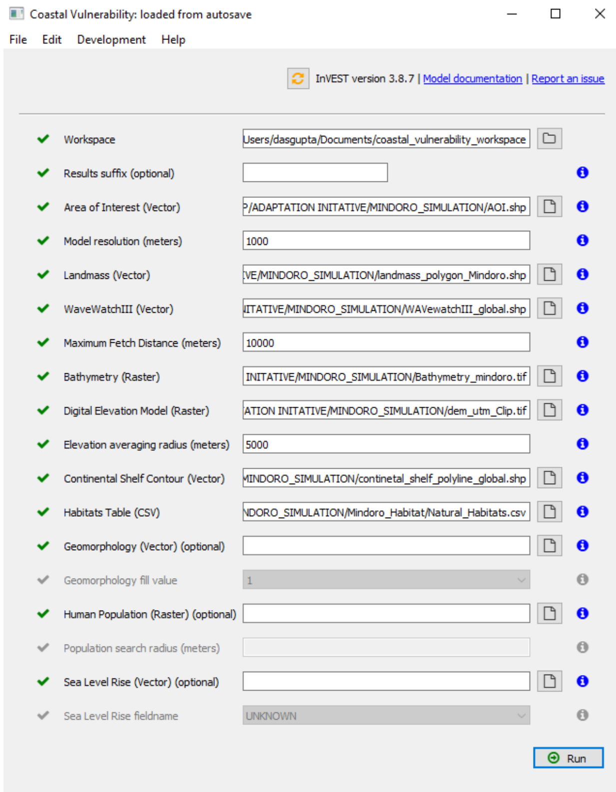
g For Digital Elevation Model, add the dem_utm_Clip.tif file from the MINDORO_SIMULATION folder.

h For Elevation averaging radius, set it as the default value of 5000. This is the radius in meters around each shore point within which to compute the average elevation.

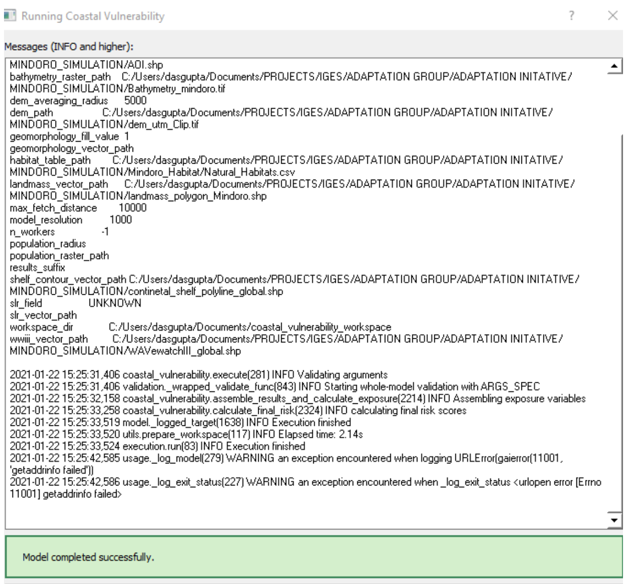
i For Continental Shelf Contour, add the continental_shelf_polyline_global.shp file from the MINDORO_SIMULATION folder.

j For Habitats Table, please add the habitat table Natural_habitats.csv from the MINDORO_SIMULATION/Mindoro_Habitat folder.

k For this tutorial, we will not use the optional geomorphology, population, and sea-level rise datasets. If you have this data for your own study site, please use it.



l Please check whether all the required fields are marked with Green checks, as shown above. If yes, Hit Run. If not, please recheck the data. Depending on the resolution of the model, it will take some time to run the entire simulation. Once complete, you will get a confirmation window like the following.



Step 10: Open the workspace and display the files

In the output folder, you will get mainly two files. (1) A point vector file by the name of coastal_exposure.gpkg (.gpkg file is a geodatabase which contain the exposure shape file) (2) An excel file containing the detailed attribute table of coastal_exposure.gpkg provided in csv format for convenience. You may further wish to modify or add to the columns of this table in case you wish to make customized scenarios. In order to display the file, please select the exposure with habitat and no habitat column to understand the contribution of coastal ecosystem services. Your final product should look something like this.

a Add the coastal_exposure file in QGIS, and modify the color scheme to range from low vulnerability (blue) to high vulnerability (red), as shown in the map legends below. If you forgot how to change the color scheme of the layer in QGIS, refer back to Chapter 2.

b Add a map title, legend, scale bar and north arrow for two maps (one with coastal habitats conserved, one without coastal habitats). Again, check Chapter 2 if you forgot how to do this. Now, your maps are complete!

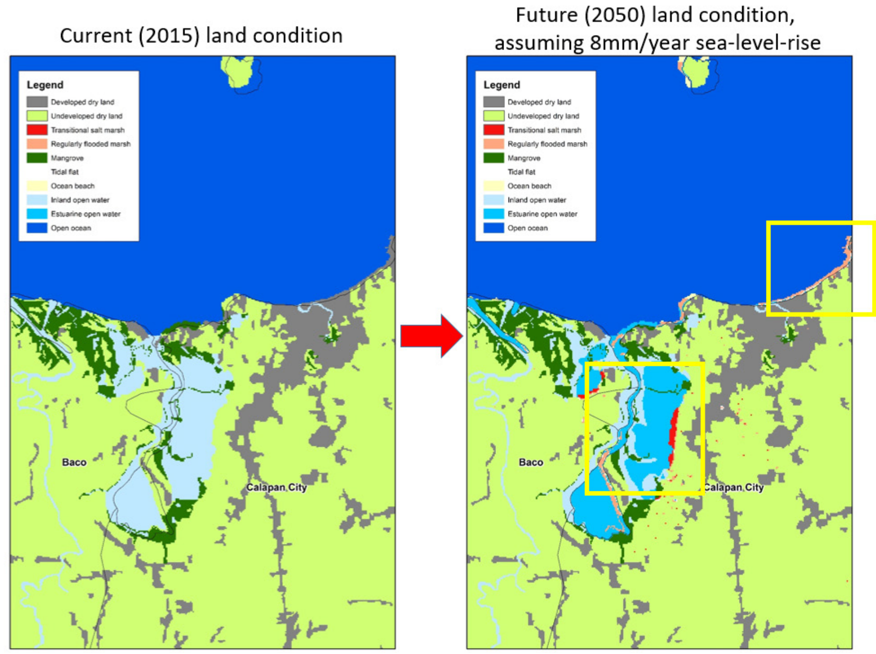
Congratulations, you've learned the basics of Coastal Vulnerability Modelling using InVEST

You can learn more from the online training manual
http://releases.naturalcapitalproject.org/invest-userguide/latest/index.html

References

Vignola, R., Locatelli, B., Martinez, C., and Imbach, P. (2009). Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists?. Mitigation and adaptation strategies for global change, 14(8), 691-696.

Chapter 5: Sea-level rise impact assessment using the Sea-Level Affecting Marshes Model (SLAMM)



Brian A. Johnson

Overview of this chapter

Climate change is already resulting in global sea-level rise, and is expected to cause further rises in sea level in the future as the climate continues to warm. The rates and impacts of sea-level rise vary from location to location, being affected by many factors including local sea-level rise rates, land subsidence/uplift rates, and soil accretion/erosion rates in coastal areas. The latter can be significantly affected by changes in land-use or land management practices. This chapter gives an overview of the impacts of sea-level rise, and demonstrates how to perform sea-level rise analysis using the free SLAMM (Sea level affecting marshes model) software. In the chapter, you will learn how to run SLAMM using different land-use and sea-level rise scenarios, and visualize the outputs of the modeling.

After completing the chapter, you will be able to:

- Understand the basics of how climate change and land-use change affect local sea-level rise impacts;
- Perform sea-level rise modeling using SLAMM software;
- Visualize the impacts of sea-level rise under different climate and land-use scenarios.

Main concepts

According to climate change projections of the Intergovernmental Panel on Climate Change (IPCC), the global mean sea level is expected to rise by 0.29-1.1 meters by the end of the century, compared to the 2005 level (IPCC, 2019). The average global sea-level rise in recent years is estimated to be around 2.8-3.2mm/year (Church and White, 2009). Local sea-level rise rates can vary significantly from the global average, as can be seen in the map of historical sea-level changes in Figure 5.1. As seen in Figure 5.1., sea-level rise rates tend to be quite high in Southeast Asia and Oceania. Various datasets containing historical sea-level rise rates exist, including those derived from satellite measurements (https://podaac.jpl.nasa.gov/dataset/AVISO_L4_DYN_TOPO_1DEG_1MO), and tide gauges (e.g. Global Sea Level Observing System: https://www.psmsl.org/gloss/). Tide gauge measurements have the benefit of also accounting for land subsidence/uplift (another important factor affecting local sea-level rise impacts), but their coverage is more limited (both geographically and temporally) than that of satellite measurements.

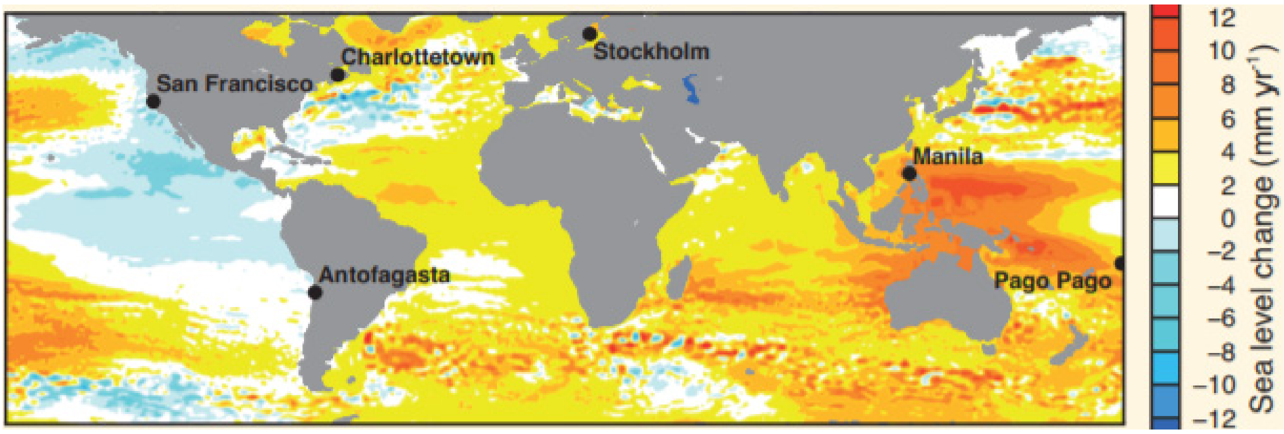


Figure 5.1. Spatial variability of sea level changes. Source: FAQ13.1 Figure 1, from Church et al. (2013).

Sea-level rise impacts can be mitigated to some degree using seawalls and other hard barriers. However, these hard infrastructure measures are costly to build and maintain, and may fail in extreme cases (e.g. during typhoons with high storm surge, or tsunami). On the other hand, nature-based solutions (NbS), which were also discussed in Chapter 4, can also help mitigate sea-level rise impacts aside from providing other benefits like reducing coastal erosion, mitigating storm surge, providing habitat, food, and fiber. Thus, NbS, as well as other "soft" measures like zoning enhancement (e.g. to ensure zero or minimal development in extremely hazard-prone areas) should be important components of coastal climate change adaptation strategies.

Mangroves are a particularly important coastal ecosystem, as they help to build-up the soil along the coastline, which raises the land elevation and thus reduces the impacts of sea-level rise and other coastal hazards (Figure 5.2.). Average rates of soil accretion in mangrove ecosystems are estimated to be 5.8mm/year (Alongi et al., 2018), which is higher than the global average sea-level rise rate. Mangrove ecosystems also mitigate a major cause of sea-level rise - greenhouse gas emissions – by sequestering an average of 171 gC/m2 (~1.9 tC/ha) annually (Alongi et al., 2018). Other types of coastal wetland ecosystems also help mitigate sea-level rise to varying degrees, but estimates of their soil accretion rates tend to be lower than those of mangrove ecosystems (Linhoss et al., 2014).

		HAZARD				
		Waves	Storm surges	Tsunami	Erosion	Sea level rise
MANGROVE FOREST PROPERTIES	Width	Hundreds of meters needed to significantly reduce waves (wave height is reduced by 13-66% per 100m of mangroves)	Hundreds of meters needed to significantly reduce wind and waves on top of surge Thousands of meters needed to reduce flooding impact (storm surge height is reduced 5 - 50 cm/km)	Hundreds of meters needed to reduce tsunami flood depth by 5 to 30% Mangroves do not provide a secure defence (nor do many engineered defences)	Sufficient mangrove forest width needs to be present to maintain sediment balance. This can help to prevent erosion and may encourage active soil build-up.	
	Structure	The more obstacles the better: dense aerial root systems and branches help attenuate waves	Open channels and lagoons allow free passage, while dense aerial root systems and canopies obstruct flow		Complex aerial root systems help slow water flows, allowing sediment to settle and causing sediment to accrete rather than erode.	
	Tree Size	Young & small mangroves can already be effective	Smaller trees and shrubs may be overtopped by tsunamis and the very largest storm surges		Young trees already enable soils to build up. The more biomass input into the soil the better.	
	Link to other ecosystems	Sand dunes, barrier islands, saltmarshes, seagrasses and coral reefs can all play an additional role in reducing waves				Allow room for landward retreat of the mangrove
	Underpinning factors	Healthy mangroves are a prerequisite for all aspects of coastal protection. Healthy mangroves require: sufficient sediment and fresh water supply and connections with other ecosystems. Conversely, pollution, subsidence (due to deep groundwater/oil extraction or oxidation upon conversion) and unsustainable use jeopardizes mangroves.				

Figure 5.2. Functions of mangrove ecosystems in coastal protection. Source: http://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf

Clearly, coastal areas benefit from protecting and restoring these ecosystems, but the benefits may be difficult to quantify without the use of computer simulation modeling. In the remainder of this chapter, we focus on how sea-level rise impact assessment can be modeled quantitatively using the Sea Level Affecting Marshes Model (SLAMM), a free software. The first version of SLAMM was developed in the mid 1980's with funding from the Environmental Protection Agency of the US (Park et al., 1986). Since then, it has undergone many improvements, and has been applied in many different sites globally to estimate sea-level rise impacts. SLAMM can consider various user-defined future sea-level rise scenarios, and outputs maps of future land-use/land cover conditions considering sea-level rise impacts (e.g. conversion of undeveloped or developed dry land to wetlands (in the case of frequent inundation) or even open water (in the case of permanent urban inundation). Within the model, sea-level rise is offset by sedimentation and accretion of the land in coastal ecosystems, and the accretion and erosion rates of different coastal ecosystems can be set for the site of analysis (e.g. according to field surveys or estimates from existing literature).

Tutorial

This tutorial focuses on sea-level rise modeling using the free SLAMM software. We have provided all of the data for this tutorial in the folder entitled "SLAMM_training".

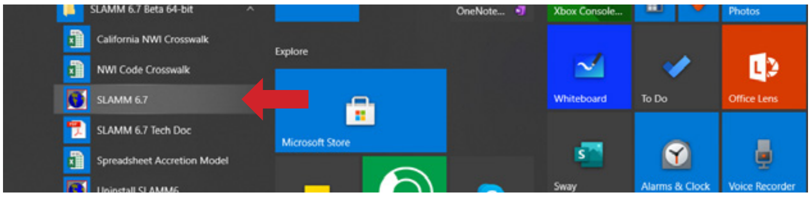
Step 1. Installing SLAMM software

The latest version of SLAMM can be downloaded from GitHub: https://github.com/WarrenPinnacle/SLAMM6.7. We have already downloaded the most recent version, SLAMM 6.7, and it is stored in the folder entitled "SLAMM6.7-master". Please navigate to this folder, and then the "INSTALL\Release\Single" subfolder, where you can find the file "" double-click the file "SLAMM6.7_64-bit.exe". Double-click this file and follow the installation instructions to install SLAMM.

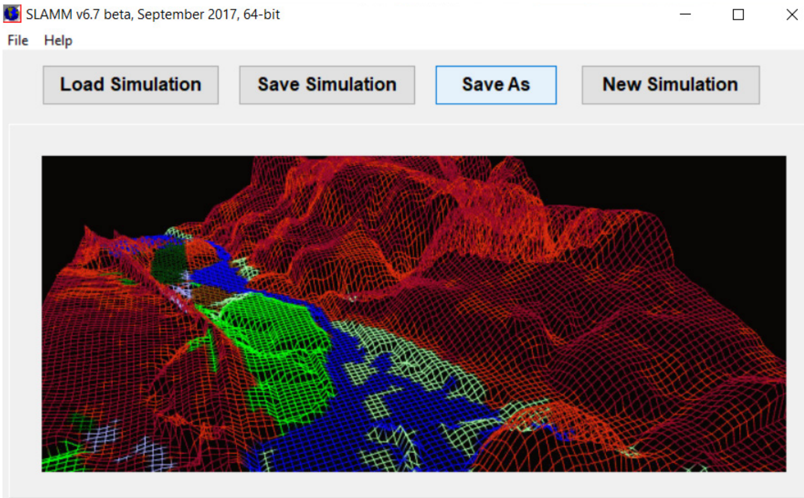
Step 2. Open SLAMM

For the sake of this tutorial, we have already downloaded QGIS and provided it to you with this training package. Let's install it.

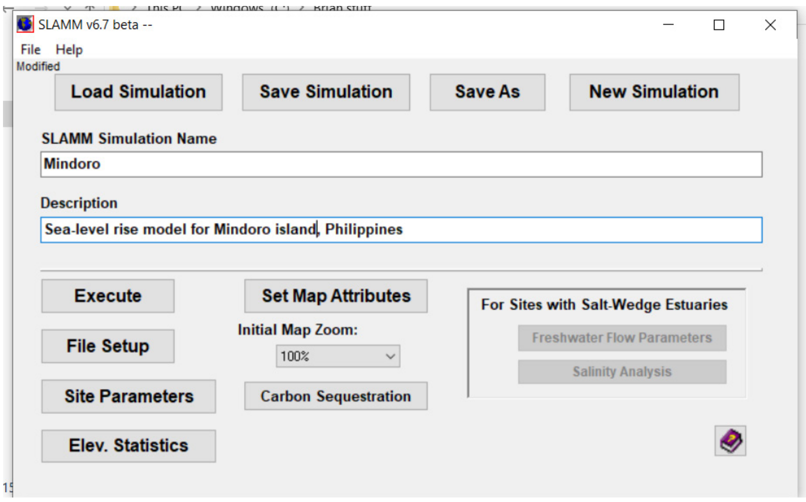
a Open SLAMM from the Windows start menu.



b The main menu of SLAMM should appear.



c Click "New Simulation" to start configuring the model. (A dialog box might appear asking if you want to use California Categories instead of classic SLAMM Categories; if this appears, click "No"). A new menu will appear. Please type the SLAMM Simulation name and Description as shown below.



d Click "Save As" to save the new model in the "SLAMM_training\SLAMM_training_outputs" folder. Please name the file "Mindoro".

Step 3. File setup in SLAMM

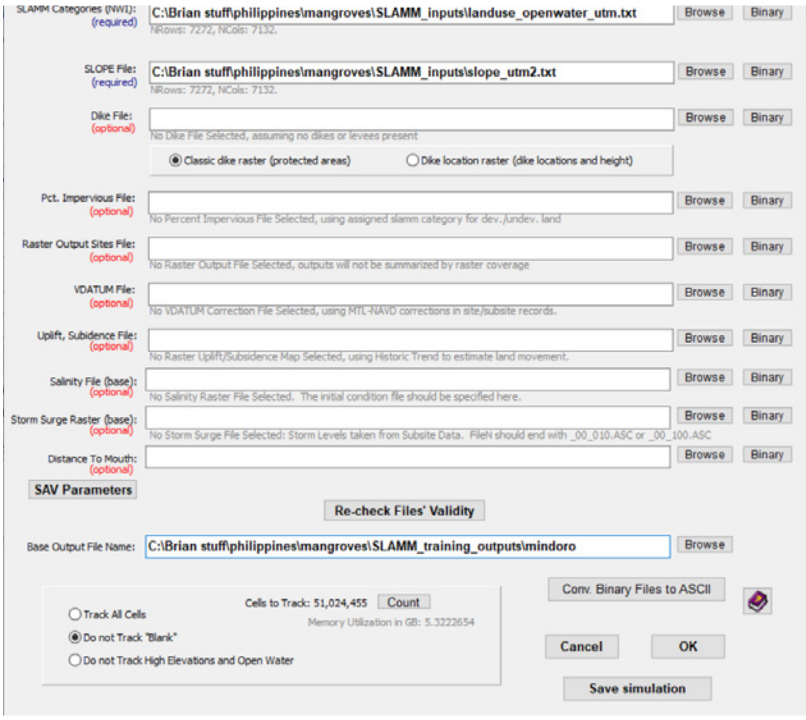
a Click the “File Setup” button to set the input data for SLAMM.

SLAMM requires, at minimum a digital elevation model, a land-use map, and a slope map. Set these files, which are found in the “SLAMM_inputs” folder, as the following:

- DEM File (elevation): “dem_utm.txt”
- SLAMM Categories (NWI): “landuse_openwater.txt” [This is the land-use map]
- SLOPE File: “slope_utm2.txt”

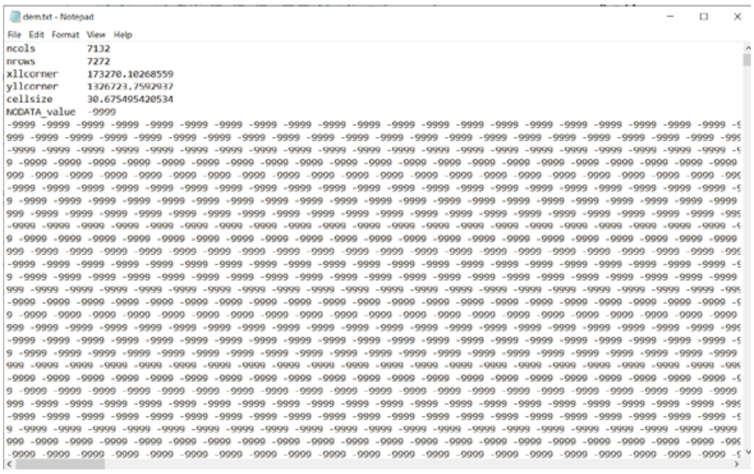
b Set the Base Output File Name. Name the file as “mindoro”, and save it to the “SLAMM_training_outputs” folder. All of the model’s outputs will be saved in this designated folder, and will have file names starting with mindoro.

c Click “Save simulation” to save these input files. Then click “OK” to exit the File Setup menu.



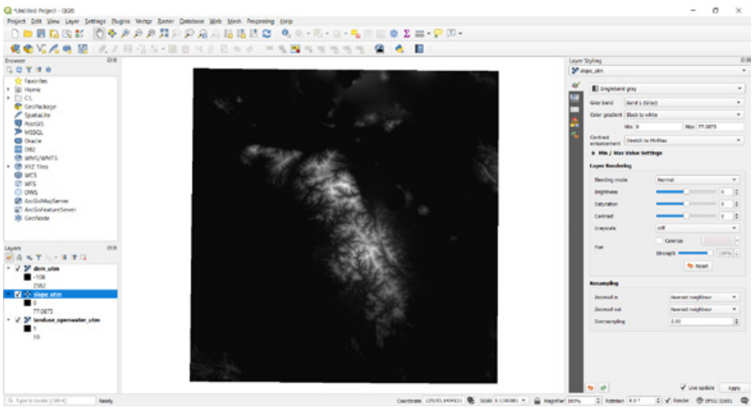
Step 4. Visualize the input files using QGIS

a These files that you have input in Step 3 are in ASCII (.txt) format, i.e. text files. Try double-clicking the "dem_utm.txt" file in the Windows Explorer to open it. You will see a text file with numbers (elevation values, and nodata values) and locational information (number of columns and rows of the DEM, the coordinates for the lower left corner of the DEM, and the cell size of the DEM). This text file also has a corresponding .tif file with the same name, which can be opened using QGIS. The other input files (landuse_openwater, slope_utm2) also have corresponding .tif files.

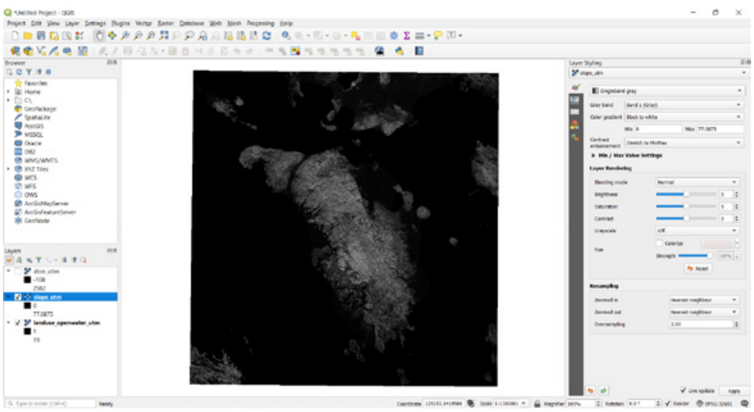


b Please open all three of the .tif files in the "SLAMM_inputs" folder using QGIS. If you forgot how to open files in QGIS, refer back to Chapter 2 for instructions!

c Check on the "dem_utm" map layer to visualize it. This is the DEM file, with each grid cell having a elevation value representing meters above a vertical datum called NAVD88 (North American Vertical Datum 1988).



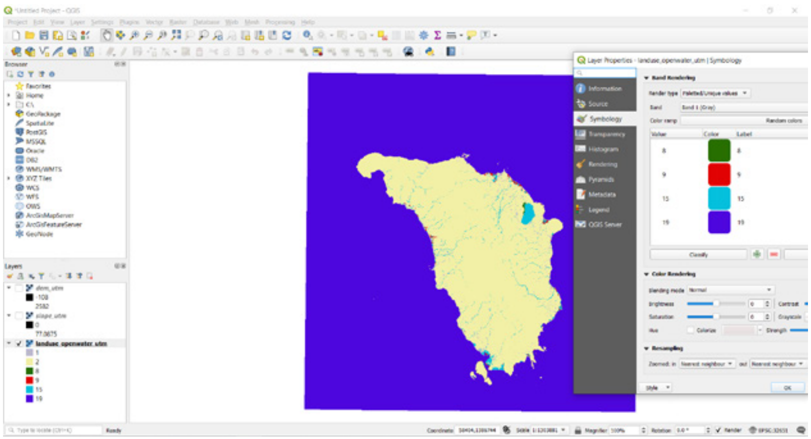
d Check on the "slope_utm" map layer to visualize it. This is a slope map generated from the DEM file, with each grid cell having a value indicating the percent slope at that location (0-90 degrees).



e Check on the "landuse_openwater_utm" file to visualize it. This is a land-use map, with each grid cell having a numerical value corresponding to a NWI (national wetlands inventory) land-use class. If this map looks familiar, it's because it was generated from the "mindoro_2015" land-use map that we used in Chapter 2, with the original land-use classes converted to corresponding NWI classes as shown in the Table below. (Note: Descriptions for all of the SLAMM classes will be shown later in the Chapter).

Original land-use class(es)	Corresponding NWI class	SLAMM code
Built-up	Developed Dry Land	1
Annual Crop, Perennial Crop, Brush/Shrubs, Closed Forest, Open Forest, Grassland, Open/Barren	Undeveloped Dry Land	2
Marshland/Swamp	Regularly Flooded Marsh (Saltmarsh)	8
Mangrove Forest	Mangrove	9
Inland Water, Fishpond	Inland Open Water	15
Ocean	Open Ocean	19

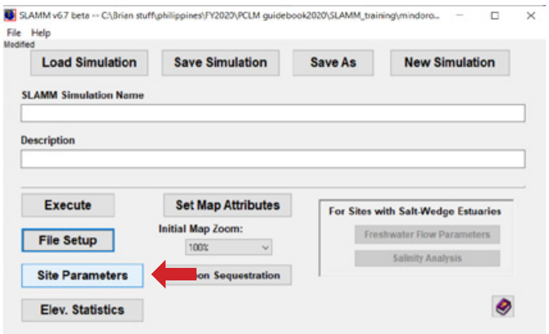
f Try changing the colors of the map to match as the image below. If you forgot how, refer back to Chapter 2 (hint: try double-clicking the layer and changing the symbology to "Paleted/Unique Colors)". Also try zooming in to the East side of the island to see the different land-use/land-cover types present.

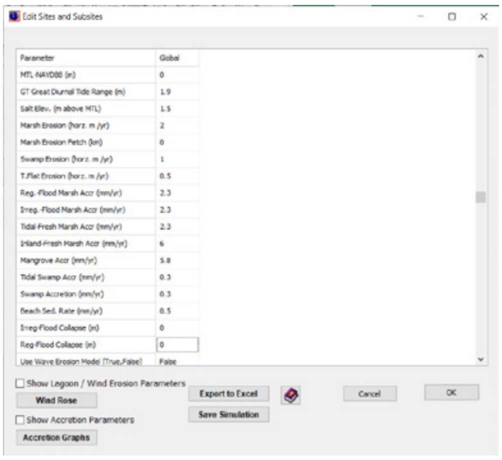


Step 5. Setting the site parameters.

Now let's set the site parameters for the SLAMM model. As the name suggests, site parameters may be location-specific, so should ideally be identified based on local information/statistics or field surveys.

a Click "Site Parameters" to start the setup. A list of several different parameters will pop up in a new menu.





b Type the parameter values in the menu, using the values indicated in the Table below. The description and rationale for each parameter/value are provided. [If you want to run SLAMM for a different study site in the future, these values should be adjusted to match the local conditions.]

Parameter	Value	Description/rationale
NWI Photo Date (YYYY)	2015	This is the year of the land-use map used.
DEM Date (YYYY)	2000	This is the year in which the elevation data was acquired. SRTM data was used, which was acquired in February 2000: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1-arc).
Direction Offshore [n,s,e,w]	East	We are interested in modeling the sea-level rise on the Eastern side of the island.
Historic Trend (mm/yr)	7.2	This is the local sea-level rise rate, which was calculated based on satellite measurements (https://climatedataguide.ucar.edu/climate-data/aviso-satellite-derived-sea-surface-height-above-geoid)
Historic Eustatic Trend (mm/yr)	1.7	This is the value recommended in the SLAMM Technical Documentation, and is based on IPCC estimates of global sea-level rise rates.
MTL-NAVD88 (m)	0	SRTM elevations are already relative to NAVD88 (instead of the mean tide level (MTL)), so no correction is necessary.
GT Great Diurnal Tide Range (m)	1.9	This is the average difference between the sea height at high and low tides
Salt Elev. (m above MTL)	1.5	This is the estimated 30-day high water mark, and land located below this level is considered to be regularly flooded and thus likely to convert to wetlands.
Marsh Erosion (horz. m /yr)	2	Based on estimates from Linhoss et al. (2014)
Marsh Erosion Fetch (km)	0	Optional parameter that we do not have data for.
Swamp Erosion (horz. m /yr)	1	Based on estimates from Linhoss et al. (2014)
T.Flat Erosion (horz. m /yr)	0.5	Based on estimates from Linhoss et al. (2014)
Reg.-Flood Marsh Accr (mm/yr)	2.3	Based on estimates from Linhoss et al. (2014)
Irreg.-Flood Marsh Accr (mm/yr)	2.3	Based on estimates from Linhoss et al. (2014)
Tidal-Fresh Marsh Accr (mm/yr)	2.3	Based on estimates from Linhoss et al. (2014)
Inland-Fresh Marsh Accr (mm/yr)	6	Based on estimates from Linhoss et al. (2014)
Mangrove Accr (mm/yr)	5.8	Based on estimates of average accretion rate of mangroves, from https://link.springer.com/chapter/10.1007/978-3-319-91698-9_3
Tidal Swamp Accr (mm/yr)	0.3	Based on estimates from Linhoss et al. (2014)
Swamp Accretion (mm/yr)	0.3	Based on estimates from Linhoss et al. (2014)
Beach Sed. Rate (mm/yr)	0.5	Based on estimates from Linhoss et al. (2014)
Irreg-Flood Collapse (m)	0	No data available, so leave blank.
Reg-Flood Collapse (m)	0	No data available, so leave blank.
Use Wave Erosion Model [True,False]	FALSE	Not necessary for this training.
Inland-Fresh Marsh Accr (mm/yr)	FALSE	Not necessary for this training.
H1 inundation (m above MTL)	0	No data available, so leave blank.
H1 inundation (m above MTL)	0	No data available, so leave blank.
H1 inundation (m above MTL)	0	No data available, so leave blank.
H1 inundation (m above MTL)	0	No data available, so leave blank.
H1 inundation (m above MTL)	0	No data available, so leave blank.

c Click “Export to Excel” to export the parameter settings that you defined.

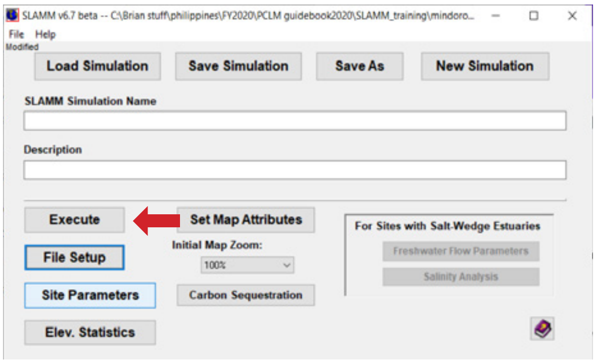
d Click “Save Simulation

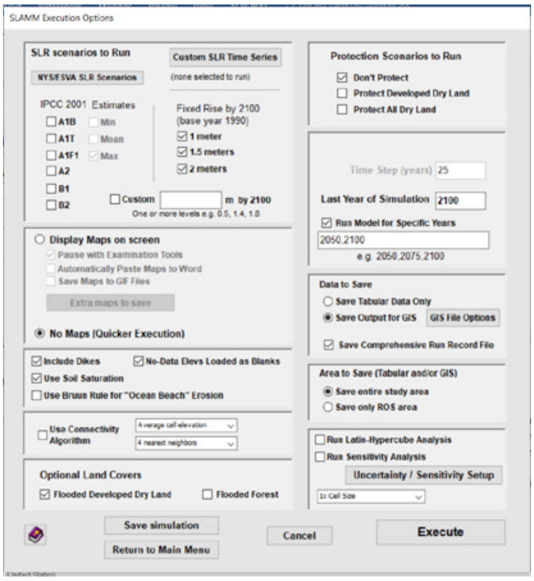
e Click “Ok” to close the menu

Step 6. Set the sea-level rise parameters and simulation period

Now that the site parameters are set, we will start running the SLAMM model for different sea-level rise scenarios.

a Click “Execute” in the main menu. A new menu will pop up entitled “SLAMM Execution Options”.





b Check the boxes “1 meter”, “1.5 meters”, and “2 meters”. We will simulate a 1-2 meter sea-level rise by 2100 scenario (compared to the base year of 1990). Other scenarios can alternatively be selected, or customized values can be input to test new scenarios.

c Check “No Maps (Quicker Execution)”. This will speed up the running of the model.

d Check “Include Dikes”, “No-data Elevs Loaded as Blanks”, and “Use Soil Saturation”.

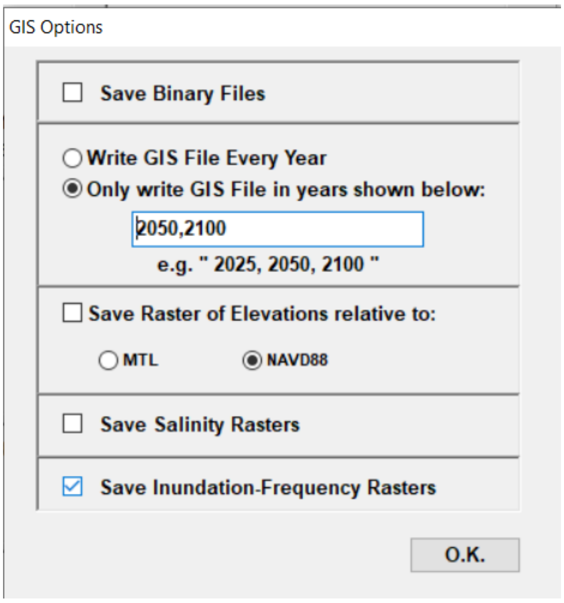
e Under Optional land covers, check “Flooded Developed Dry Land”.

f Under Protection scenarios to run, check “Don’t protect”. This means that developed land may become permanently inundated if it falls below the sea level (i.e. assuming no countermeasures will be implemented to prevent the flooding).

g For the last year of the simulation, type 2100, and check "Run the model for specific years", and type 2050, 2100. This means the model will produce outputs for the years 2050 and 2100.

h Check "Save output for GIS" and click the "GIS File Options" box. A new window will appear. Click on "Only write GIS file in years shown below", and type 2050, 2100. This means that maps of the simulation results will be output for the years 2050 and 2100.

i Finally, check the "Save Inundation-Frequency Rasters". This will output maps showing the inundation frequency at each location. Click O.K.

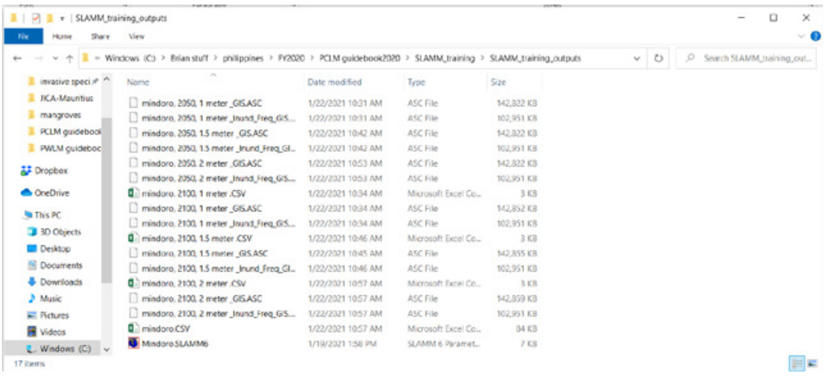


j Make sure everything matches the "SLAMM Execution Options" window shown above, and save the simulation.

k Click "Execute" to run the SLAMM model! It may take quite a long time (30 minutes or longer, depending on your computer) to run. Once it has finished, click OK.

Step 6. Visualizing the model outputs using QGIS

You will see that several new files have been created in the “SLAMM_training_outputs” folder. The ASC files are maps of the landscape in the future, considering sea-level rise impacts. However, we need to convert the ASC files back to .tif files and add coordinate information to visualize these maps in QGIS.

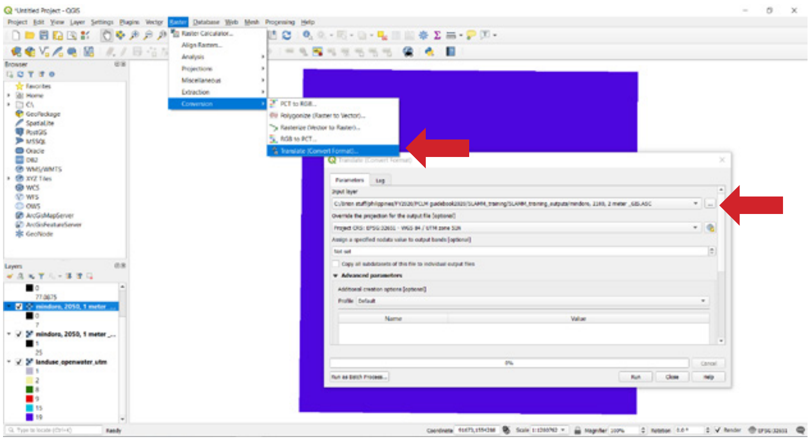


a Open QGIS (if it is not already open). If it is still open from earlier, you can just enlarge the same window.

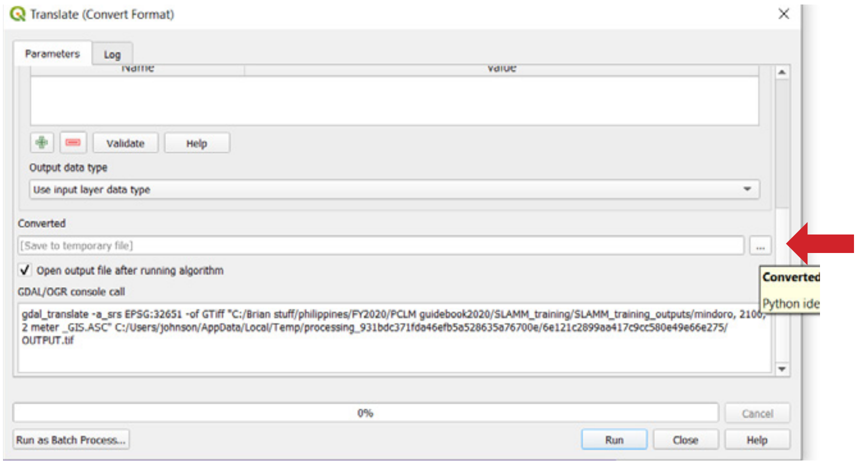
b Click on the “Raster” menu item, highlight “Conversion”, and then click on “Translate (Convert) Format”.

c Under “Input Layer”, click the ... icon and navigate to the file “mindoro_2100, 2 meter _GIS.ASC”.

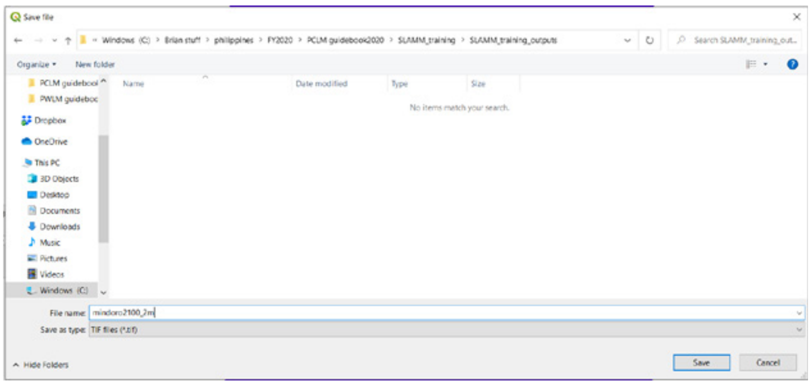
d Under “Override the projection for the output file (optional)”, select “WGS 84 / UTM zone 51N”. This will give the proper coordinates to the map output.



e Scroll down in the Translate (Convert Format) window until you see the “Converted” menu item. Click the ... icon and “Save to new file” to open a new window.



f Navigate to the “SLAMM_training_outputs” folder, check that the file type will be saved as “TIF files (*.tif)”, and name the file “mindoro2100_2m”. Click the “Save” icon (the menu will close), and then click the “Run” icon in the Translate (Convert Format) window. Finally, click the “Close” icon.

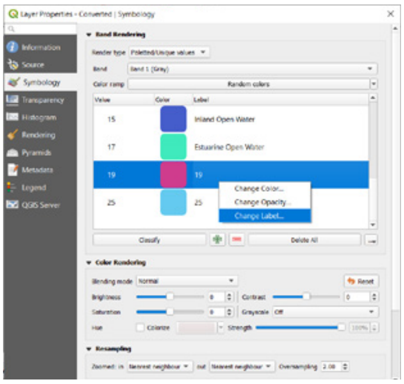


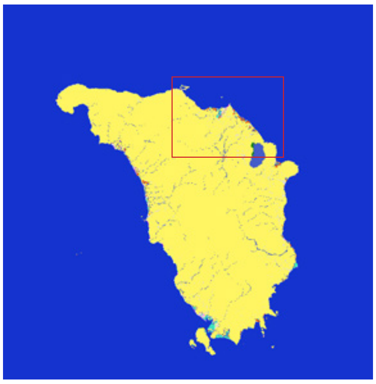
g A new map layer will appear, entitled “Converted”. This is the output map for the year 2100 considering a 2m sea-level rise scenario. The values of the map are the SLAMM codes (i.e. land-use).

h You can now compare the 2015 SLAMM code map ("landuse_openwater_UTM") with this 2100 SLAMM code map to see the changes that occur in the landscape due to 2m of sea-level rise (compared to 1990 base year). Try coloring the SLAMM code values of the 2100 map to match those of the 2015 map. There are additional values in the 2100 map that were not in the 2015, so you can choose new colors for these values. The land-use/land-cover type associated with each SLAMM code can be found in the Table below (taken from Table 3 of the SLAMM 6.7 Technical documentation.pdf). After assigning a representative color for each SLAMM code, change the label for it in QGIS to the "Category Name" shown in the Table for easier interpretation. The final result will be a map like that shown below.

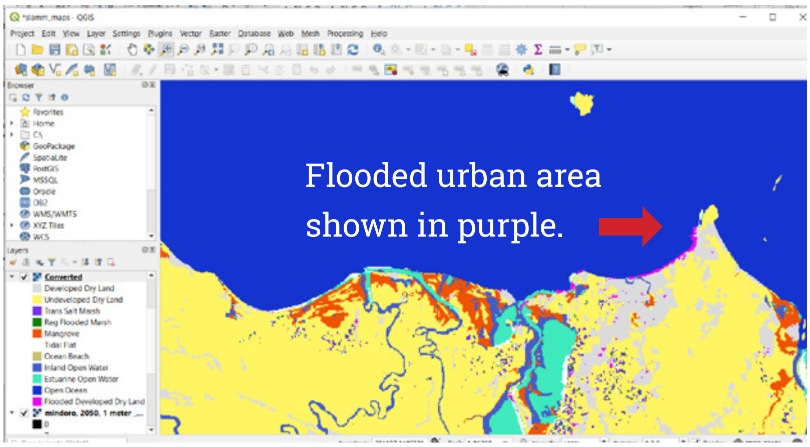
Table showing the land-use/land-cover information for each SLAMM code (GIS Number). Source: SLAMM 6.7 Technical documentation

Category Name	GIS Number
Developed Dry Land	1
Undeveloped Dry Land	2
Swamp	3
Cypress Swamp	4
Inland-Fresh Marsh	5
Tidal-Fresh Marsh	6
Trans. Salt Marsh	7
Regularly-Flooded Marsh	8
Mangrove	9
Estuarine Beach	10
Tidal Flat	11
Ocean Beach	12
Ocean Flat	13
Rocky Intertidal	14
Inland Open Water	15
Riverine Tidal	16
Estuarine Open Water	17
Tidal Creek	18
Open Ocean	19
Irreg.-Flooded Marsh	20
Inland Shore	22
Tidal Swamp	23
Flooded Developed Dry Land	25
Flooded Forest	26





i Zoom in to the upper right part of the island (shown in the red box above) to view the sea-level rise impacts in more detail. You can see purple areas in the zoomed-in map. These are locations where urban areas (i.e. developed dry land) is expected to be permanently inundated by 2100 if 2m sea-level rise occurs. You will also be able to notice various changes in vegetation (e.g. changes from undeveloped dry land to transitional/regularly flooded marshes or mangroves) by comparing the 2100 and 2015 maps in different locations.



Congratulations, you've learned the basics of running SLAMM and visualizing the outputs!

For more information on SLAMM and its uses, please refer to the SLAMM Technical Documentation (which was installed on your PC with the software).

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Chapter 6: Groundwater impact assessment using the Water Evaluation and Planning (WEAP) tool

Pankaj Kumar
Brian A. Johnson

Overview of this chapter

Groundwater quality and its evolution is closely linked to human activities (e.g. water extraction or demand, rock-water interaction, land-use/land-management) as well as local different hydro-climatic conditions. Thus, changes in population hence demand, land-use, and climate all result in modification of the groundwater quality development. Especially this will be more sensitive when we are talking about coastal aquifers because here we have a delicate balance between sea water-fresh water. Also because of any tiny disturbances in the above mentioned factors and drivers, this equilibrium between seawater- freshwater body get affected and salt water plume intrude toward inland aquifers and pollute them which is also called groundwater salinization.

This Chapter will show you how to simulate the future groundwater quality in the coastal aquifers using the "Water Evaluation and Planning System" (WEAP) software package, which is free for users in developing countries. You will learn to conduct several different types of scenarios, to understand and model the impacts of population growth, infrastructure development, land-use change, and climate change on water quality.

After completing the chapter, you will be able to:

- Use WEAP software to estimate the groundwater quality in the coastal aquifers;
- Integrate future population projections, infrastructure-related information, land-use, and climate information to develop different scenarios of the future water quality.

Main concepts

Coastal aquifers can be distinguished from other aquifers because of their dynamic coastal boundary, where tidal effects cause complicated groundwater flow and contaminant transport phenomena in regions adjacent to the coast. Lack of regular monitoring networks for groundwater in coastal regions complicates its diligent sustainable management (Kumar et al., 2013). Salt-water intrusion is the migration of saltwater into freshwater aquifers under the influence of groundwater development. Seawater intrusion is the ingress of seawater into coastal aquifers, which in turn affects the quality of groundwater. Due to increasing concentration of human settlements, agricultural development and economic activities, the shortage of fresh groundwater for domestic, agricultural, and industrial purposes becomes more striking particularly in coastal zones (Ozler 2003). Apart from human activities mentioned above, natural processes like processes at coastal zone (e.g. coastal erosion, shoreline retreat, tidal effect), sea level rise, backwater effect, seepage through the geological formations (presence of inland faults/fracture), and change in hydraulic regime (e.g. evapotranspiration, precipitation, recharge amount) also leads to change in sea water – fresh water equilibrium and favors the ground water salinization (Kumar et al 2012).

The hydrogeological/hydrogeochemical study at coastal aquifers to decipher the hydrological processes is consistently being hot research topic during the past few decades, motivated by both scientific interest and societal relevance; considering the fact that many coastal aquifers in the world, especially shallow ones, experiencing an intensive salt water intrusion caused by both natural as well as man-induced processes (Oude Essink, 2001). Integrated approach of geochemical analysis and hydrological modeling proved as an efficient tool to understand interaction between groundwater and its surrounding environment which contribute to its better management (Kumar et al., 2017). Especially for coastal aquifers, transdisciplinary and integrated approach is an efficient investigative tool to understand the aquifer matrix chemistry and water–rock interaction along the flow path in the aquifer to trace groundwater evolution and mechanism of salt water – fresh water mixing. Diagram showing list of key factors affecting coastal aquifers, their effects and countermeasure to manage this precious resource is shown in Figure 6.1.

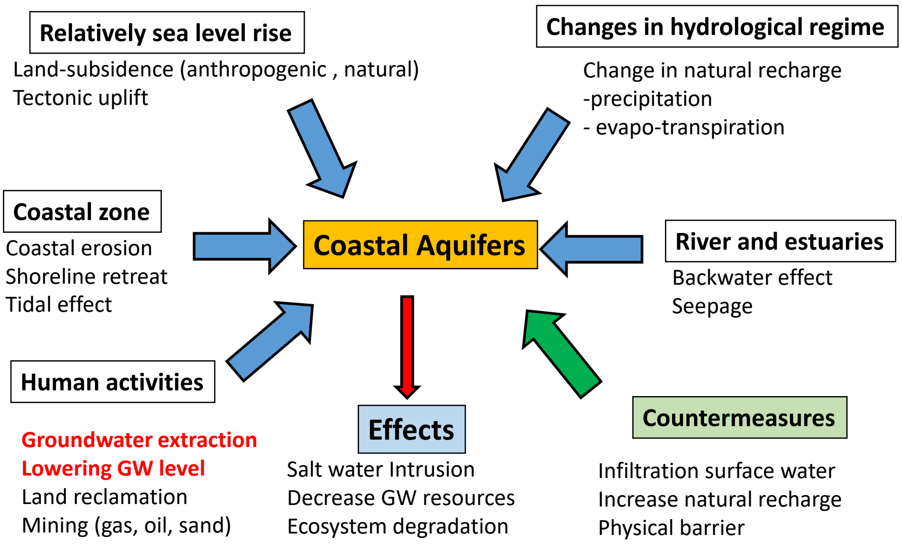


Figure 6.1. Drivers affecting coastal aquifer and their management options

For the sustainable management of this precious resource, scientific information on its future status is required. To do that, we have various scientific tools like WEAP, SWAT, MODFLOW etc., which can be used to predict contaminant transport and its fate considering different key drivers and pressures. These tools are useful in that their outputs provide science-based evidence for decision-making, and the involvement of local stakeholders in the process can improve the modeling results (e.g. by better accounting for the local context) as well as build the capacities of the stakeholders involved in water management. For creating science-based evidence, we aimed to assess water quality under various scenarios of key factors including population growth, urbanization, and climate change in the target cities. While building and running numerical simulation, we had active discussion with local counterparts to improve the models to fit to the real situation, and to show future situation with planned mitigation measures for groundwater management in year 2030.

Water quality

This chapter presents the Water Evaluation and Planning (WEAP) tool, a computer modeling tool that takes into account hydrological and water quality components to analyze/simulate the current/future water quality. WEAP is widely used as a decision support tool for integrated water resources management and planning. The model allows for the estimation of rainfall runoff and pollutant travel from a catchment to nearby water bodies. WEAP can support environmental master planning functionalities by accounting for wastewater generation and treatment, and includes a catchment module for rainfall-runoff simulation, an essential input parameter for water quality modeling. Other benefits of WEAP are that it is not data intensive, and it is freely available to people in developing countries.

The WEAP model is used to simulate water budget and water quality variables in target year i.e. 2030, Data of important water quality indicators (major ions with particular focus on chloride) at spatio-temporal scale for groundwater was used for calibration and validation of water quality module of the WEAP software.

Model set-up

First, vector or raster file of administrative boundary of the study area and river map is imported in WEAP software. After tracing the river on the top of it manually, we create out problem domain. The whole problem domain (and its different components) is divided into several sub-catchments, which have been further subdivided into different sub-basins, to consider influent locations of river and its major tributaries being represented by respective WEAP nodes. Other major considerations are many demand sites (number usually depend on lower administrative unit of study area by which data is available), groundwater as a water supply source to the demand sites to accurately represent the current situation of the study area. Here, demand sites denote domestic (population) defined with their attributes explaining water consumption and wastewater discharge in concerned river. Here average per day per capita groundwater extraction is 70 liter per day per capita. Apart of this, we do need to plot river gauge stations, ground water supply and finally different types of links (return flow, transmission flow, and runoff/infiltration) were used to finalize model set-up.

Scenario analysis is carried out by defining a time horizon for which alternative groundwater extraction and effect of different management options are explored, which is 2030 in this case. The business as usual condition is represented by a reference scenario with selection of all the existing elements as currently active. Future scenario for with no mitigation measures includes effect of climate change, land use land cover changes and population growth. Under scenario with mitigation measures, rainwater harvesting is considered which release the pressure on groundwater extraction. The baseline year under the current reference scenario for all study areas also varies based on the past data availabilities.

Model performance evaluation

Before doing future scenario analysis, performance of the WEAP simulation is justified with significant association between observed and simulated values of hydrological and water quality parameters using trial and error method. Hydrology module parameters (mainly effective precipitation and runoff/infiltration) were adjusted during simulation in order to reproduce the observed groundwater level or piezometric level for a certain period of time for hydrology module validation (Table 1). Whereas, water quality simulation part is validated by comparing simulated and observed concentration of water quality parameters in particular chloride at for two monitoring wells. Main parameters adjusted here at step by step basis are initial concentration of chloride in the groundwater and rate of rate of drawdown. Correlation between observed and simulated values once statistically satisfied to confirm suitability of the model performance in this problem domain, future simulation for both water quality and hydrological parameters were initiated.

Parameter	Initial Value	Step
Effective precipitation	100%	±0.5%
Runoff/infiltration ratio	50/50	±5/5
Household discharged water quality parameters concentrations both at the observation site and river head	X mg/L or CFU/100ml	±0.5%

Table 3.2. Summary of parameters and steps used for calibration.

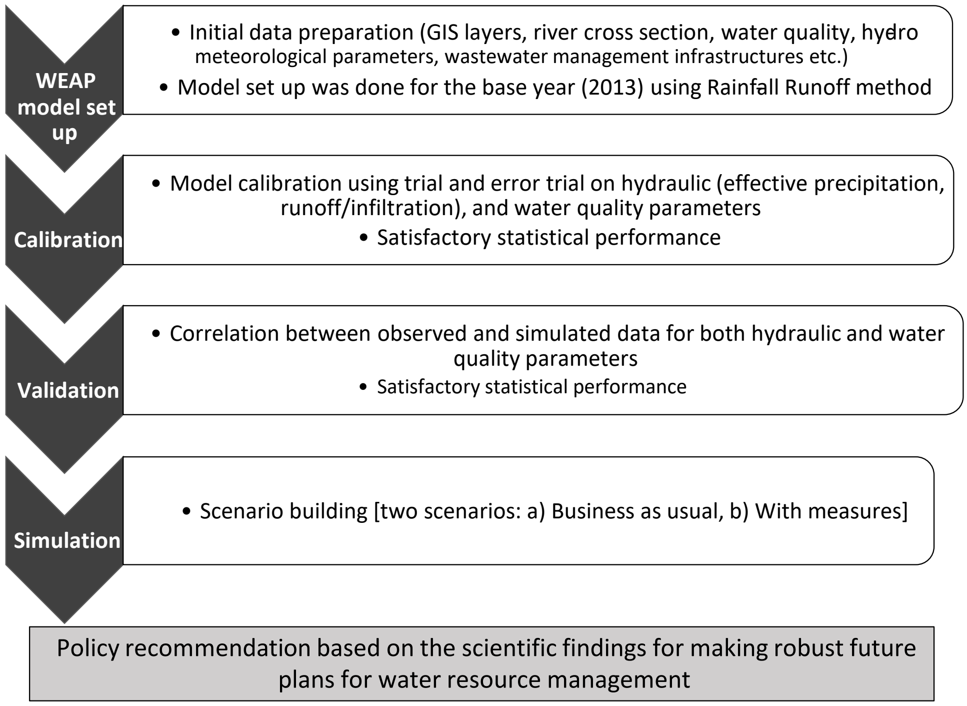
Tutorial

Risk assessment (For water quality component)

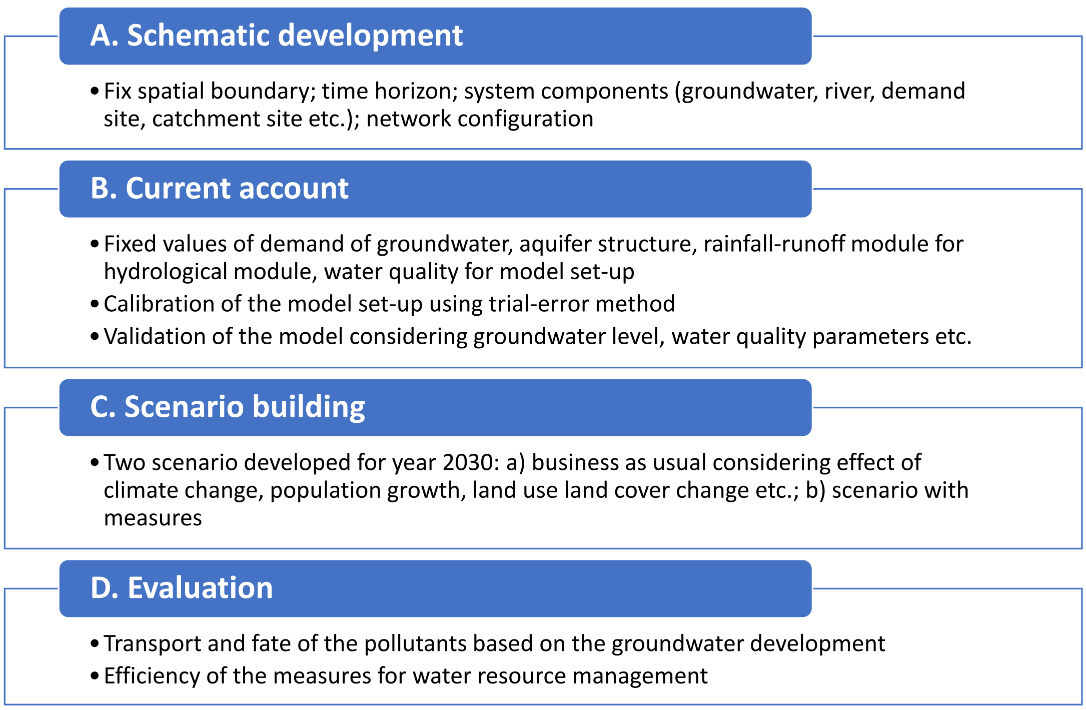
WEAP (Water Evaluation and Planning) model is used based on the following benefits:

- Free available for developing countries
- A highly flexible hydrologic-water quality model
- WEAP can model large number of pollutants
- GIS-based, graphical drag & drop interface
- Scenario management capabilities

In summary, the model framework and model structure are shown in the two figures below. Looking in to the flowchart of the model framework, there are four major components viz. WEAP model set up (schematic diagram and data input), calibration, validation and finally simulation. The structure of the model consists of four components i.e. schematic diagram, data input, scenario analysis and finally evaluation of scientific data for policy formulation (providing credible scientific evidence for policy formulation).



Flowchart showing work WEPA framework.



Flowchart showing model structure.

Expected outcome

a With scenario based simulation, we will be able to predict what will be the future situation of the water environment

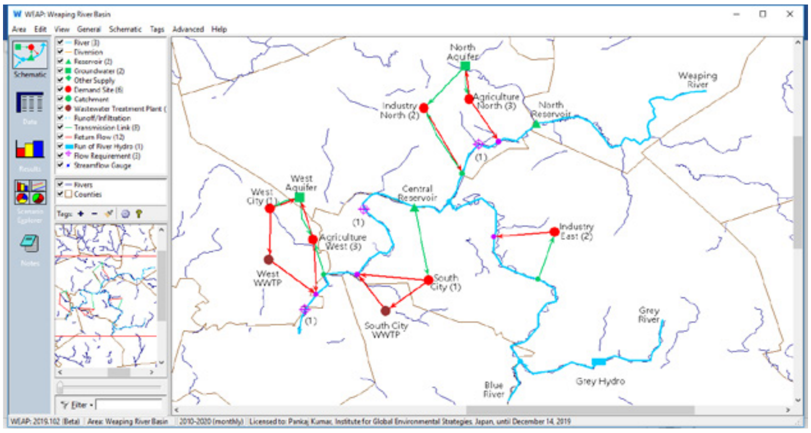
b It will also help to identify what are the suitable mitigation/adaptation measures for improving this water environment

Steps for WEAP training

Step 1. Before working on WEAP software, download and register it. After that, procure the free license.

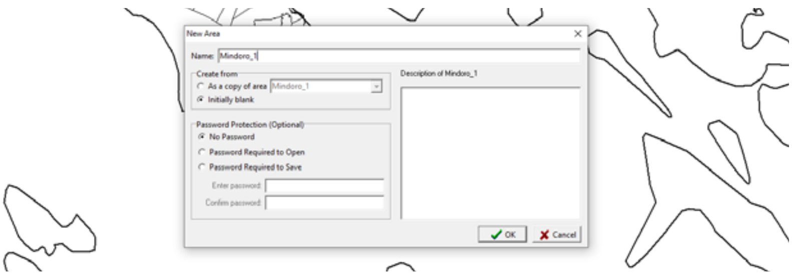
Step 2. Running WEAP for the first time

a Establish a New, Blank Area.
Open WEAP for the first time, a project area called "Weaping River Basin" will appear. Use the Area, Create Area menu option to make a new, blank area.

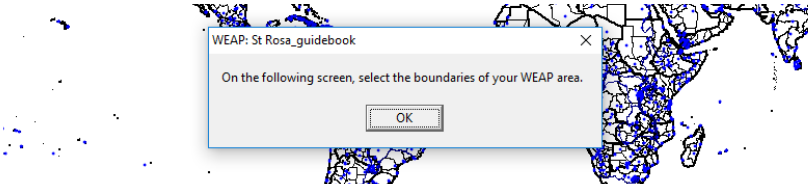


A window, as shown below, will appear in which you should click on the "Initially Blank" option. In the next steps, you will be defining this area for a specific geographic area of the world - so you can name the area based on this selection if you like (e.g., Mindoro_1).

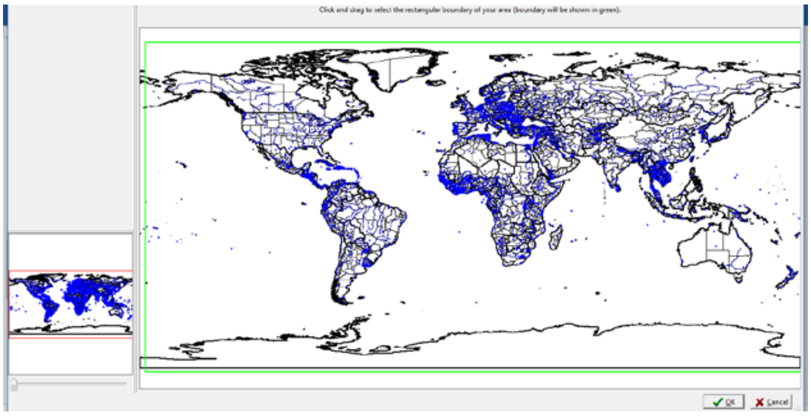
b After clicking "OK" you will be prompted to save changes to the Santa Rosa River Basin. After clicking yes, you will get the following screen:



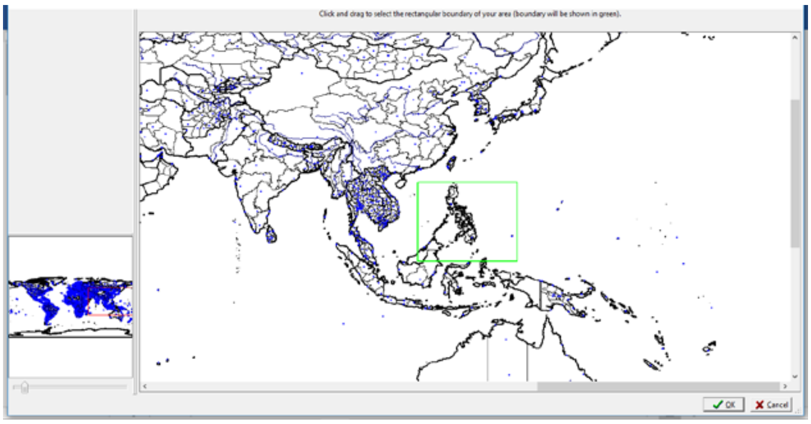
c Click "OK" again. In the next screen, you will select the geographic area for your project from the world map that appears. Use your cursor to draw a rectangle around the area that your project will represent. The boundaries will appear as a green rectangle as shown below.



d You can then use the slider bar on the lower left of the window to zoom into this selected area.



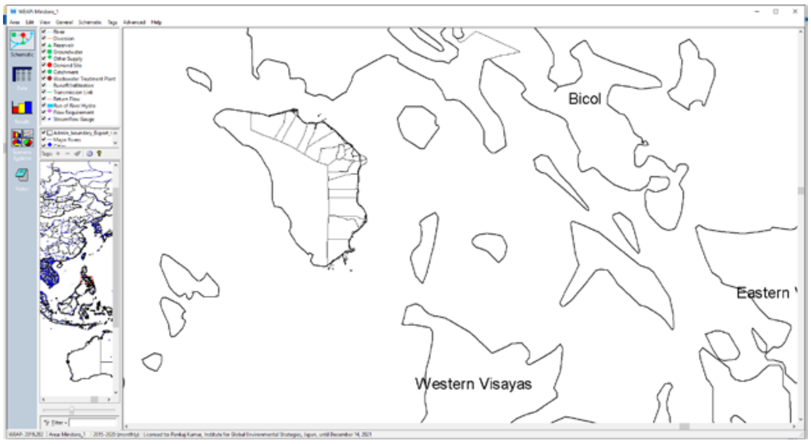
e You can redraw you green rectangle to best capture the area you want in this view. Click on "OK" when you are satisfied with your area boundaries. Note that you can modify these boundaries later by choosing "Set Area Boundaries" on the pull-down menu under Schematic on the top menu bar.



Step 3. Add a GIS layer to the Area

You can add GIS-based Raster and Vector maps to your project area - these maps can help you to orient and construct your system and refine area boundaries. To add a Raster or Vector layer, right click in the middle window to the left of the Schematic and select “Add a Raster Layer” or “Add a Vector Layer.” A window will appear in which you can redirect it to the folder having shape file. After adding the shape file of river network, groundwater and other elements for the study area.

a In this case, add the Admin_boundary_Export_Output.shp file from folder named as Mindoro_WEAP_training, as shown below.



Step 4. Setting General Parameters

Now we are going to proceed with learning how to navigate through WEAP and its functionalities.

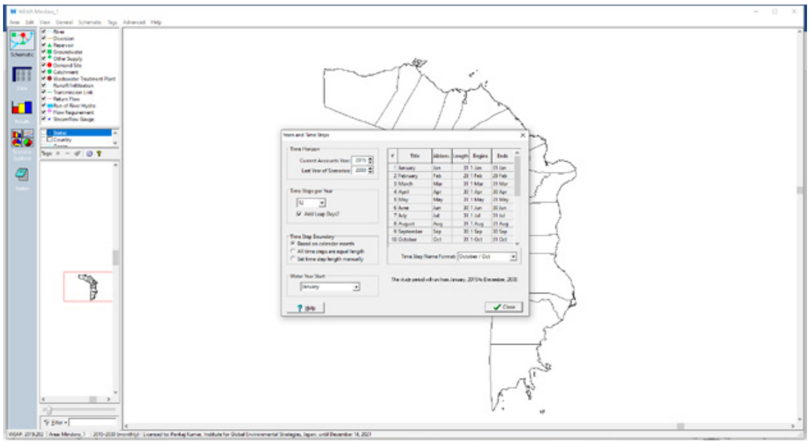
a Click “General” from menu and using drop down menu select different options and set the different parameters like to set Years and Time Steps.

b Set the Current Accounts Year to 2015 and the Last Year of Scenarios to 2030.

c Set the Time Steps per year to 12.

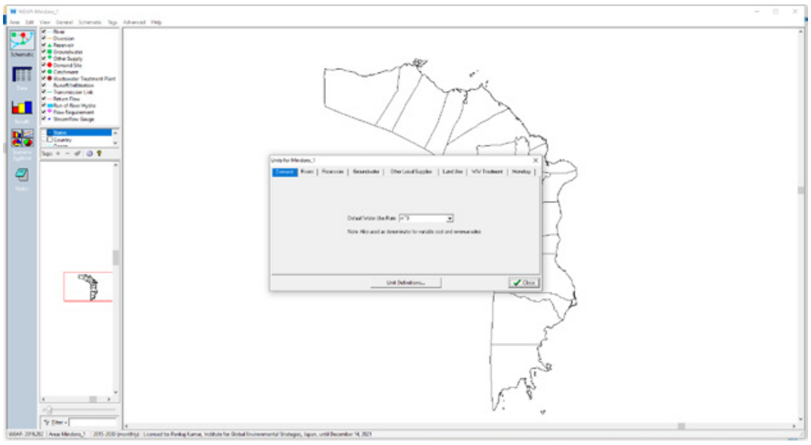
d Set the Time Step Boundary to “Based on calendar month” and starting in January (see below)

e Keep the default (SI units) for now.

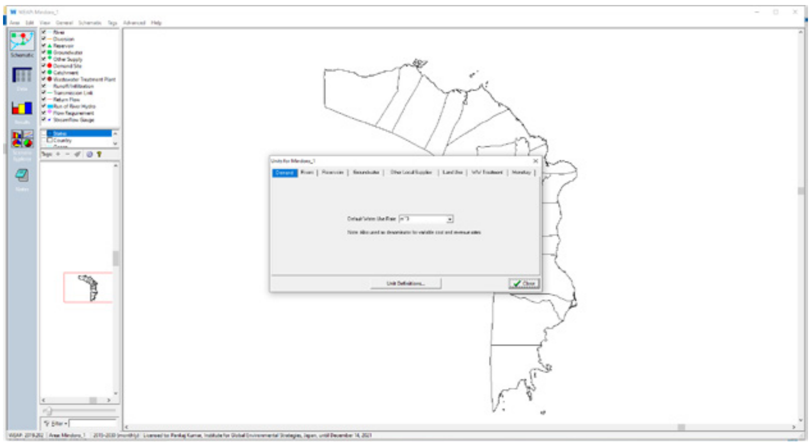


Here the year 2015 will serve as the "Current Accounts" year for this project. The Current Accounts year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the Current Accounts. The Current Accounts is the dataset from which scenarios are built. Scenarios explore possible changes to the system in future years after the Current Accounts year. A default scenario, the "Reference Scenario" carries forward the Current Accounts data into the entire project period specified (here, 2015 to 2030) and serves as a point of comparison for other scenarios in which changes may be made to the system data.

f Similarly, under "General", the units also need to be fixed as shown below.



g Next, in order to do the simulation of water quality parameters, we need to select general—water quality parameters and must click enable water quality modeling. By default, WEAP will simulate temperature, BOD and DO. However, if we need to add other parameter, we can do that after click add button and adjust units as our observed data, for example chloride in this case.



Step 5. Draw different elements to make full schematic diagram

a Click on the "River" symbol in the Element window and hold the click as you drag the symbol over to the map. Release the click when you have positioned the cursor over the upper left starting point of the main section of the river. Move the cursor, and you will notice a line being generated from that starting point.

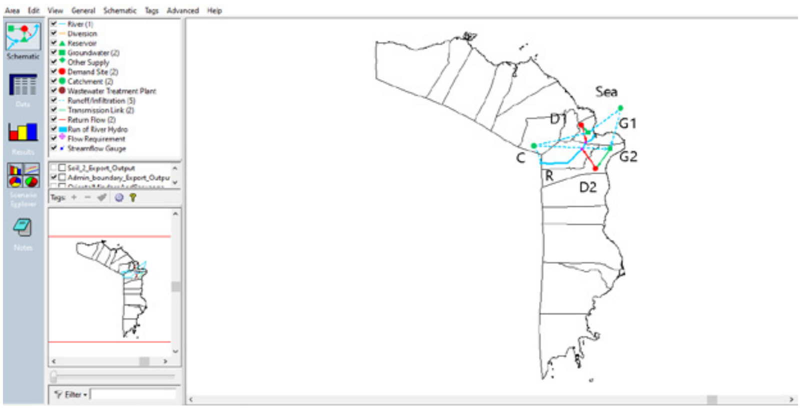
Important Note- The direction of drawing matters: the first point you draw will be the head of the river from where water will flow. You can edit the river course later on by simply clicking-moving any part of the river to create a new point, or right-clicking any point to delete it.

After finishing the river, we need to add catchment, groundwater, demand site etc. In the final schematic, we must check for the following element, how all demand is satisfied; this is accomplished by connecting a supply resource as for example a groundwater source used in this case. Surface water is used to see the interaction between surface water-groundwater interaction. Different links are used to connect catchment, groundwater, river and demand site. For example:

- Runoff/infiltration link is required to connect a catchment to a river
- Transmission link is required to connect from the groundwater to a demand site
- Return flow link is required to connect a demand site to a river.

b Add a transmission Link first to a position on the groundwater, releasing the click, then pulling the link to demand site and double clicking on this demand node. Do the same for other links as well.

Finally, the schematic will look like as in the figure shown below:



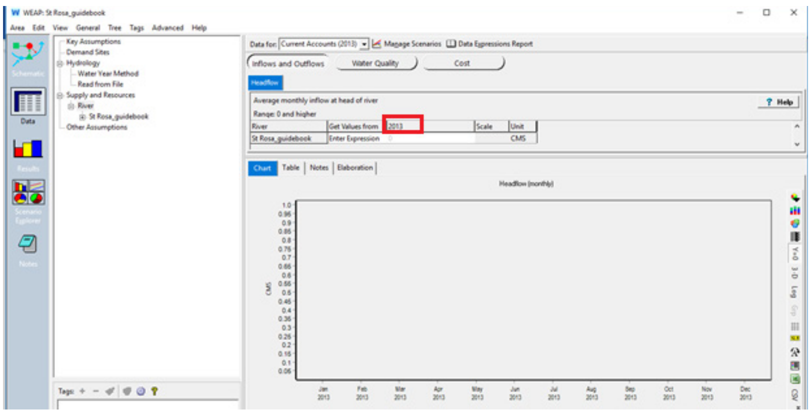
Step 6. Enter Data for the Main River

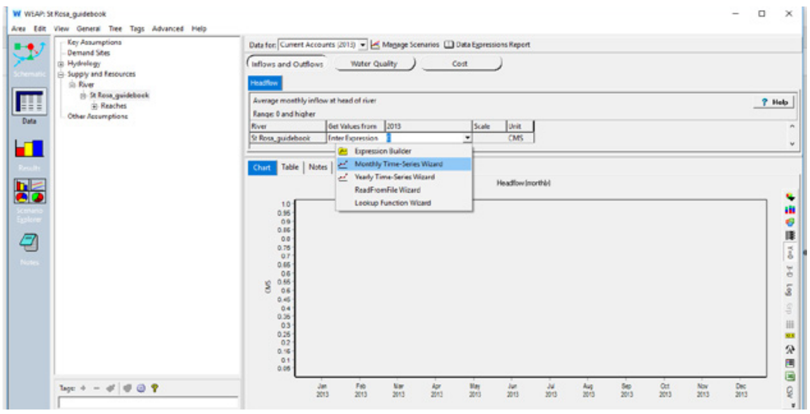
There are two ways to navigate to the data entry section of WEAP to enter data for the Main River.

a Right-click on the Main River and select Edit data and any item in the list. Switch to the Data view by clicking on the Data symbol on the left of the main screen. Select: Supply and Resources/ River /Main River in the Data tree. You may have to click on the “plus sign” icon beside the Supply and Resources branch in order to view all of the additional branches below it in the tree.

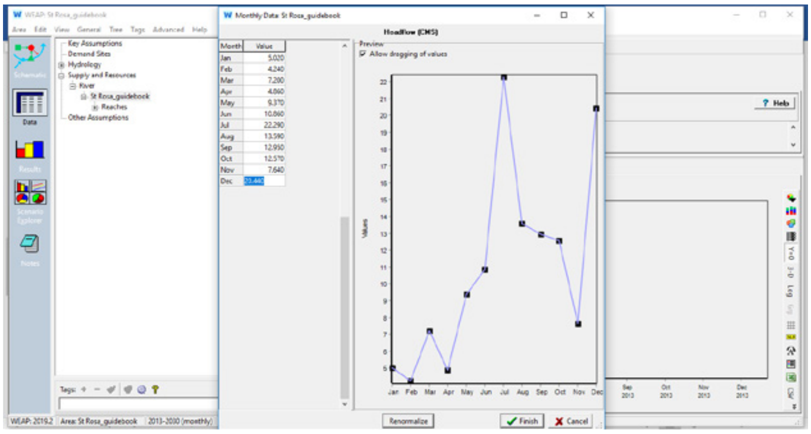
b Alternatively, you can use the Tree pull-down menu and select “Expand All” to view all branches. The “Inflows and Outflows” window should be open - if it isn’t, click on the appropriate button. Click on the “Headflow” tab. Click on the area just beneath the bar labeled “2015” in the data input window to view a pull-down menu icon.

c Select the “Monthly Time-Series Wizard” from the drop--down menu. Below the example is given for one site named as St Rosa watershed.

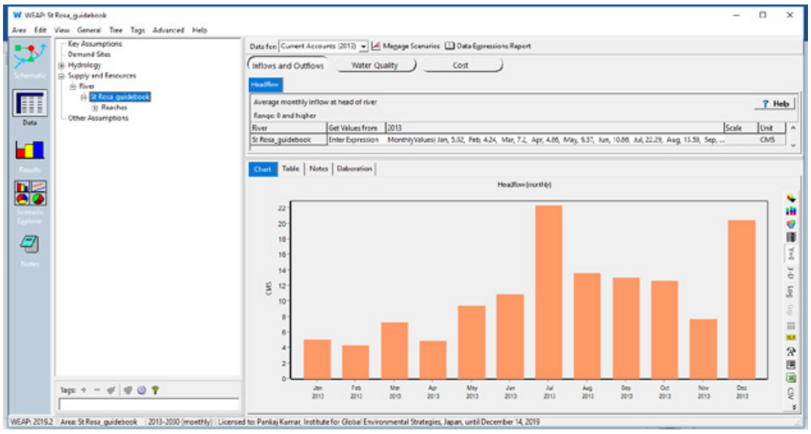




d Use the Monthly Time Series Wizard to enter the following data series shown in the image below:



e Note that as you enter each data point, the data is shown graphically also. Do not input or change any other data yet. Push Finish to close the wizard.



f Note- WEAP divides up rivers into reaches (segments). Originally your river has only one reach; as you add withdrawal and return points, WEAP will automatically create new reaches.

Step 7. Input data for demand sites D1 and D2

Creating a demand node is similar to the process you used to create a river.

a Return to the Schematic view and pull a demand node symbol onto the schematic from the Element window, releasing the click when you have positioned the node on the left bank of the river (facing downstream) inside the administrative boundary of the study area shown in black line.

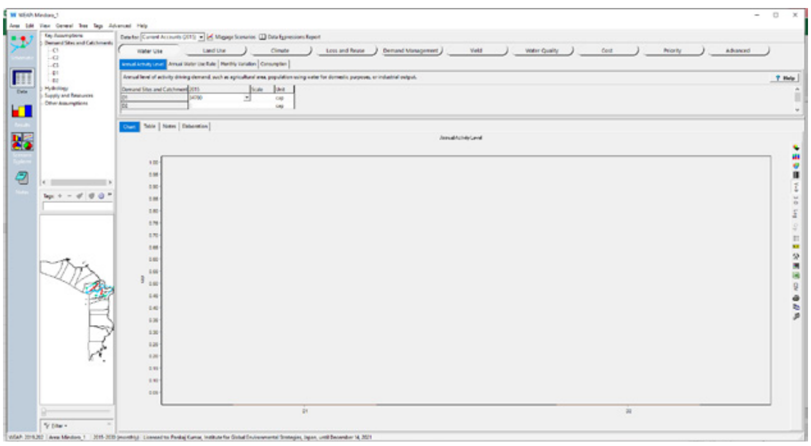
b Enter the name of this demand node as Mindoro in the dialog box, and set the demand priority to 1.

c Right click on the Big City demand site and select "Edit data" and "Annual Activity Level." This is the alternative way to edit data, rather than clicking on the "Data" view icon on the side bar menu and searching through the data tree.

> Note- The Demand Priority represents the level of priority for allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with highest Demand Priority, then moving to lower priority sites until all of the demand is met or all of the resources are used, whichever happens first.

d You must first select the units before entering data. Click on the "N/A" under Unit in the Annual Activity level tab. Pull down the arrow that appears, select "People", and click "OK." Then give the value of population for each demand sites.

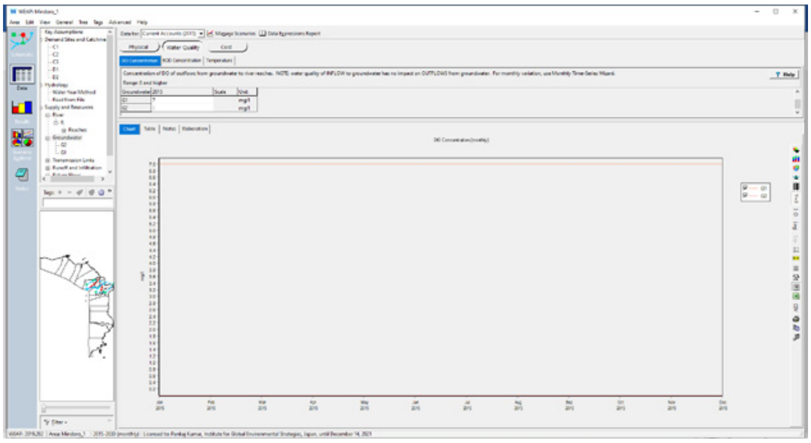
e Data for population, annual activity level will be provided at this stage as shown below. Set the "Annual Activity Level" for D1 as 34700. For D2, set as 102998.



f Next, click on the "Annual Water Use Rate" tab and enter 300 under the year 2015.

g Then consequently you need to fill information for other elements like groundwater quality and extraction rate. Set the Groundwater extraction rate as 85 liter/capita/day.

h Set the Groundwater quality in terms of Chloride at the equilibrium as 270mg/L.

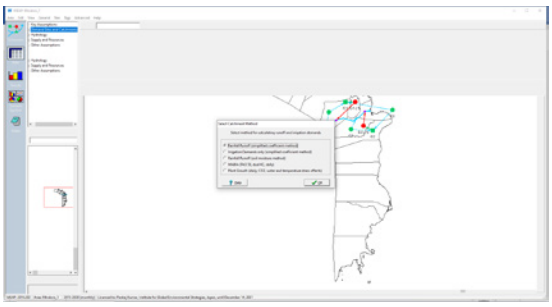


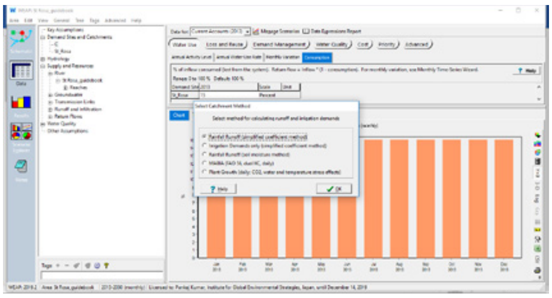
Note- The monthly variation is expressed as a percentage of the yearly value. The values for all of the months have to sum up to 100% over the full year. If you don't specify monthly variation, WEAP will prescribe a monthly variation based on the number of days in each month.
We will not edit these values for the city demand, but we will edit them later for the agricultural demand.

Step 7. Input data for catchment C

First, we will specify the catchment runoff calculation method.

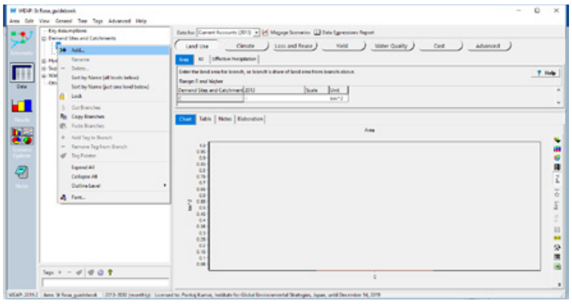
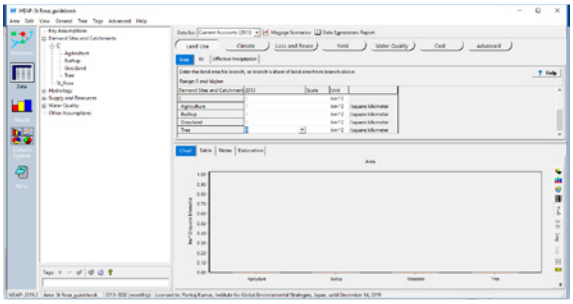
a Select "C" in the assumption tree, first select catchment method. Ideally soil-moisture method is best suitable method to calculate runoff as it divides the aquifer in two layers vadose zone and saturated zone mimicking the real world situation more closely. However, the number of input data is quite huge. In this case (Mindoro), because of data scarcity, we have selected rainfall-runoff (simplified coefficient method) as shown below.





b Now we will add the different land use classes present in the study catchment. Click data Click C click add and add all the following land use/land cover types:

| Crops | Built-up | Inland-water | Forest | Shrubs

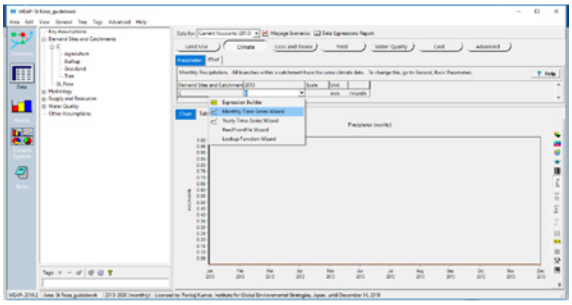
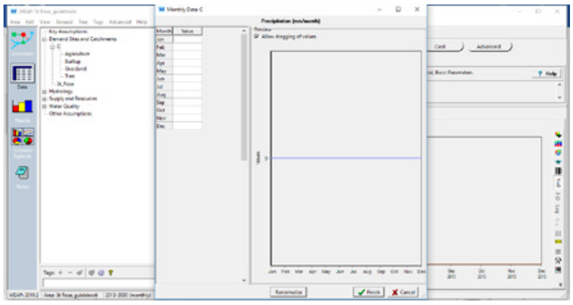



c Now within Land Use Tab, fill all the information for each of the land use types in km2, as shown below:

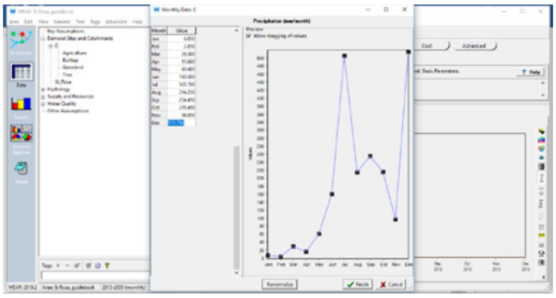
Classes	2015 (Hectares)	2030 (Hectares)
Built-up	100	140
Crops	140	120
Inland-water	100	90
Forest	260	250
Shrubs	200	200

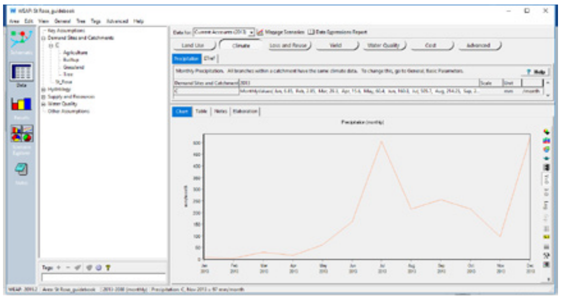
Next we will input data related to climate.

d Click on the Climate icon and the Precipitation tab. In the 2015 column, open the Monthly Time-Series Wizard.

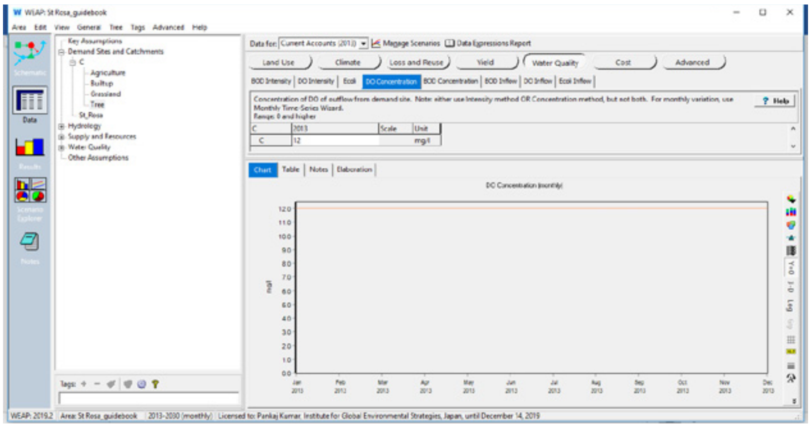
e Set the values for each month as below.



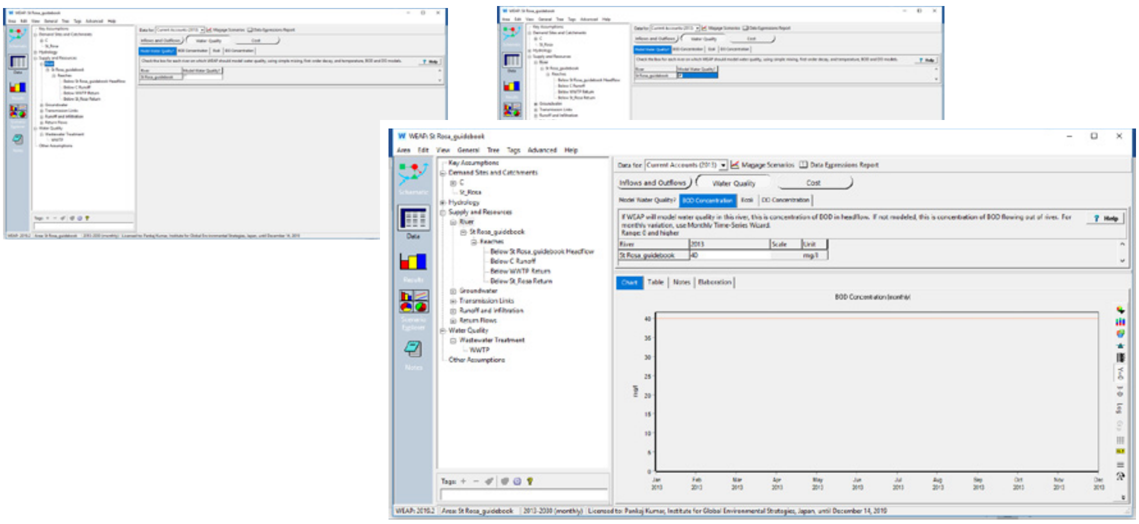


f Now click on the Water Quality tab. We can give input in terms of either intensity or concentration of the water quality parameters. Here in this study we used data in terms of concentration like shown below.

g Set the Water quality at catchment as Cl- 10 mg/L



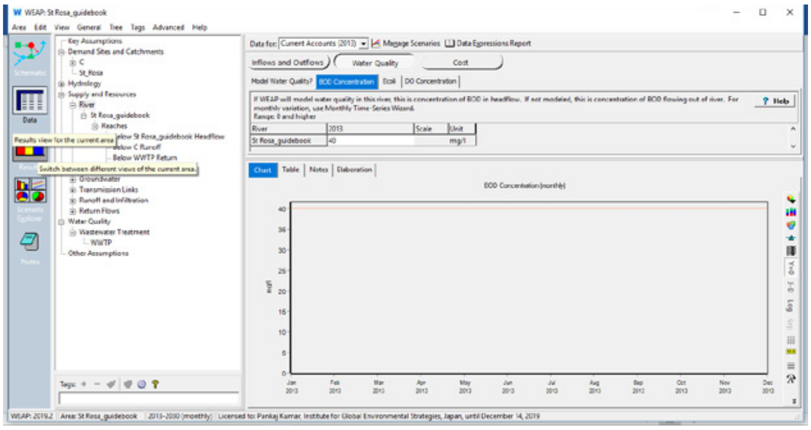
h Now, enable the water quality module within the river as shown in the image below.



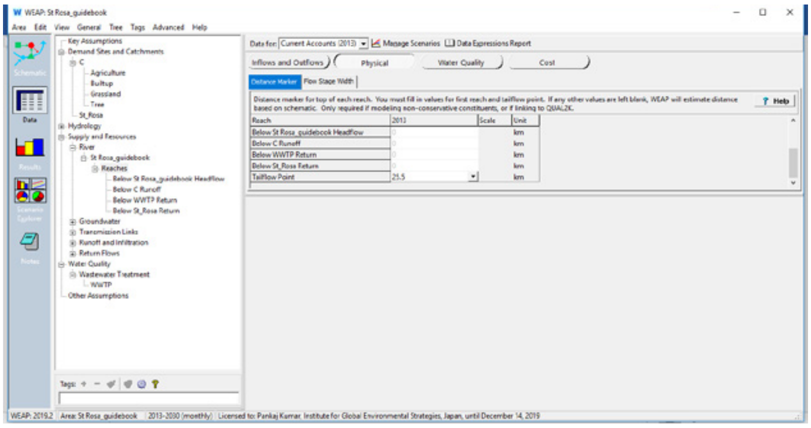
Step 8. Input data for river related parameters

In this stage, we will provide information about river cross section, stretch of the river under consideration, water quality at river head etc.

a Set the BOD Concentration in the 2015 column as 40.

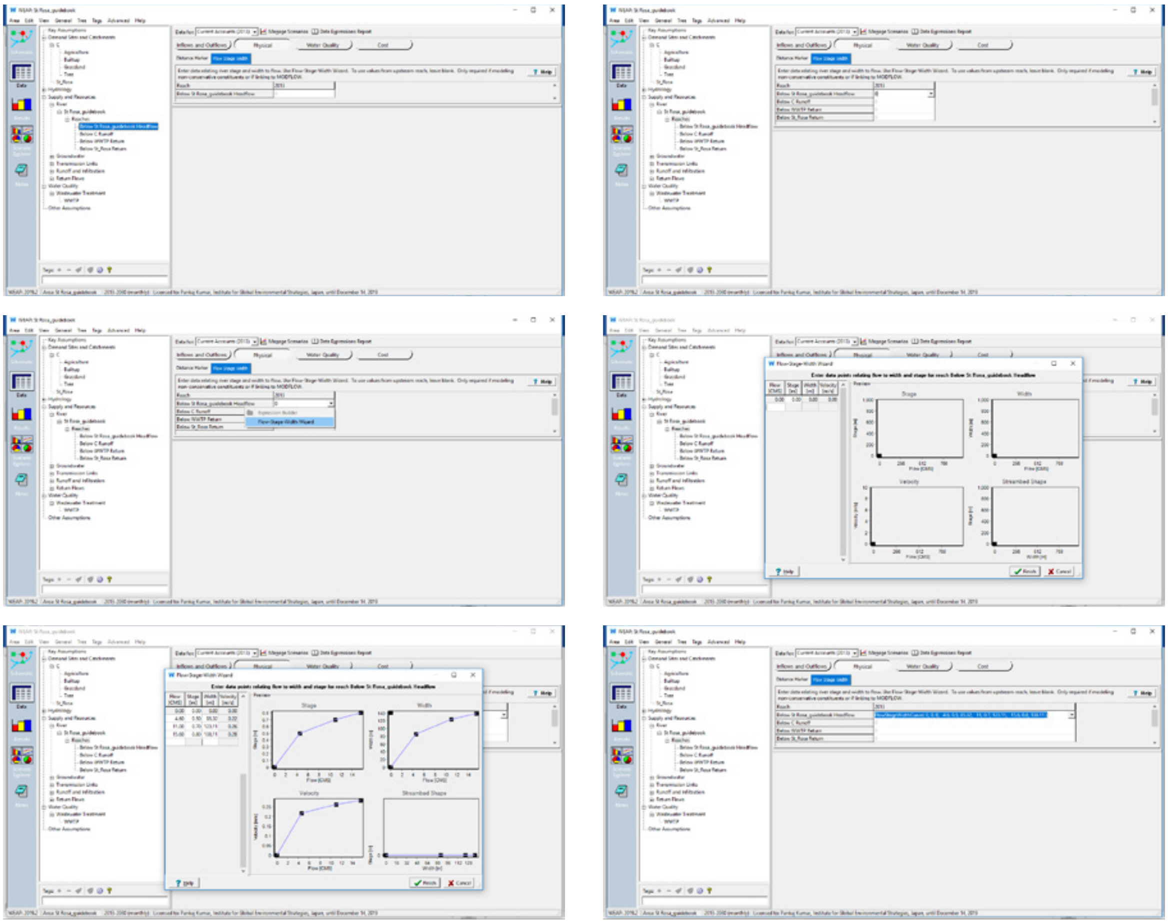


b Now give the value of distance marker and river cross section. For distance marker, as the length of river investigated is 18.3 km, put “0” below river head flow and 18.3 km for the tail flow point.



c For the river cross section, click Flow Stage Width as shown below, and give all the input data.

| 0, 0, 0 | 4.6, 0.5, 85.32 | 11, 0.7, 123.11 | 15.6, 0.8, 138.11 | 17, 1, 155.67 | 20, 1.10, 165.11 | 23, 1.20, 171.95

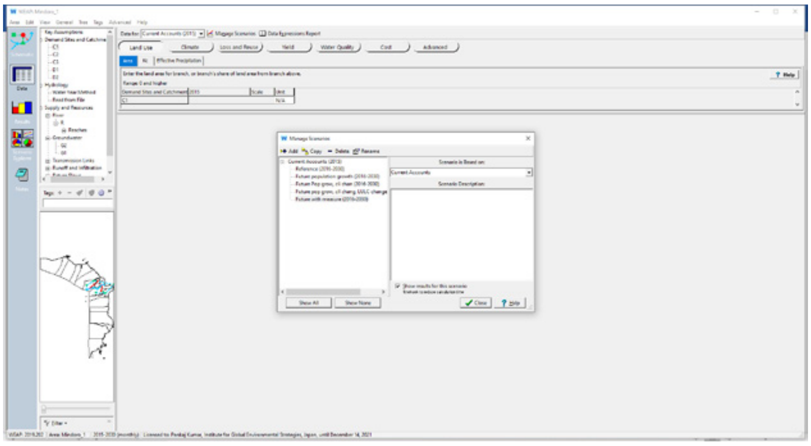


Step 9. Generate different scenarios

Now once the reference scenario is done, we can start building scenario to include drivers and pressures which has potential to impact water quality. In this case, we will build a scenario including population growth.

a To build new scenario, first click Manage Scenario.

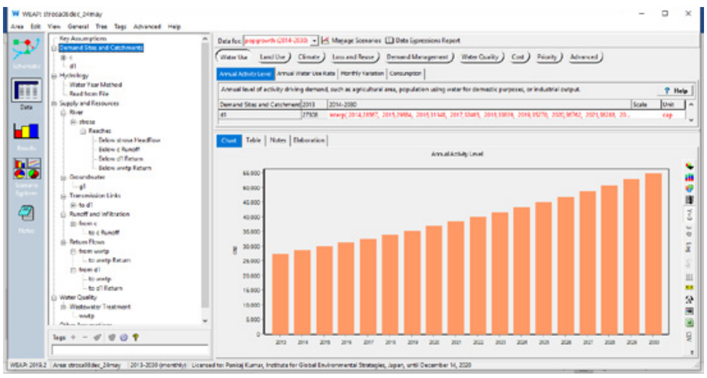
b A new window will pop up, where we need to put the name of scenario. A message will be asked that this scenario is based on: Select reference as shown in figure below. Here example is shown for Mindoro.



c Now once new scenario is created, then we need to change the concerning parameter in the new scenario while keeping other parameters the same as the reference scenario. Example- For scenario with population growth, annual activity or population value will be increased from reference year to the target year as shown in figure below.

d Let's try a scenario considering population growth. Click on the Annual Activity Level tab, and enter data for the years 2015-2030 for D1 and D2, with the values below:

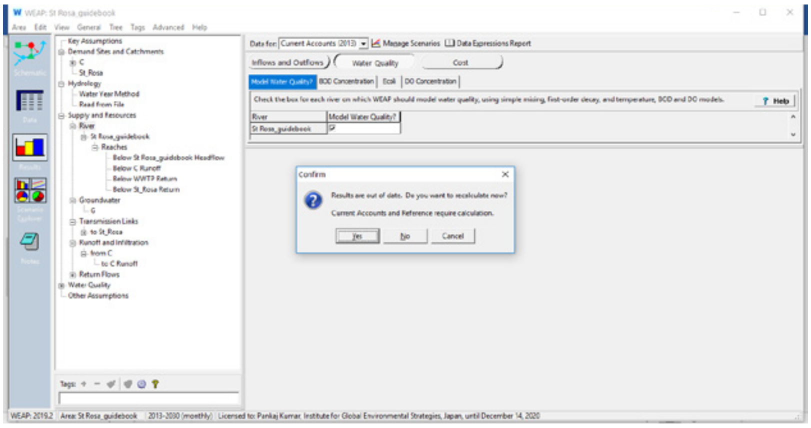
> Note: due to data limitations, we have used the same population values for years 2015-2018. The result will be a graph like the example shown below.



	D1	D2
Year	Pola	Nauhan
2015	34700	102998
2016	34700	102998
2017	34700	102998
2018	34700	102998
2019	35463	105264
2020	36244	107580
2021	37041	109947
2022	37856	112365
2023	38689	114837
2024	39540	117364
2025	40410	119946
2026	41299	122585
2027	42207	125281
2028	43136	128038
2029	44085	130854
2030	45055	133733

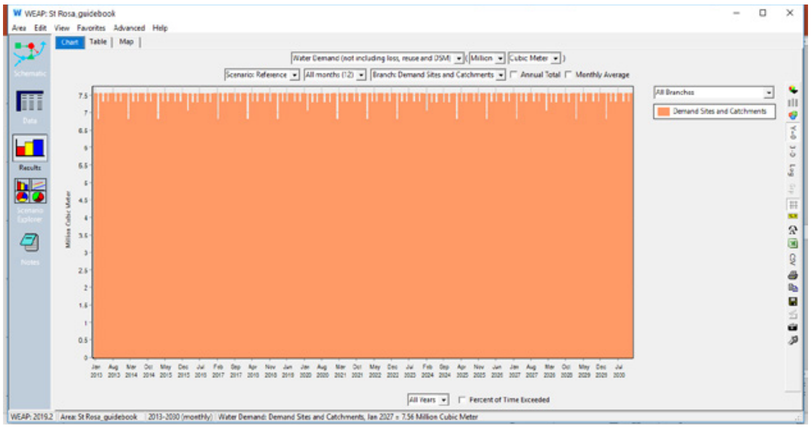
Step 10. Run the model (simulation, calibration, validation)

a Once done with data input and after saving the model, press the Result button. There will a pop-out message which will appear is "Results are out of date. Do you want to recalculate now?" as shown below. Press yes. An example is shown below.

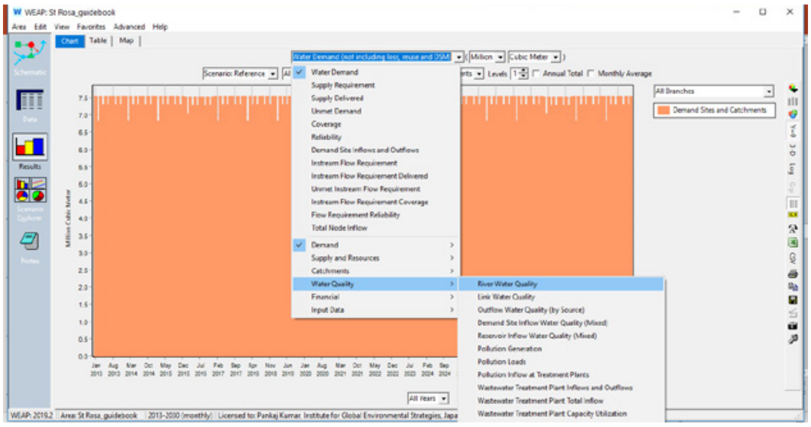


b After running the model, we might encounter messages like **"values for some of the parameters are not suitable to run this model". Fix and rerun the model.**

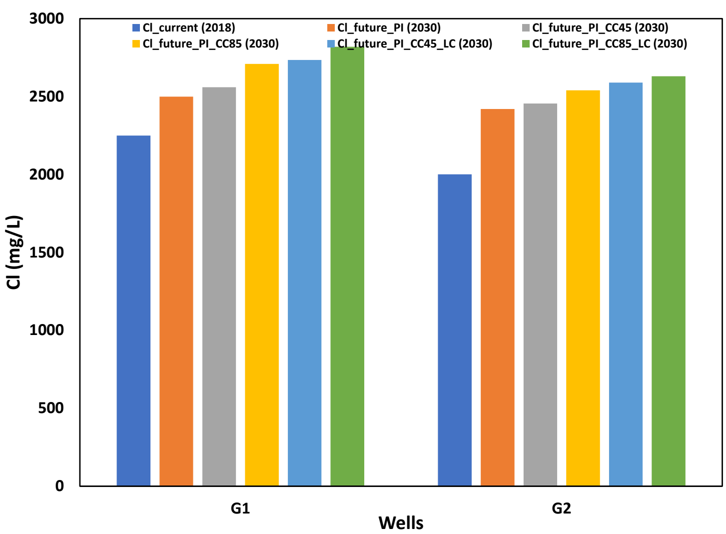
c Now again press result for model simulation, and new window will pop-up showing result for different parameters. Here after selecting result for water demand, window will look like as shown below.



d Now select the desired parameters from the dropdown menu to see the simulated result like water quality as shown below.



e We can change the chart type like bar, line, stack etc. based on our interest just by clicking and selecting it from side menu. We can also export this simulated result data in excel sheet by doing right click on the windows and export these data sets in to the desired folders. Where we can edit this output to draw different graphs as per our convenience. We can also change the type of graph we wanted to display like no comparison, relative to population growth, land use land cover, climate change, and different mitigation measures as shown in the drop-down menu shown below. An example of the outputs of WEAP considering population growth, climate change, and land-use change scenarios is shown below with regards to the Chloride (Cl) parameter.

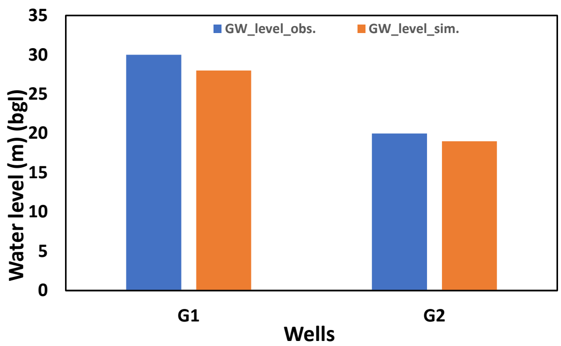


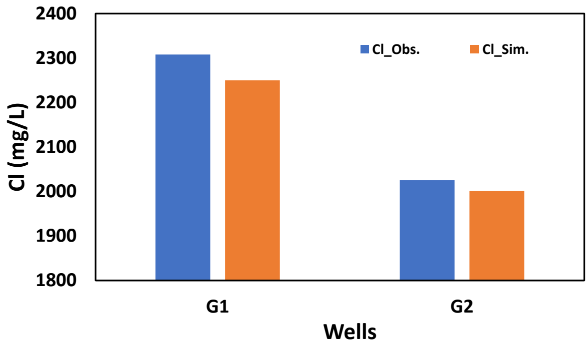
Additional information on model calibration and validation

In this tutorial, we have showed how to run the WEAP model for simulating water quality in the present and future. In practice, the model needs to be calibrated and validated to ensure that the model's simulated values are reliable. For calibration, the following two parameters and the steps for adjusting them were used. The parameters are modified by the Steps shown, e.g. subtracting 0.5% from the initial Effective precipitation value (100%) until a satisfactory match between simulated and observed values of the water quality parameters are obtained.

Parameters	Initial value	Steps	Final calibrated value for St Rosa
Effective precipitation	100%	± 0.5%	93%
Runoff/infiltration ratio	50/50	± 5/5	55/45
Groundwater quality	250 mg/L	±10/10	270
Groundwater extraction	75 liter/day/capita	± 5/5	85

Once statistically with the model calibration results, the next step is model validation. For validation, we compare the observed to the simulated values of the parameter(s) for other dates not included in the calibration process. For this study site, the results for model validation are shown in below. It is found that observed value for both parameters are significantly related.





Congratulations, you've learned how to perform water quality simulation using WEAP!

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Chapter 7: Identifying and implementing countermeasures to reduce land-use and climate change risks

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Overview of this chapter

As discussed in the previous chapters, land-use changes can exacerbate the impacts of climate change, e.g. by causing increased exposure to storm surge and sea-level rise when coastal ecosystems are converted to urban/built-up or agricultural lands. The participatory coastal land-use management (PCLM) approach presented in this guidebook provides a framework to assess these impacts, and aids in designing appropriate climate change adaptation measures with local governments and other relevant stakeholders. Previous chapters have focused on the scenario development and impact assessment steps of PCLM. The focus of this chapter is to provide some guidance for adaptation measure development and implementation, utilizing the results of the different impact assessments. It is based mainly on lessons learned from a case study in the Oriental Mindoro Province of the Philippines.

In this chapter, you will learn:

- How to identify countermeasures through a participatory process;
- About potential technologies and funding sources for climate change adaptation;

Main concepts

Science-based climate actions can be aided by the use a framework that involves several key elements including: identifying potential future climate change scenarios; assessing the impacts of the predicted changes; developing, appraising, and prioritizing management options (e.g., policies, measures); mainstreaming the options into development planning; implementing the options; and monitoring and evaluating the progress and results of the implementation. The PCLM approach presented in this guidebook incorporates these elements in its four steps. The first two steps of PCLM (Scenario Development, and Impact Assessment) represent the (mostly) technical aspects of this framework, while the third and fourth steps (Countermeasure Development, and Climate Resilient Land-use Planning and Implementation) represent the policy aspects. In this chapter, we demonstrate how these third and fourth steps of the PCLM approach can be implemented through a case study of Oriental Mindoro Province of the Philippines.

Countermeasures to reduce land-use change and climate change impacts are, by their nature, site specific, so the specific measures presented here should be taken as examples rather than "best practices". What is important is that the countermeasures contribute to enhanced land-use planning and management in the coastal areas where they are identified (e.g. to reduce land-use change/climate change impacts on coastal communities).

Case Study of Oriental Mindoro

Introduction

The island province of Oriental Mindoro of the Philippines is located approximately 140 km from the Metropolitan Manila area. Oriental Mindoro is composed of 14 municipalities: Baco, Bansud, Bongabong, Bulalacao, Calapan City, Gloria, Mansalay, Naujan, Pinamalayan, Pola, Puerto Galera, Roxas, San Teodoro, Socorro, and Victoria (Figure 7.1). The population of this province was 844,059 as of the latest census in 2015 (Philippines Statistics Authority, 2015). The largest municipality and capitol of the province is Calapan City. Oriental Mindoro can be reached by ferry boat in around 2 hours from Batangas City port on the mainland (Luzon Island). As seen in Figure 7.1, all 14 municipalities of Oriental Mindoro are located on the East side of Mindoro Island, and all except for Socorro and Victoria are located on the coastline. The main economic activities in Oriental Mindoro are agriculture and (eco-) tourism.

Figure 7.1. Location of Oriental Mindoro Province, Philippines.

PCLM pilot study in Oriental Mindoro

A research team from the Institute for Global Environmental Strategies (IGES) and the University of the Philippines Los Baños conducted a PCLM pilot study in Oriental Mindoro from 2019-2021. The remainder of this chapter focuses on this pilot study.

PCLM Step 1: Scenario Analysis

In our research team's first visit to Oriental Mindoro in 2019, we conducted a field survey of the island to understand the coastal ecosystems present, and interviewed local officials to understand how the land-use had changed over time in coastal areas. The photos in Figure 7.2 show examples of some of the typical mangrove ecosystems in different regions of the province. We learned that over the last few decades many of these mangrove sites were converted to fishponds for commercial or recreational aquaculture (see Figure 7.3 for a photograph of one of these fishponds). Indeed, conversion of mangroves to fishponds has been a common occurrence in the Philippines and other countries.

Figure 7.2. Typical mangrove ecosystems in Oriental Mindoro, Philippines.

Figure 7.3. Mangrove area that was converted to a fishpond.

After this field visit, the research team held a consultation meeting with government officials from the local government units (LGUs) and Oriental Mindoro Provincial Agricultural Office (PAGO) to understand the climate-related hazards experienced in this study area. During this meeting, we distributed a questionnaire asking the government officials to rank the impacts of different climate-related hazards in their municipality, on a scale from 1 (almost no impact) to 5 (very high impact). Based on this questionnaire, we identified that some of the main coastal hazards in the area are storm surge, sea-level rise, and groundwater salinization. Based on this hazard assessment, we selected suitable modeling software to model the future impacts of these hazards. The software that we selected are the ones presented in Chapters 4-6 of this guidebook, namely: InVEST (for storm surge and coastal erosion modeling), SLAMM (for sea-level rise modeling), and WEAP (for groundwater quality modeling).

For step 1 of PCLM, we conducted another consultation meeting with coastal resource managers of the LGUs in Oriental Mindoro in January 2020, wherein we conducted a participatory land-use mapping activity. For this activity, we asked the LGU officials to map out their future (to ~2030) planned land-use changes in coastal areas using different colored markers for various land uses on printed maps. Later, these land-use changes were digitized into GIS format using QGIS software (see Chapter 2 for how to perform this digitization). Based on this participatory mapping activity, we identified the land-use changes that were likely to occur from 2015 (date of most recent land-use map) to 2030. The main land-use changes identified were: mangrove forests are expected to increase in area by approximately 7.4%, built-up areas are expected to increase in area by approximately 3.5%, and fishponds are expected to decrease in area by approximately 3.6% (Table 7.1). Notably, several LGUs mentioned mangrove replanting as a proposed activity in the future and in some cases reconverting abandoned fishponds back to mangrove ecosystems.

Land-use/land-cover type	Ha (2015)	Ha (2030)	Change (Ha)	Change (%)
Annual Crop	164,100.34	163,713.76	-386.58	-0.24%
Brush/Shrubs	266,711.08	266,696.67	-14.41	-0.01%
Built-up	16,580.08	17,171.06	590.99	3.56%
Closed Forest	14,843.03	14,843.03	0.00	0.00%
Fishpond	7,467.28	7,198.62	-268.67	-3.60%
Grassland	151,031.57	151,031.48	-0.09	0.00%
Inland Water	23,516.55	23,510.84	-5.72	-0.02%
Mangrove Forest	4,813.59	5,169.70	356.11	7.40%
Marshland/Swamp	670.88	670.88	0.00	0.00%
Open Forest	188,082.84	188,082.84	0.00	0.00%
Open/Barren	7,460.11	7,445.06	-15.05	-0.20%
Perennial Crop	147,612.11	147,355.53	-256.58	-0.17%

Table 7.1. Future land-use changes in Oriental Mindoro, determined based on a participatory land-use mapping activity.

For step 1 of PCLM, the research team also conducted a climate change scenario analysis, focusing on sea-level rise. We calculated the local sea-level rise rate based on satellite altimetry measurements of sea surface height from 1992-2010 (acquired from : https://climatedataguide.ucar.edu/climate-data/aviso-satellite-derived-sea-surface-height-above-geoid) using the measurements centered on 12.5 degrees latitude, 122.5 degrees longitude. From these satellite measurements, we calculated the historical sea-level rise rate (excluding land subsidence/uplift) as approximately 7.2. mm/year (Figure 7.4). For our climate change scenario analysis, we assumed a slightly higher future sea-level rise rate of 8.0 mm/year to 2050, as well as more extreme scenarios (e.g. doubling the sea-level rise rate).

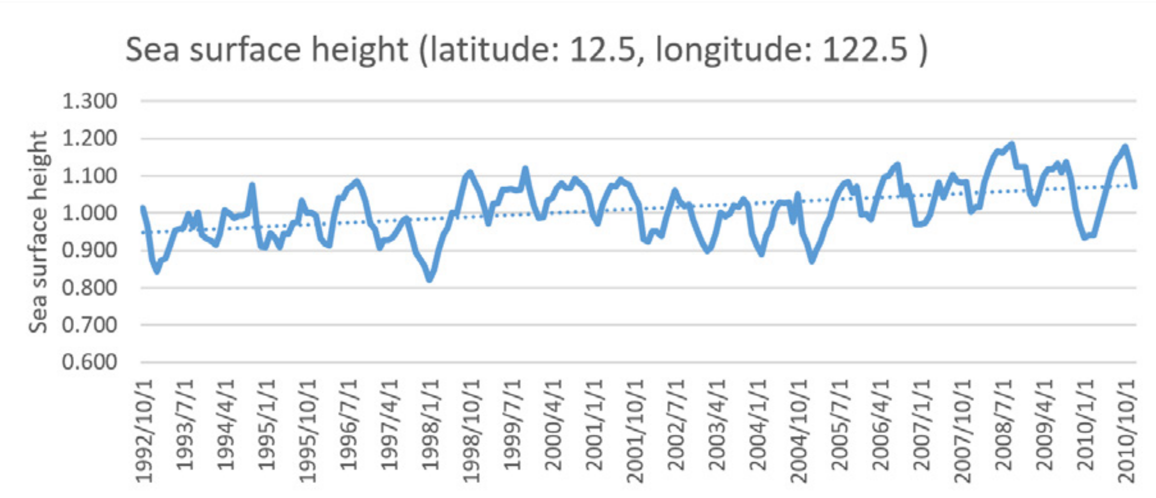

Figure 7.4. Satellite-derived measurements of sea-level change from 1992-2010.

PCLM Step 2: Impact Assessment

Next, the research team conducted a series of impact assessments to try to understand how land-use change and climate change could potentially affect coastal hazards in the future. The results were presented to LGU staff in an online workshop in October 2020, as it was difficult for the research team to travel to Oriental Mindoro due to COVID-19 travel restrictions.

To demonstrate how land-use affects storm surge and coastal erosion, the research team used the Coastal Vulnerability Index model of InVEST (see Chapter 4) to map the coastal vulnerability with and without the coastal ecosystems (e.g. mangroves). From the results of this impact assessment (Figure 7.5), it can be seen that the area from Calapan City to Pinamalayan, as well as Mansalay, are highly reliant on natural habitats to protect the coastline from these hazards. It should be noted that here we have presented the results of this extreme "without coastal habitat" scenario rather than the (more conservative) scenario from the participatory mapping activity, because the results of the participatory mapping scenario are very similar to that of the "with coastal habitat" scenario (due to the minor land-use changes of the participatory mapping scenario as well as the coarse resolution at which the model runs, i.e. 100m x 100m grid size). The main idea of this impact assessment is to demonstrate the importance of the coastal ecosystems for coastal protection.

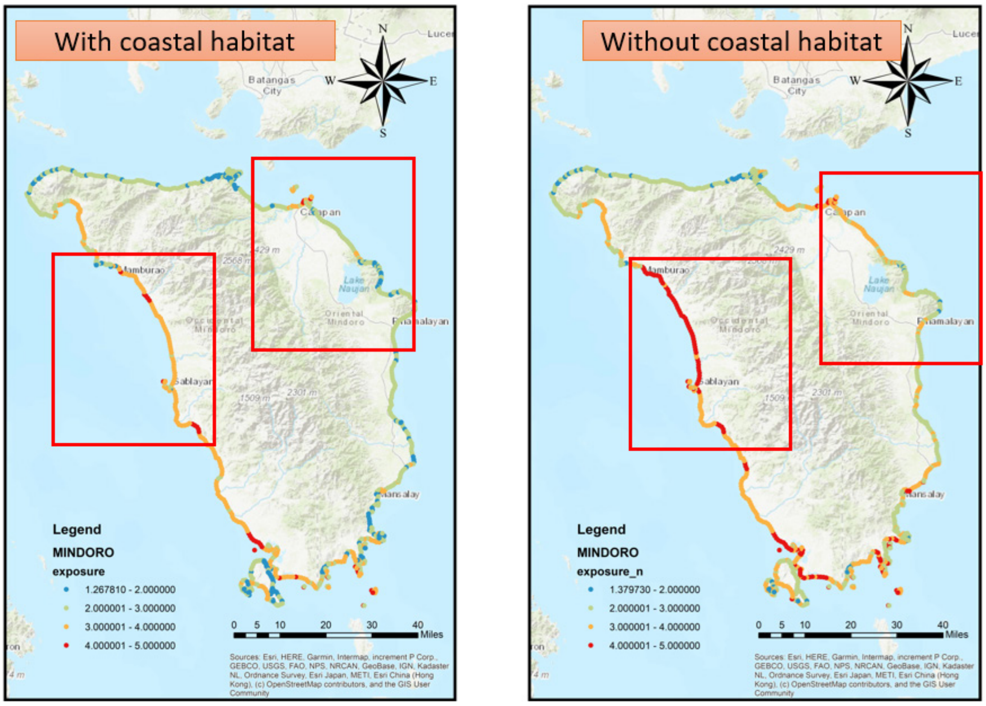

Figure 7.5. Outputs of InVEST Coastal Vulnerability Index model for Mindoro Island.

To model future sea-level rise impacts, the research team used SLAMM (Sea level affecting marshes model), as presented in Chapter 5. The main scenario considered and presented was 0.5m sea-level rise by 2050, as compared to the 1990 sea-level. This corresponds to approximately 8mm/year rise in the future, which was similar to the historical rate of ~7.2mm/year. The results of SLAMM are maps of the future land-use/land cover, assuming no additional protection from sea-level rise compared to the present. The research team presented maps of future land-use/land cover in different LGUs to the LGU staff (see Figure 7.6 for an example). In the Figure 7.6 map, it can be seen that some developed dry land (i.e. built-up areas) may be regularly flooded by 2050, and some undeveloped dry land (i.e. agricultural areas) may become transitional salt marsh due to frequent inundation.

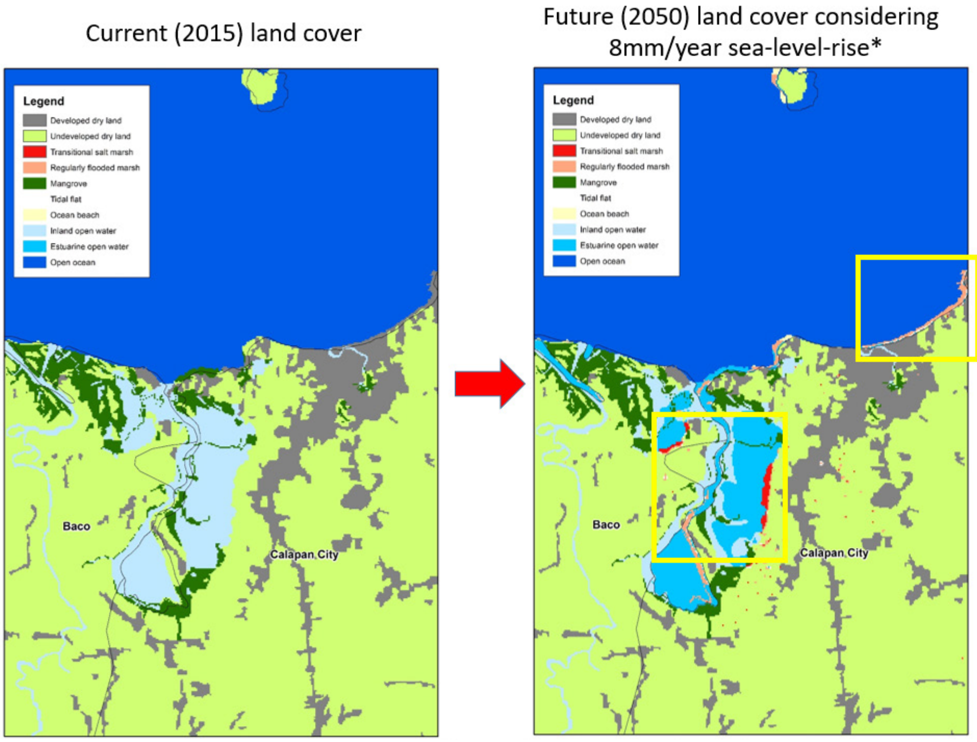

Figure 7.6. Example of outputs from SLAMM model for Oriental Mindoro (Calapan City and Baco LGUs).

Finally, for groundwater salinity impact assessment, the research team analyzed well water samples collected by LGU staff from 35 different wells, and conducted future simulation of water quality using WEAP (as presented in Chapter 6). The results of the analysis of the ground water quality from 35 well samples are shown in Table 7.2. As seen in the table, approximately 25% of the well samples were beyond World Health Organization (WHO) limits in terms of pH, Electical Conductivity (EC), Total Dissolved Solids (TDS), and Chloride (Cl). These results indicate that some of the wells are already experiencing salt water intrusion. A map of the salt water-fresh water mixing ratio was generated to show where the issue is of greatest concern (Figure 7.7). In the area of greatest concern, water quality modeling was conducted using WEAP to identify the impacts of future climate change, population growth, and land-use change on groundwater quality.

Parameters	Minimum	Maximum	Average	St Dev	WHO permissible/ desirable limit (WHO, 2011)	% of samples beyond limit	Health effect
pH	6.23	8.76	7.764	0.64	6.5-8.5	23%	Tastes bad, Bitter taste, mucous membrane allergy
DO (mg/L)	2.31	11.5	5.13	2.11			
EC (µs/cm)	129	5140	714	1083	500	26%	Gastro-intestinal irritation
TDS (mg/L)	83.2	4901	587	1014	500	20%	Gastro-intestinal irritation, Not good for people with hypertension, diabetics
Salinity (ppt)	0.06	4.17	0.47	0.87	<1	6%	Salty taste and laxatic effect and not suitable for ecosystem health
Cl (mg/L)	33.21	2308.14	258.09	479.05	200	23%	Salty taste and laxatic effect
Temp (˚C)	2.3	26	18.6	7.38			
Distance from sea (meter)	34	6220	979	1451.06			
Depth (m)	0	104	37	39.33			

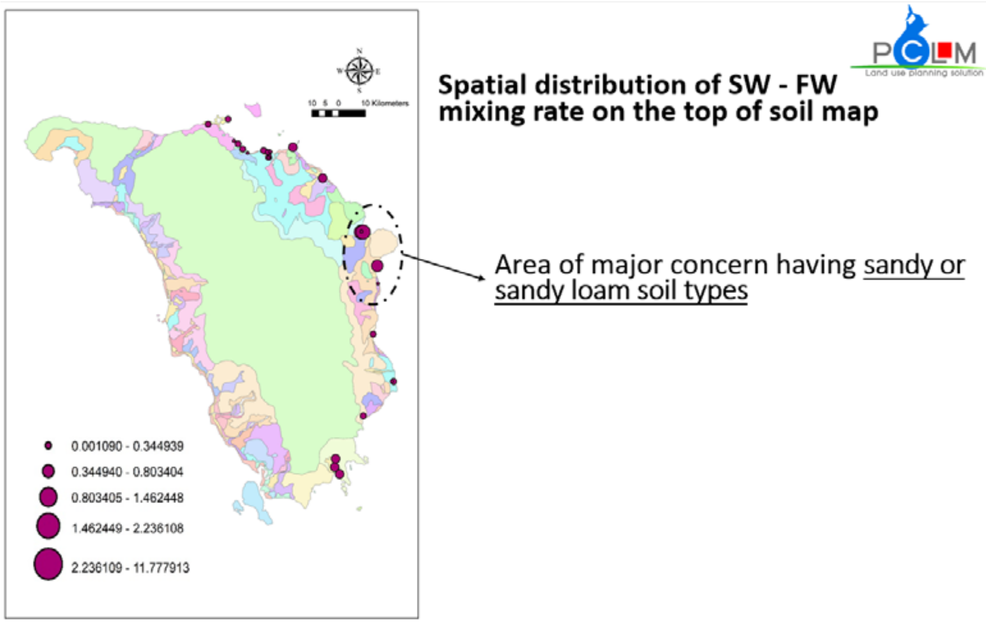

Figure 7.7. Map of salt water – fresh water (SW-FW) mixing ratio of well water samples from Oriental Mindoro. The areas with the large circles indicate the locations of major concern.

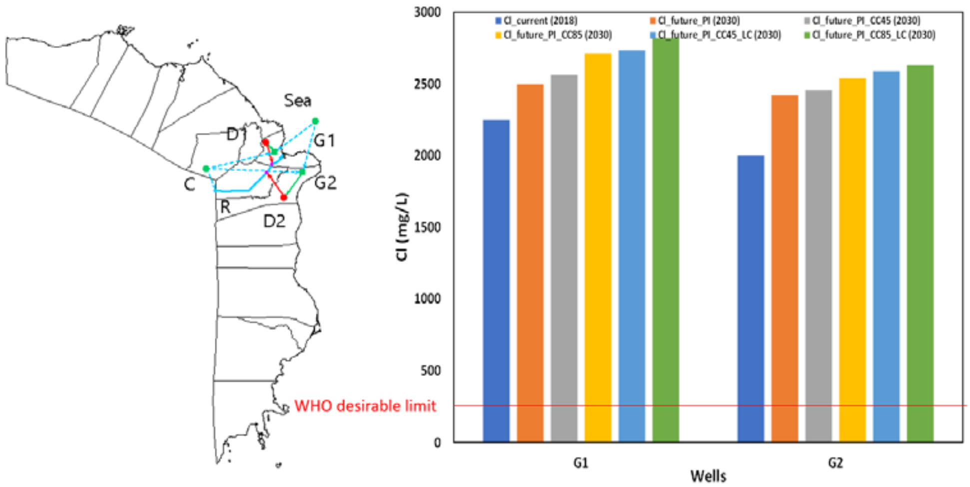

Figure 7.8. WEAP set-up and modeling results. Note: "Cl_current" indicates 2015 chloride level, "Cl_future_PI" indicates 2030 chloride level considering population increase; "Cl_future_PI_CC45" indicates 2030 chloride level considering population increase and climate change (RCP4.5 scenario); "Cl_future_PI_CC45_LC" indicates 2030 chloride level considering population increase, climate change (RCP4.5 scenario), and land-use/land cover change; "Cl_future_PI_CC85" indicates 2030 chloride level considering population increase and climate change (RCP8.5 scenario); and "Cl_future_PI_CC85_LC" indicates 2030 chloride level considering population increase, climate change (RCP8.5 scenario), and land-use/land cover change.

PCLM Step 3: Countermeasure identification

In Oriental Mindoro, countermeasures to reduce future land-use change/climate change impacts were identified through online consultation meetings with local officials from the local government units (LGUs) located along the coast, as well as the Oriental Mindoro Provincial Agricultural Office (PAGO). For this, we used Zoom Video Communications on February 24, 2021, as shown in Figure 7.9. After presenting the results of the impact assessments from PCLM Step 2, LGU officials completed an online questionnaire survey to identify relevant countermeasures. After compiling their countermeasures, we identified several common "priority" countermeasures in consultation with the LGU officials (Table 7.3).

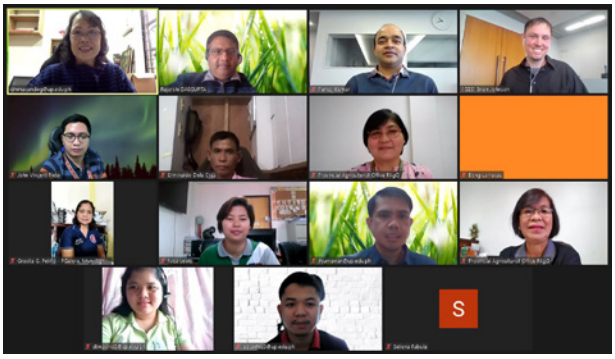

Figure 7.9. Online workshop to identify countermeasures in Oriental Mindoro.

Identified countermeasures
1. Mangrove protection/restoration
2. Seagrass protection/restoration
3. Community participation in environmental policies/initiatives
4. Expanding Marine Protected Areas (MPAs)
5. Reversion of (idle/unproductive) fishponds to mangroves
6. Seawall construction
7. Tapping deeper aquifers
8. Rainwater harvesting
9. Construction of desalinization plant/waste water treatment plant
10. Supporting "green" initiatives of local companies
11. Livelihood diversification of local communities

Table 7.3. Priority countermeasures identified for Oriental Mindoro.

Although we identified countermeasures in this case study through online workshops due to COVID-19 travel restrictions in 2020-2021, another option is through in-person workshop. In an in-person workshop, the process for identifying countermeasures is quite similar. First, the participants from each LGU are grouped together in one table. Then, the results of the scenario analysis and impact assessments (PCLM Steps 1 and 2) are presented. Based on the presented information, the LGU officials are asked to discuss among themselves to identify the actions that can be taken to address these land-use change/climate change impacts in their locality. They write their identified countermeasures on notecards, and when completed, all of the notecards are collected and displayed at the front of the meeting room. A representative from each LGU then presents identified countermeasures to the whole group (Figure 7.10). In this way, the countermeasures can be shared among all LGUs. Finally, there is a question and answer/discussion section to identify and summarize the priority/common countermeasures.

Figure 7.10. Consultation meeting with LGU officials and identification of countermeasures to reduce the negative impacts of land-use change and climate change.

PCLM Step 4: Climate-resilient land-use planning

After identifying all of these countermeasures, the step of PCLM is to incorporate these measures into the local plans and policies. For example, the countermeasures can be used as a basis for applying for domestic/international climate adaptation funds (to raise funds for implementing the countermeasures), and to improve/update the local land-use plans and climate change action plans

Two possible external funding sources were identified for this climate change adaptation fundraising: one national fund called the People Survival Fund (PSF), and one international fund called the Green Climate Fund (GCF). The PSF is special fund in the Philippine National Treasury that finances climate change adaptation programs and projects. GCF, on the other hand, is a dedicated fund set up by the United Nations Framework on Climate Change (UNFCCC) in 2010 to help developing countries reduce their GHG emissions and enhance their ability to respond to climate change.

Development of a GCF project proposal based on this project is now under consideration and still at its early stage. The Philippine Climate Change Commission (CCC) is the National Designated Authority to endorse all proposals for GCF. CCC looks at the quality of the proposal before endorsing it to GCF. The Land Bank of the Philippines is the national accredited entity implementing GCF projects. In the Philippines, one SAP (Simplified Approval Process) project, "Multi-Hazard Impact-Based Forecasting and Early Warning System for the Philippines" has been approved by GCF secretariat in November 2019. This project will strengthen the Philippines' ability to adjust to climate impacts, and implement long-term climate risk reduction and adaptation measures. It will build on best practices in multi-hazard early warning systems and link with forecast-based action to maximize impacts on the ground. This includes climate-resilient development planning and investment (GCF website: https://www.greenclimate.fund/project/sap010). Further information on GCF proposal development and the process can be obtained from GCF official website (https://www.greenclimate.fund/)

Aside from external funds for projects, green bonds are another important future opportunity of fund raising from private sector and local government. Green Bonds are defined as "Bonds issued in order to raise finance for climate change solutions and labelled as green by the issuer. They can be issued by governments, banks, municipalities or corporations and can be applied to any debt format" (Climate Bond Initiative 2018). Green Bonds have been rapidly spreading in the world. The amount of global Green Bond issuance was USD3.1 billion in 2012; however, in 2018, issuance grew to USD167.3 billion (Ministry of the Environment based on data on the CBI website). The Securities and Exchange Commission (SEC) of the Philippines has approved on 16 August 2018, the "Guidelines on the Issuance of Green Bonds under the ASEAN Green Bonds Standards." These Guidelines set out to adopt the ASEAN Green Bond Standards and provide for the rules and procedures for the issuance of ASEAN Green Bonds in the Philippines. The eligible Green Project categories includes but are not limited to 1) Renewable energy, 2) Energy efficiency, 3) Pollution prevention and control 4) Environmentally sustainable management of living natural resources and land use, 5) Terrestrial and aquatic biodiversity conservation, 6) Clean transportation 7) Sustainable water and wastewater management, 8) Climate change adaptation, 9) Eco-efficient and/or circular economy adapted products, 10) production technologies and processes, and 11) Green buildings. These categories can involve/cover the adaptation options identified in this Chapter. Further information on the trend of Green Bond can be obtained from following websites:

International Capital Market Association:
https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp/

Climate Bonds Initiative: https://www.climatebonds.net/

The Green Bond Issuance Promotion Platform: http://greenbondplatform.env.go.jp/en/

Potential adaptation technologies and measures

Since this project was supported by the Ministry of the Environment of Japan, it is possible to introduce adaptation technology developed in Japan to another country that is facing climate related disasters in recent years. The Japanese government publishes technologies owned by private companies like Joukashou (decentralized wastewater treatment technology) on the Climate Change Adaptation Platform (A-PLAT: https://adaptation-platform.nies.go.jp/en/lets/adaptationbiz.html).

Finally, with regards to land-use planning, the local governments in Oriental Mindoro are in the process of revising their Comprehensive Land-use Plans (CLUPs), following not only the Republic Act No. 9729 stipulating that climate change shall be mainstreamed into government policy formulations (Congress of the Philippines, 2009), but also the national guidelines requiring that local climate change actions shall be mainstreamed into CLUPs (Housing and Land Use Regulatory Board, 2013). Upon the approval by the Housing and Land Use Regulatory Board and the Sangguniang Panlalawigan (i.e. provincial assembly), the CLUPs serve as the basis for formulating the local Comprehensive Development Plan (CDP) and Local Development Investment Programs (LDIP) (Housing and Land Use Regulatory Board, 2013). It is essential that the scientific information provided through these types of impact assessments be incorporated into these local plans.

Conclusion

In this final chapter of the PCLM Guidebook, we have presented a case study to demonstrate how countermeasures, identified through the PCLM approach, can be identified and then implemented to increase the resilience of coastal communities in climate hazard-prone regions. We sincerely hope that this guidebook, including the various tutorials included in it, can help you to identify the future impacts of climate change and land use change in your own locality, and to develop policies and projects to reduce these future risks.

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