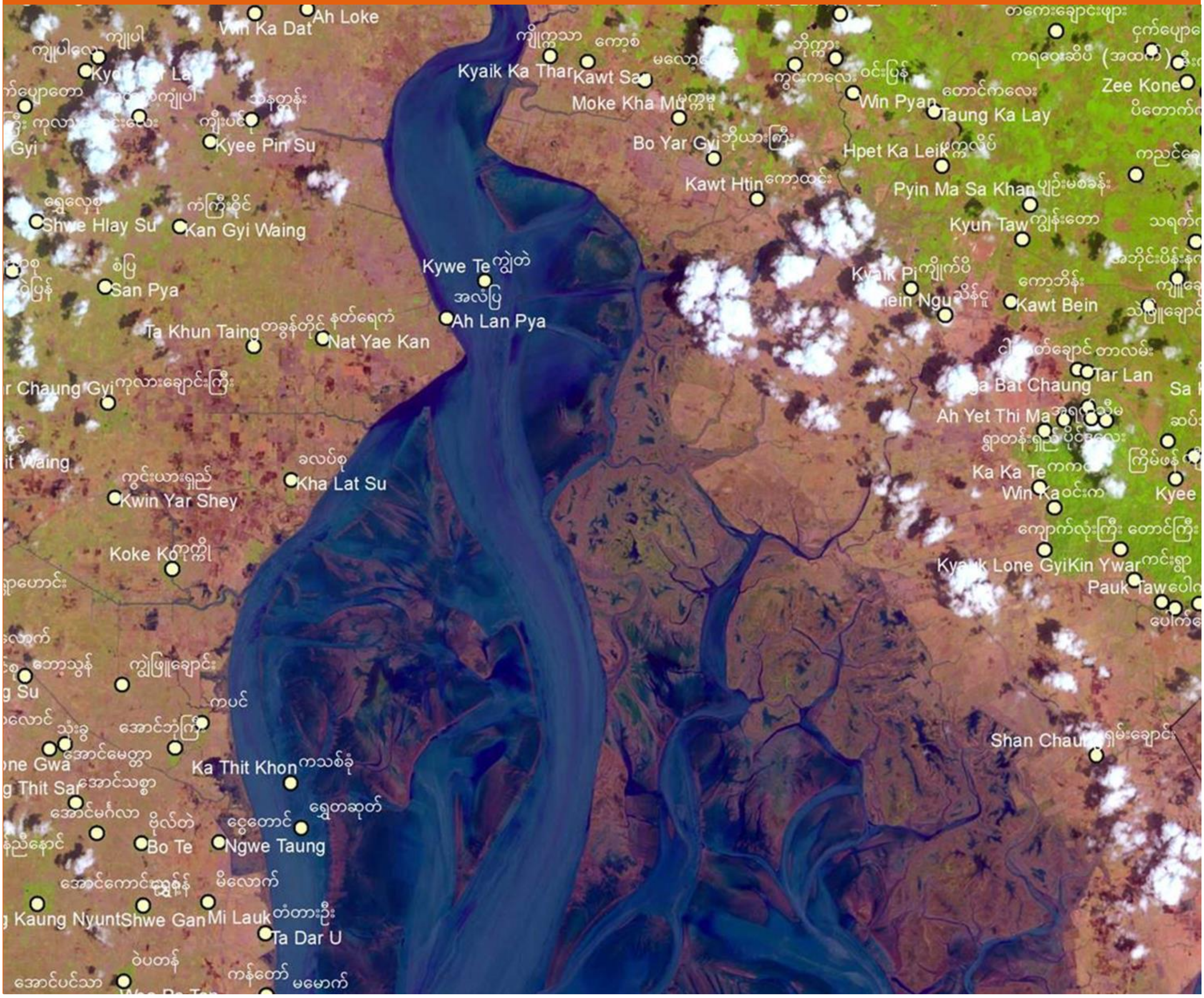
DEALING WITH COASTAL EROSION IN THE GULF OF MOTTAMA

HELVETAS Myanmar

31 DECEMBER 2018



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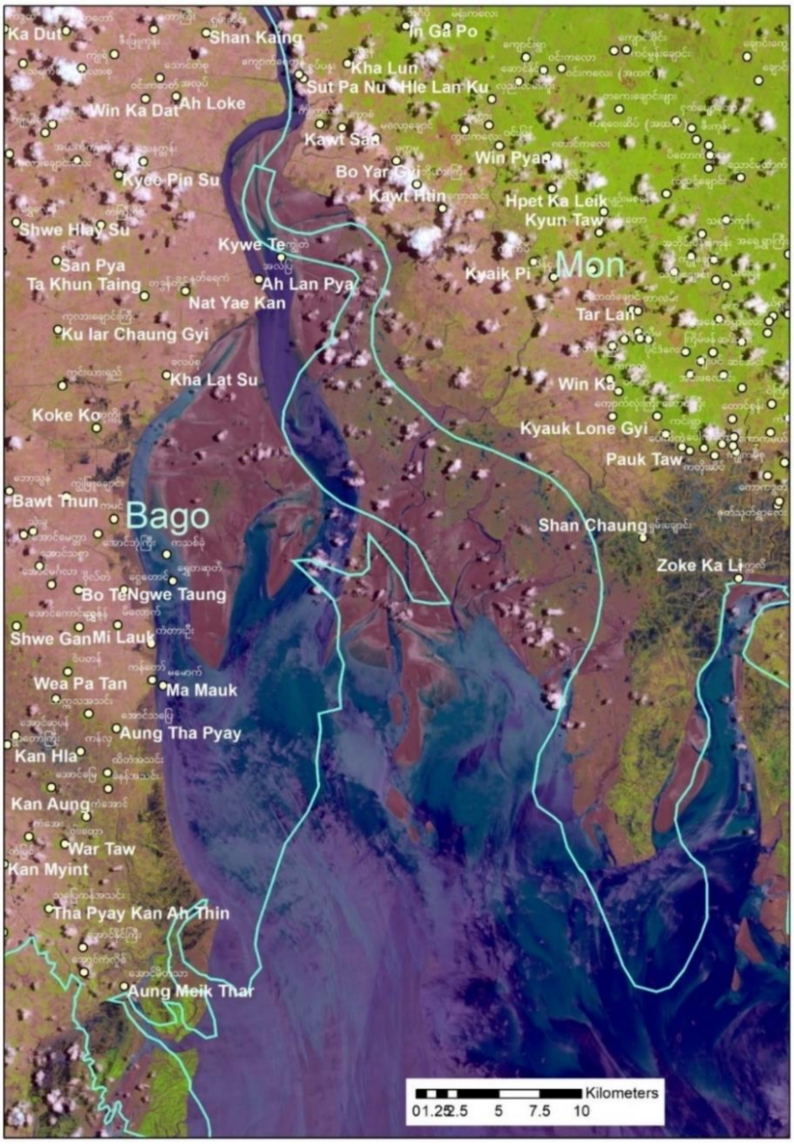
၁–၁။ နောက်ခံသမိုင်းကြောင်း

မုတ္တမပင်လယ်ကွေ့သည် များပြားသော ထူးကဲမှုဖြင့် မြန်မာနိုင်ငံ၏ အနောက်တောင်ဘက်တွင် တည်ရှိပြီး အာဒမန် ပင်လယ်နှင့်ထိစပ်လျက် ရှိသည်။ ၎င်း၏ ကျယ်ပြန့်သောနုန်းတင်မြေနုလွင်ပြင်သည် ငှက်၊ ငါး၊ အခြားတရိစ္ဆာန်များနှင့် ဒေသတွင်းအခါအားလျော်စွာပေါက်ရောက်သောအပင်များတို့၏အိမ်လည်းဖြစ်သည်။ မြစ်ဝ၏အကျယ်သည် ၁၀၀ ကီလိုမီတာခန့် ဖြစ်ပြီး စစ်တောင်းမြစ်သည် မြောက်ဘက်သို့ ကတော့ပုံစံ ကျဉ်းသွားသည် (ပုံ–၁–၂၁)။ ထိုဧရိယာသည် ၎င်း၏အားကောင်းသော ဒီရေအတတ်အကျ ဖြစ်စဉ်ကြောင့် လူသိများသည်။ ဒီရေတတ်ချိန်တွင် ဒီရေများသည် ၁ မီတာခန့် အမြင့်ရှိသော လှိုင်းပုံစံ ဖြစ်ပေါ်ပြီး မြစ်ဝ၏အထက်ဘက်သို့ တက်သွားသည်။

ဒီရေတက်သည့်အခါတိုင်းတွင်၊ မြင့်မားသောအနည်နောက်ဇုန်သည် တောင်နှင့်မြောက်ရွှေ့လျားပြီး၊ ကီလိုမီတာ ၁၀၀ အထိရှည်လျားသော ကမ္ဘာ့အရှည်ဆုံးရွှံ့နွံပြင်အဖြစ်ဖြစ်ပေါ်စေသည်။ ဘေးမှဝန်းရံထားသောမြေသည် အကြွမ်းဖျင်းအားဖြင့် မြေပြန့်နတ်စပါး၊ ကျယ်ပြန့်သော မဖွံ့ဖြိုးသေးသည့် သောင်နုမြေများ နှင့် မြေနိမ့်ဧရိယာ (ဒီရေအမြင့်ဆုံးအချိန်တွင် ကမ်းရိုး တမ်းတစ်လျှောက်ရေလွှမ်းသည့်ဒေသ) များပါဝင်ပါသည်။



မုတ္တမကွေ့နှင့်စစ်တောင်းမြစ်ဝအား ပဲခူးတိုင်းဒေသကြီး နှင့် မွန်ပြည်နယ်တို့မှ ဝန်းရံထားသည်။ စစ်တောင်းမြစ်တွင် ရွေ့လျားအားများသော ဒီရေလမ်းကြောင်းသည် ကမ်းရိုးတန်းဧရိယာအမြောက်အမြား အရှိန်ပြင်းစွာ ပြိုကျပျက်စီးမှုကို ဖြစ်စေသည်။ ပဲခူးတိုင်းဒေသကြီးတွင် ကမ်းပြိုမှုကြောင့် ရွာလုံးကျွတ်ပျက်စီးခြင်းများ ပြောင်းရွှေ့ခြင်းများပြုလုပ်ရသည်။ လယ်သမားများနှင့် ရေလုပ်သားများ၏ အသက်မွေးဝမ်းကြောင်းလုပ်ငန်း များစွာထိခိုက်ရသည်။ ကမ်းပြိုခြင်းနှင့် သောင်ထွန်းခြင်း တစ်လှည့်စီ အကြိမ်များစွာ ဖြစ်ပေါ်နေပြီး ခန့်မှန်းချေအရ ထို့အဖြစ်အပျက်များသည် ၁၀ နှစ်မှ ၁၅ နှစ်အတွင်းတွင် တစ်ကြိမ်ဖြစ်သည်။

ပဲခူးတိုင်းဒေသကြီးတွင် အဓိကကမ်းပြိုကမ်းစားမှုဒဏ်ကို ခံစားနေရသော ရွာများသည် စစ်တောင်းမြစ်အနီးရှိ မြို့နယ်နှစ်ခုမှ ဖြစ်သည်။ ၎င်းတို့မှာ ကဝမြို့နယ်နှင့် သနပ်ပင်မြို့နယ်တို့ ဖြစ်သည်။ ယခုအချိန်တွင် ထိုကျေးရွာများတွင် နေထိုင်သော ရွာသား ၇၀၀၀ ကျော်သည် ကမ်းပြိုကမ်းစားခြင်းဘေး၏ ခြိမ်းခြောက်မှုကို ယခုအချိန်နှင့် လွန်ခဲ့သောကာလ လပေါင်းများစွာက တိုက်ရိုက်ခံစားနေသည်။ ထို့ကြောင့် ပဲခူးတိုင်းဒေသကြီး၏ အစိုးရအဖွဲ့မှ မုတ္တမကွေ့၏ ကမ်းပြိုကမ်းစားခြင်းကို ကိုင်တွယ်ဖြေရှင်းရန် အထောက်အပံ့များ ရှာဖွေနေခဲ့ခြင်းဖြစ်ပါသည်။

အသက်မွေးဝမ်းကြောင်း လုပ်ငန်းအခွင့်အလမ်းများ ဖွံ့ဖြိုးရေးနှင့် သဘာဝပတ်ဝန်းကျင် ထိန်းသိမ်းစောင့်ရှောက်ရေး နှစ်ခုစလုံးအတွက် မြစ်၏ သွင်ပြင်အနေအထားပြောင်းလဲခြင်းကို ခန့်မှန်းနိုင်ရန်မှာအလွန်ပင်အရေးပါသည်။ ထိုသို့ ခန့်မှန်းတွက်ချက်ရတာပင်လယ်ရေမြင့်တက်လာခြင်းကို ဖြစ်စေသော ရာသီဥတုပြောင်းလဲခြင်း အကြောင်းအရာများကို ထည့်သွင်းစဉ်းစားရန် လိုအပ်သည်။ ကမ်းရိုးတန်းတစ်လျှောက် အများဆုံးကမ်းပြိုနိုင်သော အခြေအနေကို ကြိုတင်ခန့်မှန်းခြင်း အားဖြင့် လုံခြုံသောနေရာများနှင့် ပြောင်းရွှေ့နိုင်သော နေရာများအား သတ်မှတ်နိုင်ခြင်းတို့ ဆောင်ရွက်နိုင်သည်။

မုတ္တမကွေ့၏စီမံကိန်းကိုယ်စား Helvetas အဖွဲ့အစည်းမှ Arcadis အား ထိုကမ်းရိုးတန်းကမ်းပြိုကမ်းစားဖြစ်စဥ်အား လေ့လာခြင်းများ လုပ်ဆောင်ရန် သဘောတူစာချုပ် ချုပ်ဆိုခဲ့သည်။ ယခုစီရင်ခံစာ၏ လေ့လာမှုတွေ့ရှိချက်များကို Mr. R.C. Steijn (ပရောဂျက်အဖွဲ့ခေါင်းဆောင်) dr.J.Cleveringa, Mr.J.van der Baan (Arcadis နယ်သာလန်နိုင်ငံ) နှင့် Tanya Huizer (Arcadis မြန်မာနိုင်ငံ) တို့မှ ပြင်ဆင်ရေးသားခဲ့ခြင်းဖြစ်သည်။ Alexander de Ruijter, Floris Verbeek (Arcadis မြန်မာနိုင်ငံ) နှင့် Jasper Leuven (Utrecht တက္ကသိုလ်) တို့၏ အကူအညီများဖြင့် ဆောင်ရွက်ခြင်း ဖြစ်ပါသည်။ Prof.dr.M. Kleinhans (Utrecht တက္ကသိုလ်) နှင့် Prof.dr.Z.B.Wang (Deltares)တို့မှ သိပ္ပံနည်းကျ လေ့လာချက်များကို ဆောင်ရွက်သည်။

Figure 1.2 Two pictures (Courtesy Helvetas) of the same school. The picture at the left taken on 07.11.2017; the picture on the right was taken only one month later on 12.12.2017.

Figure – 1.1 Sittaung estuary with names of the villages in Bago and Mon states.

၁–၂။ ရည်ရွယ်ချက်များ

၁။ မုတ္တမပင်လယ်ကွေ့ဒေသ၏ ကမ်းပါးပြိုမှုကို တွန်းလှန်နိုင်ရန်အတွက် အရေးပါးသောတိုင်းတာမှု ကျယ်ကျယ်ပြန့်ပြန့် ပြုလုပ်နိုင်ရန် မုတ္တမကွေ့စီမံချက်နှင့် အစိုးရအုပ်ချုပ်ရေးဌာနများ တွေ့ဆုံးဆွေးနွေးခြင်း။

၂။ သက်ဆိုင်ရာအဖွဲ့အစည်းဌာနများနှင့်ညှိုးနှိုင်းဆွေးနွေးပြီးနောက် မဟာဗျူဟာများရေးဆွဲ၍ ပဲခူးတိုင်းနှင့် မွန်ပြည်နယ်တွင် ဖြစ်ပျက်နေသော ကမ်းပါးပြိုမှုများကို စီလျှော်စွာပြုလုပ်ခြင်း၊ ကိုက်ညီစွာပြင်ဆင်ခြင်း၊ ထိမ်းချုပ်ခြင်း (သို့မဟုတ်) တွန်းလှန်ခြင်း ပြုလုပ်သွားရန်နှင့် ၄င်းကမ်းပါးပြိုမှုများကြောင့် ဖြေရှင်းမှုကုန်ကျစရိတ်များ ခန့်မှန်းတွက်ချက်ရာတွင် “သဘာဝနှင့်ကိုက်လျှော်ညီထွေရှိသည့်ဖြေရှင်းချက်” အယူအစများ ပါဝင်ပါသည်။

၃။ ပဲခူးတိုင်းနှင့် မွန်ပြည်နယ်အတွက် အနာဂတ်တွင် မတူညီသော အချိန်ကာလများ၏ ကမ်းစပ်တစ်လျှောက် ပြိုကျမှု ခန့်မှန်းချက်များပြုလုပ်ပြီး နောက်လာမည့်နှစ်များတွင် “လုံခြုံ”သည့် ဧရိယာများခန့်မှန်းပြီး ကြီးမားသော အခြေခံအဆောက်အဦးများဖြစ်သည့် “စာသင်ကျောင်း၊ လမ်း၊ သောက်သုံးရေကန်နှင့် အခြားသော အစိုးရဝန်ဆောင်မှုများ” ပြုလုပ်ခြင်း။

၄။ သက်ဆိုင်ရာမော်လမြိုင်နှင့် ပဲခူးတက္ကသိုလ်များနှင့် ပူးပေါင်း၍ ကမ်းရိုးတန်းဒေသ တရိစ္ဆာန်နှင့်အပင်များ သက်ဆိုင်သည့် လေ့လာသည့် ပညာရှင်အဖွဲ့တခု ဖွဲ့စည်းခြင်း။

ကမ်းရိုးတန်း ထိန်းသိမ်းကာကွယ်ရေးတိုင်းတာချက်များမပြုလုပ်ခင် ကမ်းပါးပြိုမှု၏ အကျိုးအကြောင်းများကို သိရှိနာလည်ဖို့ အလွန်အရေးပါသလို ကမ်းရိုးတန်း ပြောင်းလဲဖြစ်ပေါ်မှုအယူအဆများဖြစ်သည့် ပင်လယ်ရေမြင့်တက်လာခြင်း၊ အနည်ထိုင်ခြင်း နှင့် လူသားတို့လုပ်ရပ်မှုဖြစ်စဉ်များကိုလည်း သိရှိနာလည်ဖို့ အလွန်အရေးကြီးပါသည်။

၁–၃။ ချဉ်းကပ်ပုံနှင့် နည်းလမ်းများ

ထိုဧရိယာတွင် ယခုကဲ့သို့ ကမ်းရိုးတန်းကမ်းပြိုမှု လေ့လာခြင်းသည် ပထမဆုံးအကြိမ်ဖြစ်သည်။ စစ်တောင်းမြစ်ဝတွင် ကမ်းရိုးတန်း ကမ်းပြိုခြင်းဖြစ်စဉ်များကို လေ့လာခဲ့သည့် အကြိမ်ရေနည်းခဲ့သည်။ ၂၀၁၇ ခုနှစ်တွင် De Ridder သည် လှိုင်းခေါင်းဖြူ (tidal bore) ပြန့်ပွားမှုဖြစ်စဉ်ကို လေ့လာခဲ့သည်။ တစ်ချို့သော လေ့လာဆောင်ရွက်မှုများတွင် ကွင်းဆင်းလေ့လာတိုင်းတာခြင်း များပါဝင်ခဲ့သည်။ ဥပမာအားဖြင့် ၂၀၁၆ ခုနှစ်တွင် Yamashita နှင့် Aung တို့ တိုကျိုတက္ကသိုလ်၏ ထောက်ပံ့မှုဖြင့် လေ့လာဆောင် ရွက်ခဲ့သည့် ပရောဂျက်ဖြစ်သည်။ ယခုပြုလုပ်ခဲ့သည့် လေ့လာမှုပရောဂျက်တွင် အဆင့်လေးဆင့် ပါဝင်သည်။

အဆင့် ၁။ တည်ရှိမှုအနေအထားအပေါ် နားလည်ခြင်း (Understanding the situation – Chapter 2)

ဤကဏ္ဍ၏ အဓိကအချက်သည် ကမ်းရိုးတန်းရွှံ့လျားပြောင်းလဲမှု သဘောသဘာဝကို နားလည်ပြီး ယခုလက်ရှိ တည်ရှိနေသော အချက်အလက်များကို သုံးသပ်နိုင်ရန် ကိန်းဂဏန်းနှင့်သက်ဆိုင်သည့်ပုံစံများနှင့် ကွင်းဆင်းလေ့လာတိုင်းတာခြင်းများကို အခြေခံကာ ဆောင်ရွက်သွားမည်။ ထိုလုပ်ငန်းစဉ်များ တစ်ခုနှင့်တစ်ခုကြားတွင် ရှင်းလင်းသေချာသော ဆက်နွယ်မှုများရှိသည်။ ဥပမာအားဖြင့် သုံးသပ်လေ့လာမည်ဖြစ်သော ဒေတာအချက်အလက်များသည် ကွန်ပြူတာမော်ဒယ် တည်ဆောက်ရာတွင် အသုံးပြုရမည်ဖြစ်ပြီး ကွင်းဆင်းလေ့လာတိုင်းတာခြင်းများသည်လည်း ကွန်ပြူတာမော်ဒယ်မှ ရရှိလာသော အဖြေများနှင့် ချိန်ဆနှိုင်းယှဉ်ရမည် ဖြစ်သည်။ ထိုကဲ့သို့ တိုင်းတာ၍ ရရှိလာသော ဒေတာအချက်အလက်များနှင့် ကွန်ပြူတာမှ ရရှိလာသော အဖြေများကို အတူတကွပေါင်းစည်းချိန်ဆ အသုံးပြုခြင်းသည် အနာဂတ်တွင် ဖြစ်ပေါ်နိုင်မည့် အခြေအနေများကို ခန့်မှန်းရာတွင် အကောင်းဆုံးဖြစ်သည်။

အဆင့် ၂။ အနာဂတ်အခြေအနေများကို ခန့်မှန်းခြင်း (Predicting the future – Chapter 3)

ခန့်မှန်းခြင်းလုပ်ငန်းစဉ်များကို ရေတိမ်ပိုင်းနေရာများနှင့် ဒီရေအတက်အကျ ရှိသောနေရာများ၏ သွင်ပြင် အနေအထား ပြောင်းလဲခြင်းနှင့် ၎င်းတို့နှင့် ဆက်စပ်သော ကမ်းရိုးတန်းတစ်လျှောက်ပြောင်းလဲခြင်းတို့ကို အခြေခံကာ ဆောင်ရွက်ခဲ့ပါသည်။

အဆင့် ၃။ ပြီးမြောက်အောင်ဆောင်ရွက်နိုင်မည့် လုပ်ငန်းစဉ်များ (What can be done – Chapter 4)

ဤအဆင့်တွင် ကမ်းရိုးတန်း ကမ်းပြိုခြင်းအား ထိန်းချုပ်နိုင်ရန် ဖြစ်နိုင်သောကာကွယ်ရေးနည်းလမ်းများကို ခြုံငုံ၍ ဖော်ပြသွားမည်ဖြစ်ပါသည်။ မတူညီသောနည်းလမ်းများကို ဆောင်ရွက်ရမည့် အခြေခံလုပ်ငန်း အဆင့်ဆင့်ကို ဖော်ပြမည်ဖြစ်သည်။

အဆင့် ၄။ စုစည်းတင်ပြခြင်း (Integration – Chapter 5)

ဤနောက်ဆုံးအဆင့်တွင် စုဆောင်းရရှိထားသော သတင်းအချက်အလက်များနှင့် အမြင်များပေါင်းစည်းကာ ပြီးပြည့်စုံသော အကြံပေးချက်များ တင်ပြသွားမည် ဖြစ်သည်။ ကမ်းရိုးတန်း ကမ်းပြိုမှု ဖြစ်စဉ်များနှင့် မျှော်မှန်းထားသော အနာဂတ်၏ ဖွံ့ဖြိုးတိုးတတ်မှုများကိုပါ အတည်ပြုနိုင်မည် ဖြစ်သည်။ ထို့အပြင် ကမ်းရိုးတန်းကမ်းပြိုမှုနှင့် သက်ဆိုင်သော လုပ်သင့်/မလုပ်သင့် သည့် အရာများအတွက် အကြံပြုချက်များ ပေးနိုင်မည်ဖြစ်သည်။

၁–၄။ သုံးသပ်ချက်များနှင့် အကြံပြုချက်များ

ကမ်းရိုးတန်းကမ်းပြိုမှုများအတွက် မရှိမဖြစ်အရေးကြီးသော သုံးသပ်ချက်များနှင့် ပဲခူးတိုင်းဒေသကြီးနှင့် မွန်ပြည်နယ်ရှိ ကမ်းရိုးတန်း ဒေသများ၏ စီမံခန့်ခွဲမှုများအတွက် အကြံပြုချက်များမှာ အောက်ပါအတိုင်း ဖြစ်သည်။

သုံးသပ်ချက်များ –

၁။ ပဲခူးတိုင်းဒေသကြီးနှင့် မွန်ပြည်နယ်ရှိ ကမ်းရိုးတန်းတစ်လျှောက်တွင် ဖြစ်သော ကမ်းပြိုကမ်းစားမှု များသည် စစ်တောင်းမြစ်ဝ၌ မြစ်ကြောင်းများ၏ သဘာဝအတိုင်း ပြောင်းလဲရွှေ့လျားနေသောဖြစ်စဉ်ပေါ်တွင် အခြေခံသည်။ လေ့လာတွေ့ရှိရသော မြစ်၏ဖြစ်စဉ်ပြောင်းလဲမှုပေါ်တွင် လူတို့၏ ထိန်းချုပ်မှု/ အကျိုးသက်ရောက်မှုများ မတွေ့ရှိပါ။

၂။ မုတ္တမကွေ့ရှိ ပဲခူးတိုင်းဒေသကြီး ကမ်းရိုးတန်းတစ်လျှောက်တွင် ရေပြင်အတိုင်းကမ်းပါးများ နောက်သို့ရွှေ့လျားခြင်း ဖြစ်စဉ်သည် အချို့နေရာများတွင် တစ်နှစ်လျှင် ၁ ကီလိုမီတာ (၁ ရက်လျှင် ၅မီတာ) ထက်ပို၍ ဖြစ်ပွားနေသည်။ ပြင်းထန်သော ဖြစ်စဉ်များမှလွဲ၍ ထိုကဲ့သို့ ကမ်းပြိုကမ်းစားခြင်းသည် ကမ်းပါးတစ်လျှောက်ရှိ သဘာအတိုင်းဖြစ်သော ပြောင်းလဲမှု ဖော်ပြနေသည့် ကမ်းများနောက်သို့ရွှေ့ခြင်းနှင့် ကမ်းမြေများလျင်မြန်စွာ ဖြစ်ပေါ်လာခြင်း၏ အစိတ်အပိုင်းဖြစ်သည်။

၃။ မုတ္တမကွေ့၌ ဖြစ်သော ရေစီးဆင်းမှုပုံသဏ္ဌာန် အပြုအမူများ၏ ပြင်းအားသည် ကမ္ဘာပေါ်တွင် ထူးခြားရှားပါးသည်။ ဤမြစ်ဝနှင့် အနီးဆုံးနေရာသည် တရုတ်နိုင်ငံ ဂွာန်ထန် (Qiantang) မြစ်ဝဖြစ်သည်။

၄။ ထူးခြားသည့် ရေစီးကြောင်းသွင်ပြင် ဖွဲ့စည်းပုံ နှစ်နေရာအား ပုံတွင်ဖော်ပြထားသည်။ မြောင်ဘက်ပိုင်းရှိ ဧရိယာ (နံပါတ် – ၁)တွင် သဲသောင်များ လျင်မြန်စွာ ကြီးထွားလာပြီး ရေစီးကြောင်းများသည် နောက်သို့ တွန်းပို့ခံနေရပုံ ပေါ်သည်။ ဧရိယာ (နံပါတ် –၂)တွင် ရေစီးကြောင်းများသည် အရှေ့ဘက်နှင့် အနောက်ဘက် နှစ်ဘက်လုံးအား ရွှေ့လျားစီးဆင်းနေဟန်ရှိပြီး ပိုမို၍ လည်း အရှိန်များသည်။

၅။ တိကျသော အဖြေကို မသိရသေးသော်လည်း ပို၍ကြမ်းတမ်းသော အနည်များသည် မြောက်ဘက်သို့ သယ်ယူပို့ ဆောင်ခြင်း ခံရပြီး ဧရိယာ(နံပါတ် – ၁) အနည်များပို့ချသည်။ ထိုကဲ့သို့ မြောက်ဘက်သို့ သယ်ယူပို့ဆောင်ခံရခြင်းသည် ရေကြီးမှုဖြစ်စဉ်၏ လွှမ်းမိုးမှုကြောင့်ဖြစ်ပြီး ဒီရေလှိုင်းများ ဖြစ်ပေါ်ဖွဲ့စည်းမှု ကြောင့်လည်း ဖြစ်သည်။ သဲသောင်ပြင်များ ရွှေ့လျားမှုနှင့်အတူ သဘာဝအတိုင်း မြစ်ကွေ့များဖြစ်ပေါ်လာမှုသည် မြစ်ကြောင်းများ ပြောင်းလဲရွှေ့လျားခြင်းကို ဖြစ်စေပြီး ထိုမှတစ်ဆင့် ကမ်းရိုးတန်းတစ်လျှောက်တိုက်စားမှုများ ဖြစ်ရသည်။

၆။ ဧရိယာ ၂ တွင်၊ ရေစီးလိုင်းသည်ခန့်မှန်းရပါက အောက်ခံမြေလွှာသည်ရေစီးကြောင်းကိုခံနိုင်သည့်အလွှာ (ရွှံ့ သို့မဟုတ် ကျောက်လွှာ) ဖြစ်သောကြောင့် ပိုမိုနက်လာနိုင်တော့မည်မဟုတ်ပါ။ ဤအချက်က မြစ်ဝ၏ရေပြင်ညီစီးကြောင်း အရှိန်အလွန်မြင့် နေကြောင်းကို ရှင်းလင်းစေပါသည်။ (တစ်နှစ်လျှင် ကီလိုမီတာများခန့်) နက်ရှိုင်းသောရေစီးကြောင်းများထက်စာလျှင် ပိုမို သိပ်သည်းဆ နည်းသောမြေများ တိုက်စားရပြီး ရေတိမ်သော ရေစီးကြောင်းများဖြစ်ပေါ်စေသည်။ ထို့ကြောင့်ရေစီးကြောင်းသည် ပိုမိုကျယ် ပြန့်လာနိုင်ပါသည်။ (“bank pull”)

၇။ ကမ်းရိုးတန်း တစ်လျှောက်ရှိ မြစ်ကြောင်း ပြောင်းလဲစီးဆင်းမှု ဦးတည်ချက်သည် ကမ်းပြိုကမ်းစား ဖြစ်မည့်နေရာကို ဆုံးဖြတ်ပေးသည်။ မြစ်လမ်းကြောင်း အနောက်ဘက်သို့ ပြောင်းရွှေ့သွားပါက ပဲခူးတိုင်းကမ်းရိုးတန်းတစ်လျှောက် ကမ်းပြို ကမ်းစားမှုဖြစ်ပြီး အရှေ့ဘက်သို့ ပြောင်းရွှေ့သွားပါက မွန်ပြည်နယ် ကမ်းရိုးတန်းတစ်လျှောက်တွင် ကမ်းပြိုမှုဖြစ်သည်။

၈။ မြစ်ဝ၏ မြောက်ဘက်အခြမ်း (ဧရိယာ – ၁) တွင် မြစ်ကြောင်းပြောင်းလဲရွှေ့လျားမှုနှင့် ကမ်းရိုးတန်းတစ်လျှောက် ကမ်းပြိုခြင်းဖြစ်စဉ်သည် နှစ် ၃၀ ခန့်မနည်း ကြာမြင့်နေပြီး ဖြစ်သည်။

၉။ မြစ်ဝ၏ တောင်ဘက်အခြမ်း (ဧရိယာ– 2a နှင့် 2b) တို့တွင်လည်း မြစ်ကြောင်းပြောင်းရွှေ့ခြင်းနှင့် ကမ်းရိုးတန်း တစ်လျှောက် ကမ်းပြိုခြင်း ဖြစ်စဉ်သည် ၁၀ နှစ်မှ ၁၅ နှစ်အတွင်း ပြောင်းလဲမှု မရှိသေးပါ။`မစ်ကြောင်းများဦးတည်ချက် လမ်းကြောင်းပြောင်းလဲမှုသည်လည်း နောင်တစ်ချိန်တွင် ထပ်တလဲလဲ ပြန်ဖြစ်နေဦးမည်ဖြစ်သည်။ သို့သော်တိကျသော အချိန်ကာလနှင့် အကြိမ်အရေအတွက်ကို သတ်မှတ်၍ မရနိုင်ပါ။

ကြိုတင်ခန့်မှန်းချက်များ –

၁၀။ သဘာဝတရားအား ကြိုတင်ခန့်မှန်းခြင်းသည် ကန့်သတ်ချက်များရှိပြီး ထိုသို့ဖြစ်ရခြင်းသည် အမြဲသမာသမတ်ထဲ မရှိသော သဘောတရားကြောင့် ဖြစ်သည်။ ဖွဲ့စည်းပုံ စနစ်တစ်ခုသည် ပို၍ရှုပ်ထွေးလာလေလေ ပို၍ခန့်မှန်းရခက်လာလေလေ ဖြစ်သည်။ မိုးလေဝသခန့်မှန်းခြင်းနှင့်လည်း သဘောတရားတူသည်။ ဥပမာအားဖြင့် တစ်ကေရှိသော နေရာလေးကိုပင် နောင် လာမည့် ၂ နှစ်တွင် မိုးရွာသွန်းနိုင်ခြင်း ရှိမရှိကို မည်သူမှ မခန့်မှန်းနိုင်ပါ။ ထိုအမှန်တရားသည် မုတ္တမကွေ့၏ ကမ်းရိုးတန်းတစ်

လျှောက် ကမ်းပြိုကမ်းစားခြင်းကို ခန့်မှန်းရာတွင်လည်း အတူတူပင်ဖြစ်သည်။ နောင်လာမည့် ငါးနှစ်အတွင်း ကမ်းပြိုကမ်းစား ဖြစ်နိုင်ချေရှိသော နေရာများကို ခန့်မှန်းရာတွင် အကောင်းဆုံးနည်းလမ်းမှာ ရနိုင်သမျှအချက်အလက်ဖွဲ့စည်းပုံ အခြေအနေများ အပေါ်အခြေခံ၍ တွက်ချက်ခြင်းဖြစ်သည်။ ထိုသို့တွက်ချက်ရတွင် ကွန်ပြူတာမော်ဒယ်များနှင့် အချက်အလက်များ ခွဲခြမ်းစိတ်ဖြာ၍ နားလည်သဘောပေါက်လာမှုများပေါ်တွင် အခြေခံကာ ဆောင်ရွက်ရမည်။ ရာသီဥတုပြောင်းလဲမှု၏ အကျိုးသက်ရောက်မှုများ ပါဝင်သော ရေရှည်ပြောင်းလဲမှုများကိုပါ ထည့်သွင်းဖော်ပြသင့်သည်။

၁၁။ မြောင်ဘက်ပိုင်းရှိ ဧရိယာ– ၁ တွင် အနောက်ဘက်ကမ်းပါးပြိုမှုသည် နောက်ငါးနှစ်တွင် ဆက်လက်ဖြစ်ပွားမည် ခန့်မှန်း ရပြီး ကမ်းရိုးတန်းသည် နောက်သို့ မီတာ ၅၀၀ ခန့်လောက် ရွေ့လျားသွားနိုင်သည်။ ထိုကဲ့သို့ ကမ်းပြိုကမ်းစားမှုသည် ကမ်းရိုး တန်းတစ်လျှောက်လုံးတွင် ဖြစ်ပွားသည် မဟုတ်သော်လည်း တိကျသော မြစ်ကြောင်းပြောင်းရွှေ့မည့် နေရာအား ထောက်ပြဖို့ရန် ခက်ခဲသည်။ ထိခိုက်နိုင်သောနေရာများသည် မြေနိမ့်ပိုင်းဖြစ်ပြီး စိုက်ပျိုးမြေမှလွဲ၍ အဆောက်အအုံများ ရှိနိုင်ချေ နည်းပါးသည်။

၁၂။ မြစ်ဝ (2a)၏ တောင်ဘက်ပိုင်းတွင် ၂၀၁၇ မှစ၍ဖြစ်ပေါ်လာသောအခြေအနေများသည် ဒီရေစီးကြောင်းသည် မြစ်ဝ၏အလည်တွင် ပို၍နေရာယူ နေရာမှချက်ချင်းပင်ရေစီးကြောင်းကို အနောက်ဘက်ကမ်း ပါးဘက်ကိုရွှေ့ပြောင်းလိုက်သည် ကိုဖော်ပြပါသည်။ ယခုမှစ၍နောက် ၂ နှစ်အတွင်း အနောက်ဘက်ကမ်း ခြေ၏မြေတိုက်စားမှုများရပ်တန့်သွားမည်ဟုခန့်မှန်းရပြီး ဧရိယာ 2a ၏မြောက်ဘက်မှစမည်ဖြစ်သည်။ ယခုလက်ရှိကမ်းခြေလိုင်းနေရာ (နိုဝင်ဘာ ၂၀၁၈)နှင့်စပ်ဆက်၍ ခန့်မှန်းရသော ဆက်လက်တိုက်စားမှုနှုန်းမှာ နောက်လာမည့်ငါးနှစ်အတွက် ဤဧရိယာ၏မြောက်ဘက် ၀ မှ ၂၅၀ မီတာ အထိဖြစ်ပြီးတောင် ဘက်သို့ ရွှေ့လျားလာလေလေ တစ်ဖြည်းဖြည်းတိုးလာလေလေဖြစ်ကာ တိုက်စားနှုန်းမှာ ၁ကီလိုမီတာထက်ကျော်နိုင်ပါသေး သည်။

၁၃။ အနောက်ဘက်ကမ်းရိုးတန်း၏ မြောက်ဘက်ပိုင်း (ဧရိယာ – 2a)တွင် မြေကြီးများ လျင်မြန်စွာ နောက်နှစ်အနည်းငယ် အတွင်းတွင် ဖြစ်လာနိုင်ခေရှိကြောင်း ခန့်မှန်းရသည်။

၁၄။ မြစ်ဝ၏ အရှေ့ဘက်ဖြစ်သော မွန်ပြည်နယ်ဘက် အခြမ်းတွင် ဒီရေအတတ်အကျရှိသော မြေများသည် မြစ်ကြောင်း အရှေ့ဘက်သို့ ရွှေ့လျားစီးဆင်းခြင်းနှင့်အတူ တိုက်စားခံရနိုင်ကြောင်း ခန့်မှန်းရသည်။

၁၅။ တောင်ဘက်ပိုင်းအလွန် (ဧရိယာ – 2b) တွင် ပင်မရေစီးကြောင်း သည် တိုးတက်ပြောင်းလဲမှုမရှိဘဲ အနောက်ဘက် ကမ်းတွင်ရှိသော ကမ်းပြိုကမ်းစားမှုများသည် ဆက်လက်ဖြစ်ပွားနိုင်ချေရှိသည်။ ထိုကဲ့သို့သော ကမ်းပြိုမှုသည် ယခုကဲ့သို့ အရှိန်များများဖြင့် ဆက်လက်ဖြစ်ပွားနိုင်ပြီး တစ်နှစ်လျှင် ၁ ကီလိုမီတာ ကျော်ခန့် တိုက်စားခံရနိုင်သည်။

၁၆။ နောင်နှစ်ပေါင်း ၂၀ မှ ၅၀ အတွင်းတွင် မြစ်ကြောင်းများ ပြောင်းလဲမှုကြောင့် ယခုထက် ပို၍ကြီးမားသော ဧရိယာသည် ကမ်းပြိုကမ်းစားဒဏ်ကို ခံစားရနိုင်သည်။ ဆိုလိုရင်းမှာ ထိုနှစ်အပိုင်းအခြားတွင် ကမ်းရိုးတန်းလွင်ပြင် တစ်ခုလုံး ကမ်းပြိုကမ်းစား မှုကို ခံရနိုင်သည်။

၁၇။ ပင်လယ်ရေပြင်မြင့်တက်မှုအကျိုးသက်ရောက်မှုသည် စစ်တောင်းမြစ်ဝနှင့် ကမ်းခြေလိုင်းအတွက် အကျိုးသက်ရောက်မှု သိပ်မရှိပါ။ ဤစနစ်ထဲတွင် နုန်းအနည်များအမြောက်အများရှိခြင်းက ကမ်းရိုးတန်းလွင်ပြင်များ ပေါ်ပေါက်စေပြီး မြစ်ဝတွင် အနည်း ဆုံး တစ်နှစ်လျှင် ၄၄မီလီမီတာ (ယနေ့ခေတ်ပင်လယ်ရေပြင်မြင့်တက်နှုန်း၏ ၂ဆ) ခန့်မြင့်တက်စေပါသည်။ ထို့ကြောင့်ပြောင်း လဲလွန်းလှသောမြစ်ဝ နှင့် ကမ်းခြေလိုင်းအတွက် အမြန်မြင့်တက် ပင်လယ်ရေမျက်နှာပြင်၏ အကျိုးဆက်ကြောင့် အကျိုးသက် ရောက်မှုမရှိပါ။ မြစ်အထက်ဘက်ပိုင်းတွင် ၄င်းအကျိုးသက်ရောက်မှုခံစားရနိုင်ပြီး၊ ပင်လယ်ရေမျက်နှာပြင်မြင့်တက်ခြင်းကြောင့် မြစ်ကြောင်းပြောင်းလဲခြင်းများ ပိုမိုဖြစ်ပေါ်စေနိုင်ပါသည်။

၁၈။ ရာသီဥတုပြောင်းလဲခြင်းကြောင့် မိုးရာသီတွင် မြစ်ရေစီးဆင်းမှု ပိုမိုမြင့်တက်စေပါသည်။ ရေကြီးမှုအများစုမှာ ကမ်းရိုးတမ်း လွင်ပြင်များနှင့် သက်ဆိုင်မည်ဖြစ်သော်လည်း ရေစီးဆင်းမှု မြင့်တက်ခြင်းကြောင့် မြစ်ဝအပေါ်ပိုင်း တွင်နောက်ထပ် ရေကြောင်း ပြောင်းလဲမှုများ ဖြစ်စေနိုင်ပါသည်။ ဤအချက်သည် မြစ်ခါးပတ်တစ်ခုလုံးကို အနောက်ဘက်သို့ပင် ပြောင်းလဲပစ်နိုင်ပြီး သဘာဝမျိုး စိတ်တစ်ခုလုံးအပေါ် သက်ရောက်စေနိုင်ပါသည်။ ဆင့်ကဲဖြစ်စဉ်များကို စောင့်ကြပ်ကြည့်ရှုခြင်းက ဤကျယ်ပြန့်သော ပြောင်းလဲ ခြင်းများကို နားလည်နိုင်စေရန်အတွက် အရေးကြီးပါသည်။

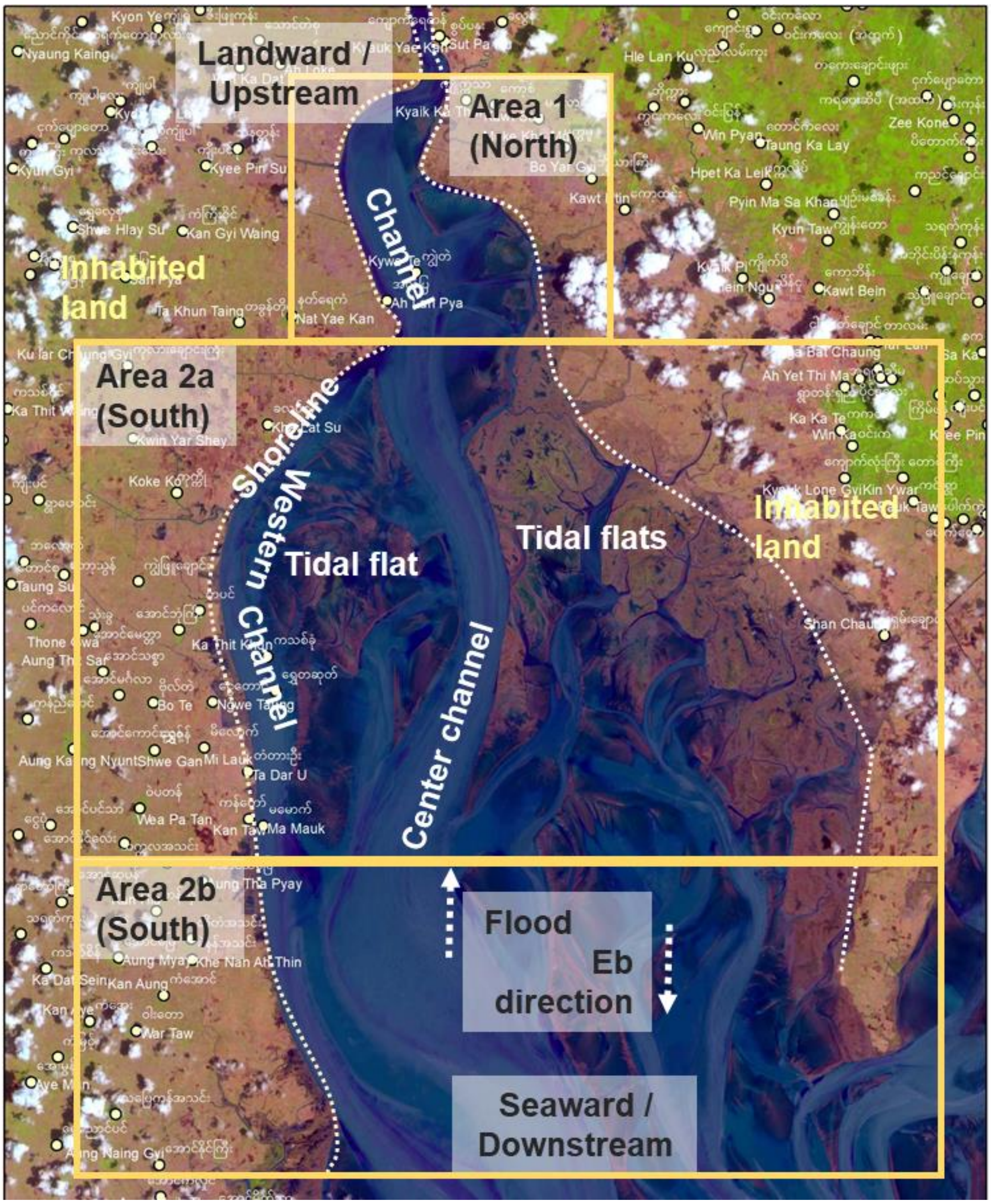


Figure 1.3 Overview of the main features of the Bago and Mon coasts along the Sittaung estuary.

၁၉။ ရာသီဥတုပြောင်းလဲမှုကြောင့် မြစ်တွင်းမြေပြန့်တွင် သဘာဝပေါက်ပင်များကိုသက်ရောက်စေပြီး ၄င်းကြောင့်စစ်တောင်းမြစ်၏ နုန်းမြေဝန်ကိုသက်ရောက်နိုင်ပါသည်။ ယင်းသက်ရောက်မှုသည် မည်သို့ဖြစ်သည်ဆိုသည်မှာ လေ့လာရန်ခက်ခဲပါသည်။ အဘယ့်ကြောင့်ဆိုသော် ၄င်းမှာနုန်းမြေဝန်တစ်ခုတည်းအပေါ် ဆက်နွယ်နေခြင်းမဟုတ်ပဲ မြစ်ကြမ်းပြင်ဗေဒပြောင်းလဲခြင်းနှင့် မြစ်ချောင်းအင်းအိုင်ဒေသတို့အပေါ်တွင်ပါ မူတည်နေခြင်းဖြစ်သည်။ ထိုနည်းတူစွာပင် မြေအသုံးချမှု (တောပြုန်းခြင်း)ကြောင့်နှင့် ရေအားလျှပ်စစ်တာမံများတည်ဆောက်ခြင်းကြောင့် သက်ရောက်မှုများကို လေ့လာရန်ခက်ခဲပါသည်။ သို့သော် ဤသည်တို့ကြောင့် တော့ ရေတိုခန့်မှန်းထားချက်ကို ပြောင်းလဲစေမည်မဟုတ်ပါ။

ကာကွယ်မှုနည်းလမ်းများနှင့် interventions

၂၀။ ကမ်းရိုးတန်း တစ်လျှောက်ရှိ ကမ်းပြိုကမ်းစားဖြစ်စဉ်ကို ကာကွယ်သော/လျော့ချသော နည်းလမ်းများသည် မြစ်ကြောင်းများ ပြောင်းရွှေ့ခြင်းကိုပါ ကိုယ်တွယ်နိုင်ရမည်။ ကာကွယ်ရေး နည်းလမ်းများထဲတွင် အခိုင်အမာ တည်ဆောက်ခြင်း

(ကျောက်ခဲ/ ကွန်ဂရစ်များနှင့် မြစ်၏ကမ်းပါး ပေါ်တွင် တည်ဆောက်ခြင်း) သို့မဟုတ် အခိုင်အမာတည်ဆောက်ခြင်း မဟုတ်သော နည်းလမ်းများဖြင့် ကာကွယ်ခြင်း (သဲ/ ရွှံ့မြေများ သုံးခြင်း) တို့ပါဝင်သည်။

၂၁။ ကမ်းပါးနှင်းရေစီးကြောင်းကမ်းစောက်ကာကွယ်ခြင်းသည် ခက်ခဲသောနည်းလမ်းမှာ ရေပြင်ညီကျောက်သိပ်အကာ အကွယ်ပုံစံယူဆောင်ခြင်း (falling apron ဟုအသိများကြသော)ဖြစ်နိုင်ပါသည်။ ဤလုပ်ဆောင်ချက်မှာကာ ကွယ်မှုလို အပ်သောကမ်းပါတလျှောက်လုံးအတွက်လိုအပ်ပါသည်။ ရေစီးနှုန်းသည် မြင့်သောကြောင့် (တစ်စက္ကန့်လျှင် ၃မီတာအထက်) အတော်အသင့်ကြီးမားသော ကျောက်တုံးများလိုအပ်ပါသည်။ ဒေသတွင်းရနိုင်သော ကုန်ကြမ်းများဖြင့် အကွာအဝေး အနည်းငယ်သာ ကာကွယ်ခြင်းသည် အကျိုးသက်ရောက်မှုမရှိပဲ အချိန်ကုန် လူပင်ပန်းသာ ဖြစ်စေပါသည်။

၂၂။ အနောက်ဘက်ဒီရေရေစီးကြောင်းကို ရွှေပြောင်းရန်သက်သာသောနည်းမှာ ရေစီးကြောင်းအနောက်ဘက်ဝင် ပေါက် (2a) တွင်မြင်နိုင်သည်) အား ဥပမာ တူးထားသော သောင်နုန်းများဖြင့် အပြည့်ပိတ်ခြင်းဖြစ်သည်။ ဤနည်းလမ်းသည် ခန့်မှန်းအားဖြင့် သဲ နှင့် ရွှံ့ ကုဗမီတာ ၂၅ သန်းခန့်လိုအပ်မည်ဖြစ်ပြီး ၄င်းသည် လုပ်ဆောင်ရန်မဖြစ်နိုင်ပါ။ (အလွန်တိမ်၊ အလွန်မြန်သော ရေစီး နှုန်း၊ ကုန်းပေါ်အဆောက်အဦးဆောက်ရန် လမ်းမရှိခြင်း)။ အကယ်၍ဆိုလျှင် ဤရေစီးကြောင်းပိတ်ဆို့မှုကြောင့် ၄င်း၏လုပ်ရက်ဖြင့် အကျိုးသက်ရောက် မှုတိုးစေပါသည်ဟု ကိန်းဂဏန်းစမ်းသပ်ခြင်းက ဖော်ပြထားပါသည်။

၂၃။ ကမ်းခြေလိုင်းအများအပြားကိုတိုက်စားမှု ဖြစ်စေသော ရေတက်ရေကျရေစီးကြောင်း၏လုပ်ရပ်မှာ သဘာဝ အလျောက် ဖြစ်ပေါ်လာသော အနီးအနားရှိ ဒီရေမြေပြန့်များ၏ တိုက်ရိုက်အားဖြည့်ပေးခြင်း (ဖြစ်ပေါ်ရန် ခက်ခဲသော်လည်း) ကြောင့်သော် လည်းကောင်း နန်းမြေများဖမ်းယူပေးသောစိမ့်တောများကြီးထွားလာစေခြင်းဖြင့်လည်းကောင်း အားဖြည့်ထောက်ပံ့ပေးပါသည်။

၂၄။ တွေးတောစဉ်းစားထားသော လုပ်ငန်းများ နည်းစဉ်များအားလုံး အသုံးပြုလိုက်ရသော ဘတ်ဂျတ်အ တွက်ထိုက်တန် သော အကျိုးသက်ရောက်မှုမရှိပါ။ ဆိုလိုရင်းမှာ အစိုးရသည် ကာကွယ်လိုသော စီးပွားရေးက ဏ္ဍထက်ပိုမိုသောရင်းနှီးမှုကို အသုံးပြုရမည်ဖြစ်သည်။ ထို့ကြောင့် စီးပွားရေးရှုထောင့်အရ ကမ်းရိုးတမ်းလိုင်းကို ကာကွယ်ရေးသည် အဓိပ္ပာယ်မရှိပါ။

၂၅။ မြေအားလိုက်လျောညီထွေစွာ အသုံးချခြင်း၊ စီမံခန့်ခွဲထားသော ကမ်းရိုးတန်းဆုတ်ခွာမှုနှင့် တိုးချဲ့မှုသည် ယခုကျေး လတ်ဖွံ့ဖြိုးတိုးတက်မှုအတွက် အဆင်ပြေစေနိုင်သော အခြားရွေးချယ်မှုဖြစ်နိုင်ပါသည်။ ဤသည်ကို ရွေးလျားနိုင်သော အခြေခံအဆောက်အဦးများ (လမ်းများ၊ ကျေးလတ်စီးပွားရေးများအပါအဝင်)နှင့် တွဲဖက်ထောက်ပံ့မှုများ (အိမ်ရာ၊ ကျောင်း၊ ရေတိုင်ကီများ အစရှိသည်ဖြင့်) တို့ဖြင့်အဆင်ပြေအောင် ဆောင်ရွက်နိုင်ပါသည်။

အကြံပြုချက်များ

၂၆။ ကမ်းရိုးတန်းတစ်လျှောက်ရှိ ဖွံ့ဖြိုးတိုးတတ်မှုများ ဒီရေအတက်အကျ ရှိသော မြစ်ကြောင်း အခြေအနေနှင့် အရေးပါသော အချက်အလက်များအား စောင့်ကြည့်ခြင်းသည် ပဲခူးတိုင်းဒေသကြီးနှင့် မွန်ပြည်နယ် တို့အတွက် လိုအပ်သော သင့်တင့်မျှတစွာ ပြုပြင်နေထိုင်ရေး နည်းဗျူဟာ ပေါ်ပေါက်လာရေးအတွက် အရေးကြီးသည်။ လက်တွေ့ကွင်းဆင်းကြည့်ရှုခြင်းနှင့် ဂြိုလ်တုရုပ်ပုံများ အား ယှဉ်တွဲလေ့လာခြင်းဖြင့် နောက်ဆုံးပေါ် သတင်းအချက်များအား စီမံခန့်ခွဲမှုပြုလုပ်နိုင်ရန် ထောက်ပံ့ပေးနိုင်မည် ဖြစ်သည်။ နှစ်စဉ် သတင်းအချက်အလက်များကို သုံးသပ်ရာတွင် ပဲခူးနှင့်မော်လမြိုင်တက္ကသိုလ်မှ ပညာရှင်များ ပူးပေါင်းပါဝင်သင့်သည်။

၂၇။ သတိပြုရန်၊ တွေ့ရှိရသော နှစ်စဉ်ပြောင်းလဲမှုများကို လူမှုအဖွဲ့အစည်းများဖြင့် တိုင်ပင်ဆွေးနွေးပါ။ အချိန်နှင့်အညီ အသစ်ဖြစ်သော သတင်းအချက်အလက်များသည် ၄င်းတို့ကိုယ်တိုင် ဆုံးဖြတ်ချက်များအတွက် အထောက်အကူပေးပါမည်။

၂၈။ စစ်တောင်းမြစ်ဝနှင့် ၄င်း၏ ကမ်းရိုးတန်းတစ်လျှောက်ရှိ ပြင်းထန်သော ရွေ့လျားမှု အခြေအနေနှင့် သင့်တင့်မျှတအောင် နေထိုင်နိုင်ရန် လိုအပ်သည်များကို လက်ခံပြင်ဆင်ရမည်ဖြစ်သည်။ အလွယ်တကူ ရွှေ့ပြောင်းလို့ရသော အိမ်များ အဆောက် အအုံများ ဆောက်လုပ်ခြင်းအားဖြင့် သင့်တင့်မျှတအောင် နေထိုင်နိုင်ခြင်းစွမ်းကို မြင့်တင်ရမည်။ အခြေခံအဆောက်အဦးများကို တိုးတက်လာအောင် ဆောင်ရွက်ရန်လည်း လိုအပ်သည်။ ဥပမာအားဖြင့် ဒေသ၏ စီးပွားရေးဖွံ့ဖြိုးရန်နှင့် လမ်းပန်းဆက်သွယ်ရေး ပိုမိုကောင်းမွန်လာစေရန် လမ်းများကို တိုးချဲ့သင့်သည်။ ပြောင်းရွှေ့ရန် လိုအပ်သော လယ်သမားများအတွက်လည်း ဘဏ္ဍာငွေ အလုံအလောက် ရှိစေရန် စဉ်းစားဆောင်ရွက်ရန် လိုအပ်သည်။

1 INTRODUCTION

1.1 Background of the study

The Gulf of Mottama, located in the southwest of Myanmar and bordering the Andaman Sea, is unique in many ways. Its extensive intertidal mudflats are home to many shorebirds, fishes and other flora and fauna. Its mouth is around 100 km wide and narrows into a funnel-shaped bay towards Sittaung River in the north (Figure 1.1). The area is known for its powerful tidal bore phenomenon where the incoming tide forms a wave that can reach heights of over a meter in the upper estuary.

On the rhythm of each tide, the highly turbid zone moves north and south over more than 100 km building up the largest mudflats in the world. The surrounding land is generally flat, rural (rice), largely under-developed and low-lying (flooded along the shores at highest water).

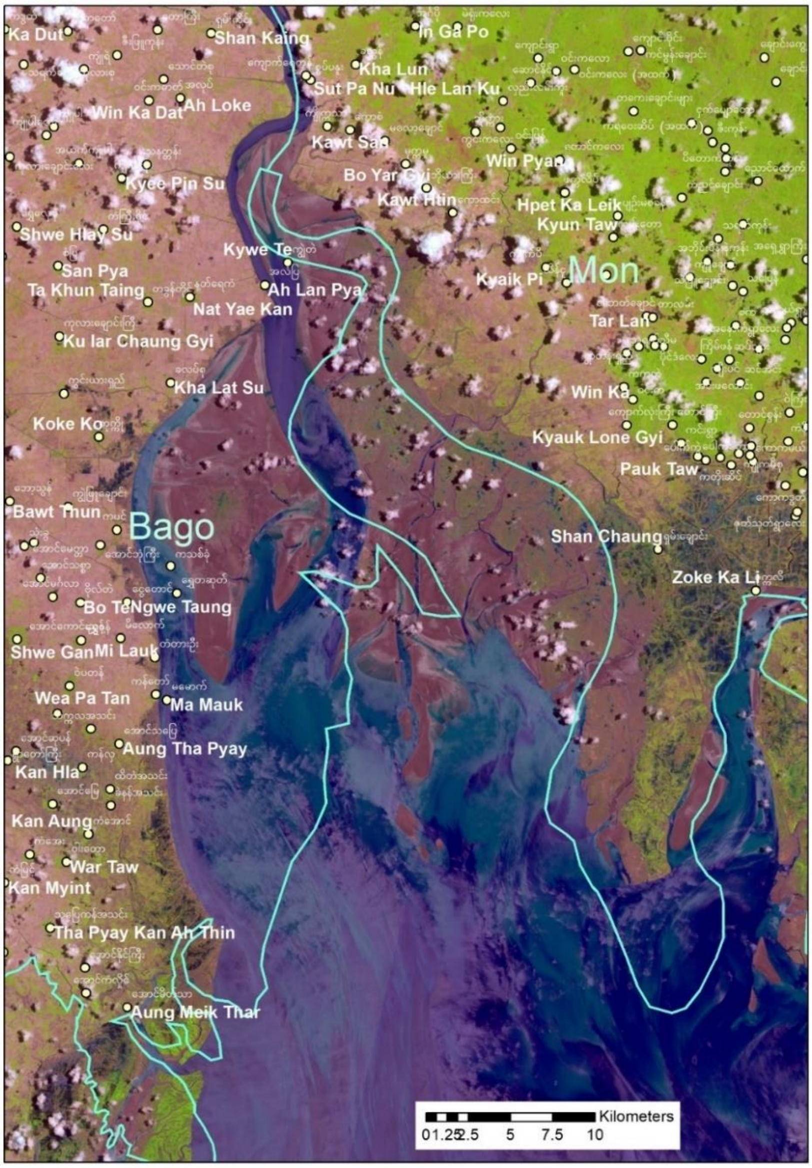


Figure 1.1 Sittaung estuary with names of the villages in Bago and Mon states.

Bago Region and Mon state flank the Sittaung estuary and the Gulf of Mottama. The dynamics of the tidal channels in the Sittaung estuary result in severe coastline regression, at immense rates and over large distances. Erosion in the Bago Region has forced entire villages to retreat and to abandon the area. Livelihood patterns of farmers and fishers are adversely affected. Changes in erosion and sedimentation patterns are frequent with anecdotal evidence reporting the erosion cycle repeats each 10 to 15 years.

The major effected areas in the Bago region are near the Sittaung river bank villages from two townships, Kawa and Thanatpin township.

At present over 7,000 villagers living in these villages are under direct threat of being washed away, or have done so in the past months. The Regional Government of Bago region has therefor been seeking assistance from the Gulf of Mottama project[1] how to deal with this erosion.

[1] In 2015, the Gulf of Mottama Project (GoMP) was initiated in 2015. This long-term initiative is a project of the Swiss Agency for Development and Cooperation (SDC), implemented by a consortium led by HELVETAS Swiss Intercooperation (HELVETAS) and comprising of the International Union for Conservation of Nature (IUCN), the Network Activities Group (NAG) and as associate partner the Biodiversity and Nature Conservation Association (BANCA).

Both for improving livelihood as well as for nature conservation purposes, it is important to predict the morphological changes in the estuary also taking into account climate change induced sea-level rise. Based on a prediction on maximum shoreline retreat, for example, safe zones can be specified which will help with identifying specific safe resettlement areas.

On behalf of the GoMP, Helvetas has contracted Arcadis to carry out such coastal erosion study. The findings from this study are presented in this report, which has been prepared by Mr. R.C. Steijn (project leader), dr. J. Cleveringa, Mr. J. van der Baan (Arcadis-Netherlands) and Tanya Huizer (Arcadis-Myanmar). Support has been provided by Alexander de Ruijter, Floris Verbeek (Arcadis-Myanmar), and Jasper Leuven (University Utrecht). Scientific review of the work has been done by prof. dr. M. Kleinhans (Utrecht University) and prof. dr. Z.B. Wang (Deltares).

Figure 1.2 Two pictures (Courtesy Helvetas) of the same school. The picture at the left taken on 07.11.2017; the picture on the right was taken only one month later on 12.12.2017.

1.2 Objectives of the study

The objectives of this study are:

1. To assess potential measures to combat erosion in the Gulf of Mottama in a comprehensive manner and discuss these with project and local governance units.
2. After the consultations, develop strategies to adapt to, adjust, control or combat the erosion in Bago Region & Mon State and make rough cost estimates for the potential solutions, including the “living with nature” concept.
3. Estimate the retreating shoreline for different times in the future for both Bago Region and Mon State, behind which it is “safe” for the coming years to make major infrastructural investments for the Government like schools, roads, drinking water and other services to be provided by the government.
4. To cooperate with the Universities of Mawlamyine & Bago, to build the expertise on Coastal Morphology in Myanmar.

Before any type of coastal protection measure can be considered it is important to understand the causes of the coastal erosion (diagnosis) and to understand the response of the coastal behavior to changes in sea-level rise, subsidence and human interventions.

1.3 Approach and methods

This coastal erosion study is the first of its kind for this area. A restricted number of studies on the coastal processes in the Sittaung estuary have been carried out in the past, for instance on the propagation of the tidal bore (De Ridder, 2017). Some of the studies have included field measurements, such as those under guidance of Tokyo university (Yamashita & Aung, 2016). The project has been carried out in four subsequent steps:

Step 1: Understanding the situation (Chapter 2)
The focus is on the understanding of the coastal dynamics, through the analysis of existing datasets, with the use of numerical modeling and by performing field measurements. There is a clear interrelation between these activities. The data contributed to the development of the numerical hydraulic model (tides and river runoff). The field measurements were used to calibrate the model. The use of the numerical model in combination with the measurements, gives the opportunity to investigate future human interventions.

Step 2: Predicting the future (Chapter 3)
A prediction is made of the morphological changes in the shallow areas and tidal channels and – related to them – changes in shoreline position.

Step 3: What can be done (Chapter 4)
In this step an overview of the potential measures is given to deal with or to combat the coastal erosion. General working principles of different types of measures and interventions will be described including how that relates to our understanding of the coastal system (the diagnostic model).

Step 4: Integration (Chapter 5)
In this last step all collected information and insights are combined in a comprehensive advice. It addresses the mechanisms of coastal erosion and the expected future developments (forecast) and gives recommendations on do's and don'ts on how to deal with the coastal erosion.

This is a concise report: most of the data and analysis are described in more detail in the Appendices.

1.4 Conclusions & recommendations

The essential conclusions on the coastal erosion and the recommendations for the management of the Bago Region and Mon State shorelines (as shown in Figure 1.3) are:

Diagnosis

1. The coastal erosion of the shorelines of Bago Region and Mon State result from the natural migratory dynamics of the flow channels of the Sittaung estuary. There is no human forcing behind it nor any human control on the observed dynamics;
2. The horizontal shoreline retreat along the Bago coast in the Gulf of Mottama has been more than 5 m/day or 1 km/year at some locations. Although extreme, this kind of erosion is part of natural shoreline dynamics showing periods of very rapid land growth as well as land retreat.
3. The intensity of the hydro-morphodynamic behavior of the Gulf of Mottama is unique in the world. The estuary that comes closest is the Qiantang estuary in PR China (see separate Textbox in Section 2.7);
4. Two areas with different morphological behavior can be distinguished (Figure 1.3). In the northern area #1 sand bars grow fast and seem to push the flow channels westwards; in area #2 the flow channels tend to migrate in both directions (eastwards and westwards) and at much faster rates.
5. Although not entirely clear, it seems that coarser sediment (fine sand) is being transported northwards and deposited in area #1 as sand bars ("Bedload Convergence Zone"). The explanation for this northward transport is the extreme flood dominance which can also be recognized from the occurrence of the tidal bore. The (moving) sand bars in combination with the nature of flow channels to meander, lead to migrating channels (sometimes called "bar push") that erodes the shoreline.
6. In area #2 on the other hand, it seems as if the flow channels can't get much deeper probably because of the presence of any kind of flow-resistant layer in the subsoil (clay or rock). This may explain why the speed of the horizontal channel movement in this part of the estuary, is so extreme (km's per year): less unconfined land needs to be removed with shallower channels compared to deeper channels. The cross-sectional areas of the flow channels further are systematically "too small" (i.e. compared to similar type of channels in other estuaries), resulting in high flow velocities (further increased by the tidal asymmetry). As a consequence, the channels can go wide-out ("bank pull");
7. The direction of the migration of the channel along the shoreline determines the location of the erosion: migration to the west results in erosion of the Bago shoreline and migration to the east results in erosion of the Mon shoreline;
8. In the northern part of the estuary (area #1 in Figure 1.3) the migration of the channel and the erosion of the shoreline has prolonged over a period of at least 30 years;

9. The direction of the migration and the erosion does change in periods of 10 to 15 years in the southern part of the estuary (area #2a and #2b in Figure 1.3). The change in direction seems to be repetitive, but the frequency does not allow to identify a clear cycle with a fixed duration.

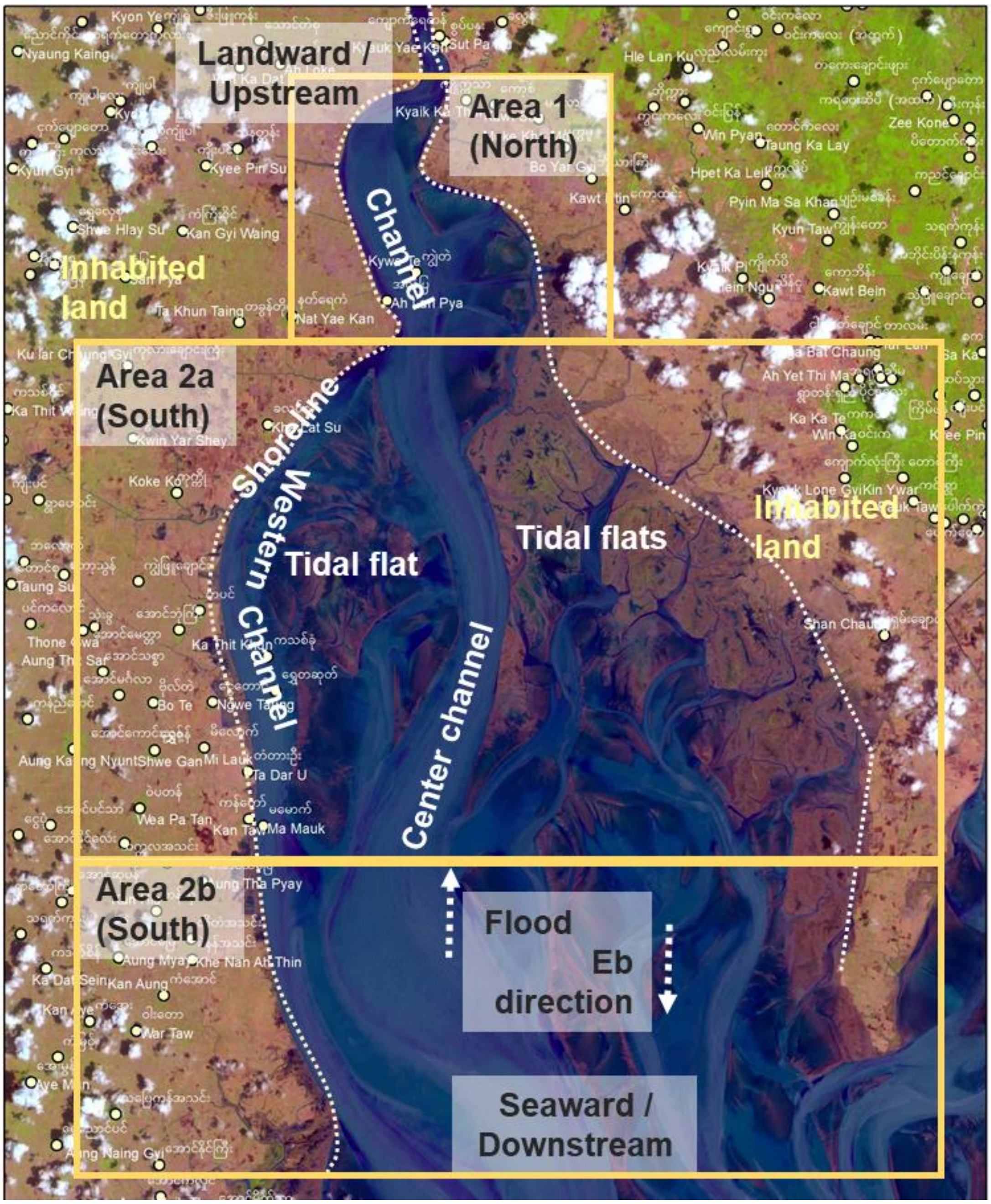


Figure 1.3 Overview of the main features of the Bago and Mon coasts along the Sittaung estuary (situation April 2018).

Prediction

10. There is a limit to nature's predictability and that is because of so-called non-linear system interactions. The more complex a system, the less predictable it is on a longer time horizon and on a smaller spatial scale. In weather predictions this is widely accepted: nobody can predict the precipitation for example on one specific acre in exactly two years from now. The same is true for the prediction of the shoreline erosion in the Gulf of Mottama on a local scale (village) and on the longer term (years). The best possible is to predict zones of possible erosion for the next five years based on extrapolation of data and systems understanding from the data analyses and computer modelling. A prediction for the coming decades, as requested in the ToR for this study, is not deemed possible for the shoreline

positions in the Gulf of Mottama. The impact of long-term changes, including climate change impacts, can only be described in terms of scenarios: possible changes in the erratic natural dynamics.

11. In the northern area (#1), the erosion of the western shore is expected to continue for at least the next five years, leading to a coastal retreat of up to 500 m. This erosion is not likely to occur along the entire shoreline, but the exact location of channel migration shifts and is hard to pinpoint. The affected areas are relatively low-lying with hardly any infrastructure except farmland (rice fields).
12. Recent developments (since 2017) in the southern part of the estuary (#2a) show the development of a tidal channel more located in the center of the estuary, that rapidly takes over the role of the migrating channel along the western shore. Within two years (starting now), the erosion on the western shore is expected to stop, starting in the north of area 2a. The amount of expected ongoing erosion relative to the shoreline's current position (November 2018) is 0 to 250m in the northern part of this area for the coming 5 years and gradually increase when moving to the south, where erosion may still exceed 1 km;
13. In the northern part of the western shoreline (area #2a), rapid land growth is expected which may result in new land that after some years may be used again.
14. On the eastside (Mon side) of the estuary, the current tidal flats are expected to be eroded fast with the expected further eastward migration of the (new) central channel towards the east;
15. Further to the south (area #2b) there is no development of a single central channel and the erosion of the western shore is expected to continue. The erosion in this part of the estuary may continue for the next few years at the current extreme rates of over 1 km/year;
16. Over prolonged periods (many decades to centuries) a much larger area is prone to erosion by the migration of the channels. Given the extreme rates of change (m/day), the evidence in the landscape for large-scale dynamics (remnants of ancient meanders at large distances from the shoreline) and the lack of natural obstacles to delimit erosion in the largely flat and low-lying coastal plain, it is not impossible that the entire coastal plain may be subject to erosion at this time scale. The upstream river dynamics have a large influence on the shoreline locations in the estuary and on the Gulf of Mottoma. Models cannot be applied for forecasts. Academic models may be used to better understand the dynamics and their extent, but such models are not predictive tools.
17. The effects of accelerated sea-level rise will be limited for the Sittaung estuary and its shorelines. There is an abundance of sediment available in the system that allows for buildup of the coastal plain and estuary at rates up to at least 40 mm/year (twenty times more relative sea level rise than today). The already extremely dynamic nature of the estuary and its shorelines will not change due to the effect of accelerated sea-level rise. There may be an effect of sea-level rise more upstream in the river domain, where accelerated sea-level rise may result in more avulsions of the river.
18. Climate change may result in an even more peaked river discharge during the rainy season. Although much of the flood waters will be accommodated in the coastal plain, the increase in peak discharge may result in additional channel migration in the upstream regions of the estuary. This could even lead to shift of the entire river belt more to the west that would affect a large inhabited area. Monitoring of the developments is therefore important to be able to recognize any such system-wide changes.
19. Climate change may result in changes in the vegetation of the hinterland that may affect the sediment load of the Sittaung river. How such a change would affect the Sittaung estuary is difficult to assess, because this does not only depend on the sediment load, but also on the morphodynamics of the river and the fluvial plain. Similarly, it is difficult to assess the impact of changes in land use (deforestation) and the construction of hydropower dams. It is not likely, however, that this will change the predictions on the short term.

Figure 1.4 View of the western shoreline of the Gulf of Mottama (29 September 2018; near An Lan Pya). The steep, nearly vertical bank and the slumped blocks are evidence of the main erosional mechanism of the bank (slope collapse) that results from the ongoing landward migration of the tidal channel.

Measures and interventions

20. Measures and interventions to effectively stop or reduce the erosion of the shoreline must tackle the migration of the channels. This may be achieved with 'hard' measures on the channel slope and bank, with 'hard' referring to rock, concrete or other solid materials. Alternatively, 'soft' solutions, meaning interventions with sand or mud, may be considered;
21. 'Hard' protective measures that protect the full channel slope and bank, can take the form of a horizontal rock riprap apron (generally known as a 'falling apron'). Such measures need to stretch over the entire length of shoreline that need protection. Given the extreme flow velocities (>3 m/s), and necessity to also consider high wave attack in the design (cyclone), this require considerable rock dimensions (more than 500 kg). If concrete is being used instead, then the structure will probably have to be built on (concrete) piles because of the expected low carrying capacity of the substrate. Moreover, it is very unlikely that such engineered solutions can actually be constructed as the sites cannot be accessed with the required heavy equipment (requiring road construction over tens of km's first and/or the excavation of the channels including landing facilities for floating equipment. Assuming that all challenges can be overcome, the costs for effective hard protective measures are estimated to range from 25.000 to 100.000 USD per meter alongshore. The costs for construction over a distance of at least 3 km are then 75 to 300 million USD. Cheaper solutions with locally available material that can be placed without heavy equipment (grouted rock with rock sizes up to 50 kg), over short distances (less than one km) are not effective to stop this type of channel migration;
22. A 'soft' intervention to reduce the migration of the tidal channel along the west coast is the full blocking of the southern entrance to the channel (visible in area #2a) with for example dredged sediments. Such an intervention will require the dredging and dumping of approximately 25 million cubic meters of sand and mud which is virtually not doable (too shallow, too high flow velocities, no road infrastructure for land-based building). Despite this, such a channel entrance blockade would reduce the flow through the channel and enhance its demise, as indicated by the numerical model simulations;
23. The demise of the tidal channel that has caused so much shoreline erosion, may also be enhanced by accelerating the natural developments of the nearby tidal flats, either by direct nourishment (though difficult to execute) or by stimulating the growth of marsh plants that naturally captures sediments;
24. None of the considered measures and intervention is considered positive from an economic cost-benefits perspective. This is because the required investments would be significantly more than the value of the protected economic assets. From a purely economic perspective therefore, protection of

the shorelines does not make sense; it would be cheaper to financially compensate local inhabitants who loose their lands and assets;

25. Adaptive use of the land i.e. managed coastal retreat and managed coastal expanse, may be a viable alternative for this rural environment. This may be facilitated by the use of mobile infrastructure (including roads to support local economy) and accommodations (housing, schools, water tanks, etc,). Internet searches for water tanks indicate a price range from hundred to several hundred USD for water tanks for variable size. Flexible adaptations for houses and other buildings will range up to several hundred USD when locally available building materials can be applied. Flexible construction for housing, hospitals and schools van easily reach up to several thousand USD, depending on type and size. The price for the construction of flexible roads ranges up to ten of thousands of USD per kilometer, depending on the building materials.

Recommendations

26. Monitoring of the actual development of the shorelines, tidal channel and critical points is an important aspect of any (adaptive) strategy for Bago Region and Mon State, given the rapid and (on the longer term) unpredictable changes that occur in the estuary. Interpretation of the publicly available satellite images (guidance is included in Annex G), in combination with observations in the field, will provide up-to-date information that allows adequate management decisions. A yearly analysis by two designated specialists from Bago and Mawlamyine Universities is suggested. OneMap Myanmar, an SDC sponsored initiative, could provide training to both universities;
27. Be Aware: Explain and communicate the observed yearly changes with the people from the communities. Up to date information will help them in making their personal choices.
28. Be adaptive: Accept the need to adapt to the extreme dynamics of the Sittaung estuary and its shorelines. Increase the adaptive capacity through investment in mobile/transportable housing and infrastructure. Improve the infrastructure, specifically the roads, to support local economy and to facilitate transport of goods in times of coastal retreat and community resettlement. It may also be considered to develop a system of financial 'solidarity compensation' for farmers who are forced to relocate.
29. Adaptation to the extreme dynamics of the shoreline does require a thorough legal and financial framework, especially when regarding resettling and 'solidarity compensation'. Governance at national, regional and local level will have to allow for the societal dynamics associated with adaptation strategies.

2 DIAGNOSIS: THE NATURE OF THE SHORELINE DYNAMICS

2.1 Introduction

Basic data on the morphology and the hydrodynamics of the Sittaung estuary were collected from various sources. The basic data encompassed:

- Maps, heights;
- Geological data;
- Drainage basin river Sittaung and river discharge;
- Tides of nearby tidal stations; and
- Morphology from satellite imagery.

For a full description of the collected data and their physical interpretation, reference is made to Appendix A. In this Chapter, only the most relevant aspects of the data analysis have been reproduced.

In addition to the basic physical data the local knowledge of the users of the estuary (fishermen) and inhabitants (mostly farmers) was obtained via a questionnaire (Appendix F). During the data analyses, the newly developed numerical model of the area was used to verify specific assumptions on the system's behavior (Appendix C). Two additional field measurements were carried out to obtain missing data (Appendix B).

2.2 Setting of the Sittaung estuary and its shorelines

Figure 1-1 gives and overview of the study area. The Sittaung estuary and the Gulf of Mottama have an eastern boundary that consists of hills. The geological constraints on the eastern side are very clear in the east-west cross-section in Figure 2.1. The middle part of this cross section is almost horizontal; this is the coastal plain. The western boundary of the Sittaung estuary is formed by the water divide between Bago river and Sittaung river, as is indicated by the red arrow. This boundary between the two river basins is marked by a small topographic high.

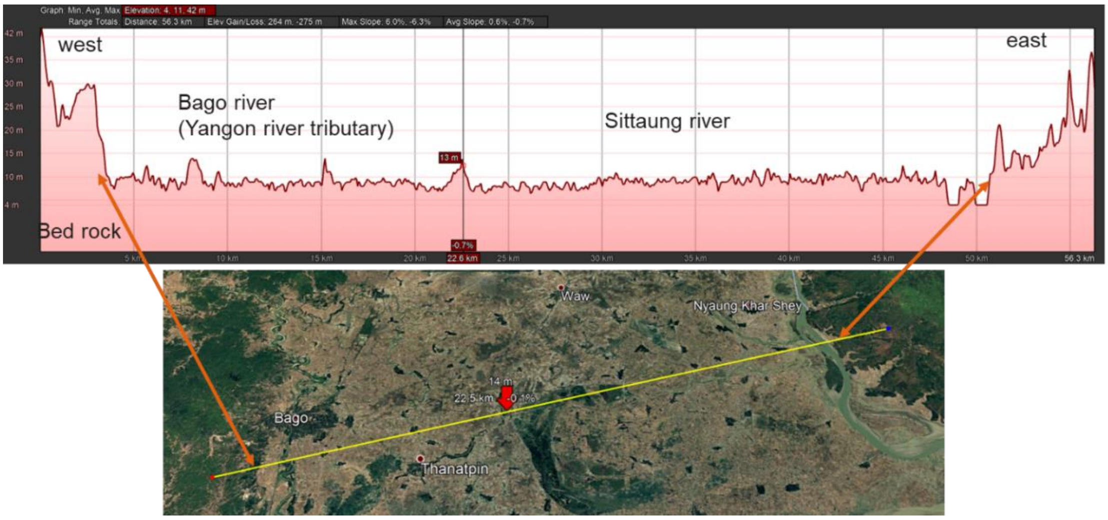


Figure 2.1 West-east cross-section of the river belt of the Bago and Sittaung rivers and its coastal plain.

The coastal plain has been formed by depositional processes in the past (i.e. centuries to possibly thousands of years ago). The sediments that have been deposited originated from the river(s) and from the seaside, where abundant volumes of sediments are being discharged by the nearby Ayeyarwady and Salween Rivers.

It is likely that the subsurface of the estuary and the gulf have been subsiding, and maybe still are, as a result of its geological setting. The subsidence of the coastal plain has allowed repeated flooding and deposition, that has led to the current almost horizontal topography in the coastal plain.

2.3 Hydrodynamics

Drainage basin and river run-off
The Sittaung River drainage basin is fed entirely by precipitation (rain) as the drainage basin does not cover high mountain ranges with snow and ice cover. The precipitation in the drainage basin is governed by the monsoon, with the wet season period from June to October. The most intense rain occurs from June to August; from November to May there is hardly any precipitation. The dry and wet season are clearly reflected in the run-off of the Sittaung river, with roughly 400 m^3/s in the dry season versus 4,000 m^3/s in the wet season. The average river discharge is about 1,500 m^3/s.

Tides
The water levels in the estuary show strong fluctuations due to the semi-diurnal tide in the Gulf of Mottama, that result in two high- and low waters per day. At the mouth of the estuary the tidal range is 3 to 6 m (neap-spring tide). The water levels within the estuary have been recorded during the second measurement campaign. The hydrodynamic model provides prediction on the tidal levels for other locations. The spring tide water levels under conditions of high discharge for nine locations in the estuary are shown in Figure 2.2, with the location of the four stations in *Figure 2.3*. These modelled conditions reflect the situation with a high river discharge (4000 m^3/s). The computer model shows that the tide has large asymmetry, with a short flood period when the water level rises quickly and a prolonged ebb period, when the water level falls slowly. In reality this situation can be recognized by the occurrence of a tidal bore at the beginning of the flood period (note that modelling a bore as such would require a different kind of modelling). The water levels are somewhat lower upstream (in the river) for low river discharges (400 m^3/s in the model), which makes sense because less water is flowing through the river. More towards the seaside, the computed tidal conditions do not differ much under high or low river discharges, because the influence of the river gets smaller.

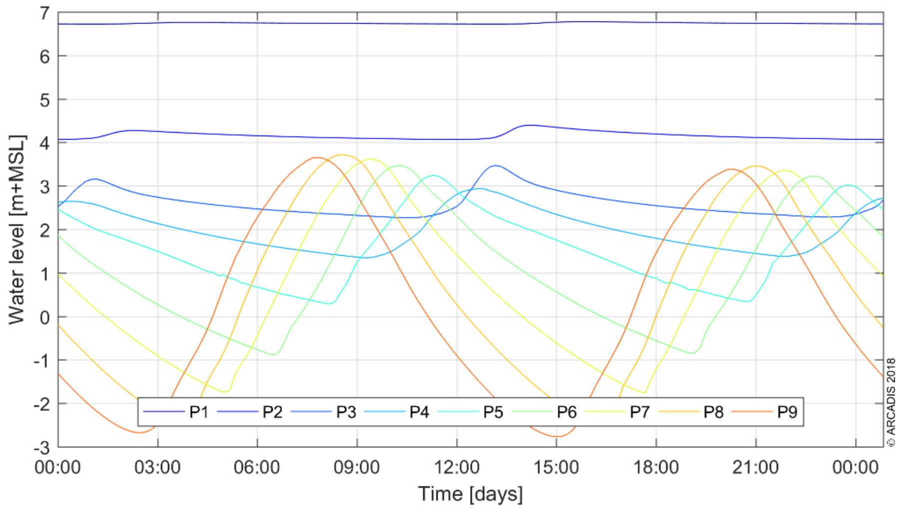
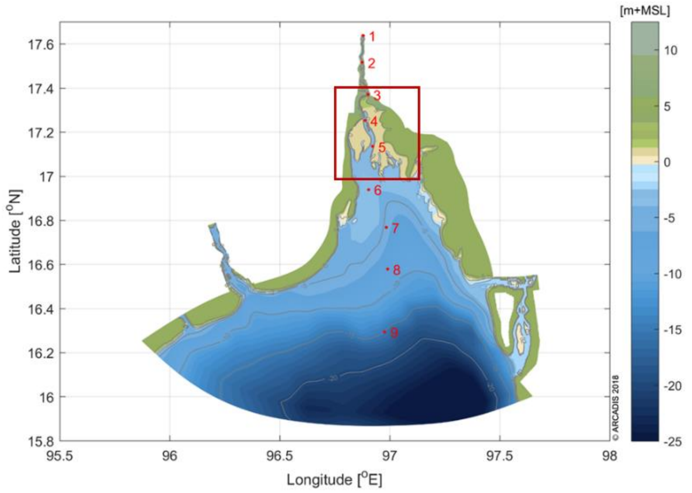


Figure 2.2 Modelled water-levels under conditions of high river discharge at nine locations in the Sittaung estuary (for locations see Figure 2.3*).*

A special feature of the Sittaung estuary is the occurrence of a tidal bore in a part of the estuary. A tidal bore or bore means that the leading edge of the incoming tide forms a short- breaking wave that travels up the estuary. The tidal bore is a symptom of an extreme asymmetry in the tides, with the flood coming in, in a very short time span.

The flow velocities in the channel have been measured during the two measurement campaigns. Right after the passage of the tidal bore the flow velocities are very high, with values above 3 m/s (Appendix B).



The flow in the estuary is dominated by river flow in the upstream domain and tidal movement in the downstream (seaside) domain. During the wet season a major part of the estuary can be regarded as fluvial dominated, while during the dry season a major part of the estuary can be regarded as tide-dominated.

Because the flow controls the erosion, sediment transport and deposition, it can be inferred that during the wet season the river dominates the dynamics in a major part of the estuary, while during the dry season the tidal flow dominates the hydrodynamics.

Figure 2.3 Locations 1 to 9 in the Gulf of Mottama and the Sittaung estuary

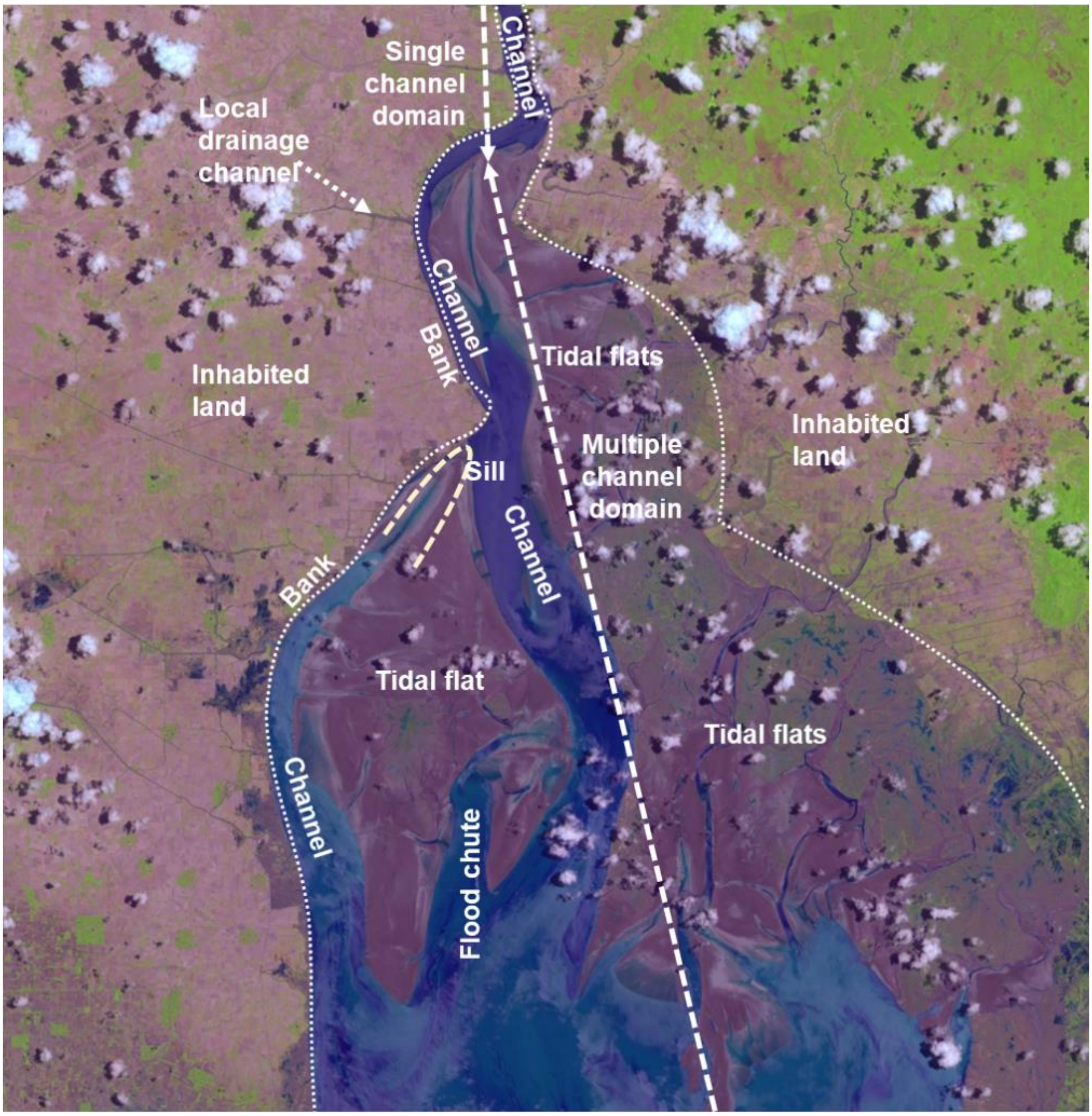


Figure 2.4 Morphological elements and domains in the Sittaung estuary (situation May 2018)

2.4 Sediment transport and morphodynamics

Morphodynamics is about the dynamics in morphology (such as tidal flats, channels, shoreline shapes and positions). A morphodynamic analysis looks into the interaction between the seafloor topography (hereafter referred to as bathymetry) with the forcing hydrodynamic conditions. While hydrodynamic processes respond instantaneously to morphological change (the flow of water follows the underwater topography), morphological change requires redistribution of sediment. As sediment takes time to move (days, sometimes years), there is a time lag in the morphological response to hydrodynamic forcing. It takes time for a shoreline to retreat. Since the boundary conditions of hydrodynamic forcing change regularly (wet/dry season; neap spring tide), this may mean that the bathymetry never reaches a stable, constant equilibrium. The morphology is always changing: it is morpho-dynamic.

The Sittaung estuary has a distinct funnel shape observed in many estuaries around the globe, with a wide seaward boundary that converges towards a narrow river (Figure 2.4). This funnel shape is on both sides bounded by inhabited land. Note that smaller creeks and tidal channels extend outside the funnel shape of the estuary, from the land into the estuary. The parts of the estuary that become exposed during low water are called tidal flats. The tidal flats cover a vast part of the estuary and have large ecological values. In the downstream section of the estuary at least two parallel channels are present. In the upstream part of the estuary there is a single channel present. The major channel continues through the estuary.

The western boundary of the estuary in Figure 2.4 is very distinct. It is formed by the steep channel bank that directly flanks the inhabited land. On the eastern side of the estuary the transition from the tidal flats to the inhabited land is less distinct. The higher tidal flats are gradually turned to agricultural use and this transition from estuary to inhabited land is fuzzier and changes over time.

The depth and cross-sectional area of the tidal channels have been measured during the first measurement campaign. The general observation is that the channels in the estuary are all remarkably shallow (compared to similar types of tidal channels worldwide), with depths only up to 5 or 10 m, and widths of 250 m to more than 1 kilometer. The shallow nature of the channels is acknowledged in conversation with the local fisher that navigate the estuary (Appendix F). Some of the channels can only be accessed under specific tidal conditions, even for their shallow draught vessels.

Insight in sediment transport patterns have been obtained from the numerical model simulations (see Appendix C for the complete report on the model simulations). Although the resultant flow is in seaward direction especially during the wet season, the Sittaung estuary is shown to be year-round flood-dominated. This is caused by the tidal asymmetry, meaning that the incoming tidal wave has a relatively short duration with high flow velocities, while the ebb tide is relatively long with lower flow velocities.

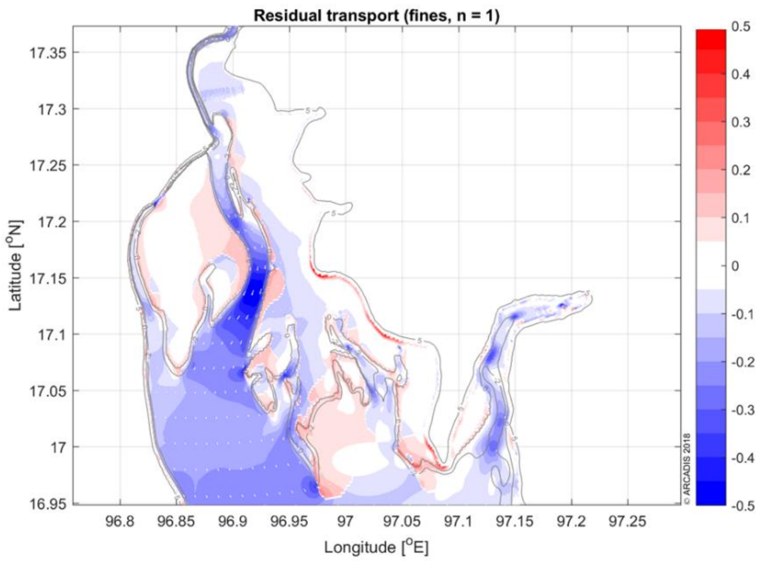


Figure 2.5 Factor indicating the residual transport of fines (suspended load) during mean spring tide in combination with a low river discharge. Blue colors indicate transport downstream (eb) and red colors indicate transport upstream (flood)

The tidal flow results in the transport of large amounts of fine sediments and sand into and out of the estuary each tide. The difference between these bidirectional transports, also known as the residual sediment transport, results in net changes of the sediment distribution and therefore in changes in the morphology. For the high and low river discharge, the residual transport of fine sediments (< 100 µm) is directed in southward direction (where it is probably partly discharged into the Andaman Sea and partly kept in suspension). Figure 2-5 is a map of the calculated residual transport of these fine sediments (dry season, 400 m^3/s). The residual transport in the channels is largely directed southwards (downstream). Locally, upstream transport onto the tidal flats occurs. In the western tidal channel parallel zones of downstream and upstream transport patterns can be observed which indicate local sediment circulation cells (building up new bars and flats).

The residual transport of sand (sediment coarser than say 100 µm) is more dependent on the river discharge. With the output from the hydrodynamic model, a residual bed load transport capacity has been computed; for the low river discharge its result is shown in Figure 2.6. It shows that almost in the entire estuary, the resultant direction of the bedload material is northwards, with the exception of the center tidal channel. This situation results in a zone of sediment convergence in the upstream parts of the estuary (close to the actual river mouth). In sandy estuarine systems this area is known as bedload convergence zone (BLC zone, Dalrymple & Choi, 2003).

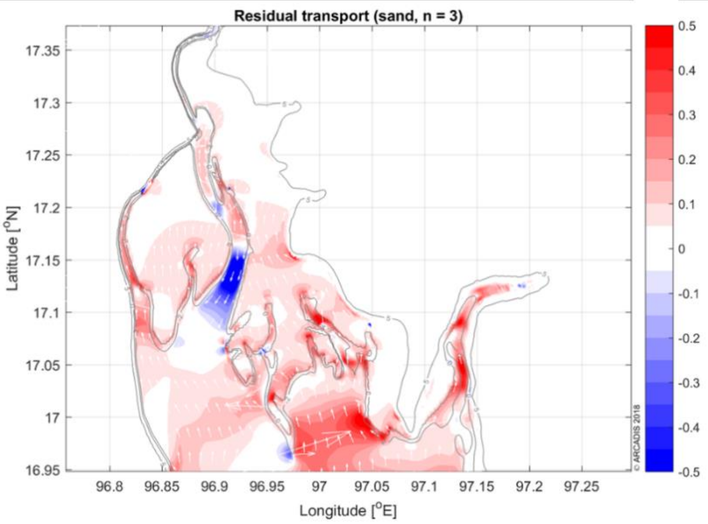


Figure 2.6 Factor indicating the residual transport of sand (bedload) during mean spring tide in combination with a low river discharge. Blue colors indicate transport downstream (eb) and red colors indicate transport upstream (flood).

The same has been computed for the wet season (4000 m^3/s); see Figure 2-7. The main channel system in the center of the estuary, which is connected to the Sittaung river now shows downstream residual bedload transport capacity. In the eastern part of the estuary, the residual transport is still directed in the upstream direction.

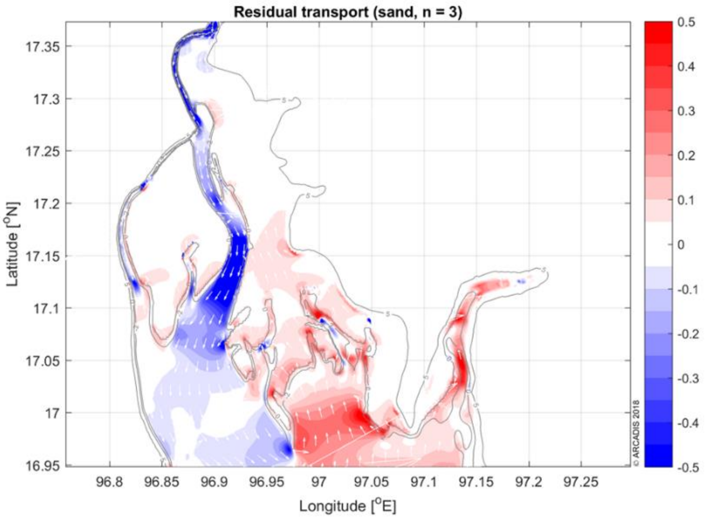


Figure 2.7 Factor indicating the residual transport of sand during mean spring tide in combination with a high river discharge. Blue colors indicate transport downstream (eb) and red colors indicate transport upstream (flood).

The presence of adjacent upstream and downstream directed zones in the estuary points to sediment circulation at the scale of the entire estuary, indicating that redistribution of sediment takes place in the entire estuary.

The calculated residual transports of fine sediment and sand under conditions of high and low river discharge point to large-scale and local (channel) scale redistribution of sediments, with clear differences between dry and rainy seasons. The areas in the estuary display different combinations of transport directions for sand and fine sediments under high and low river discharges that indicate that these areas display different morphological developments.

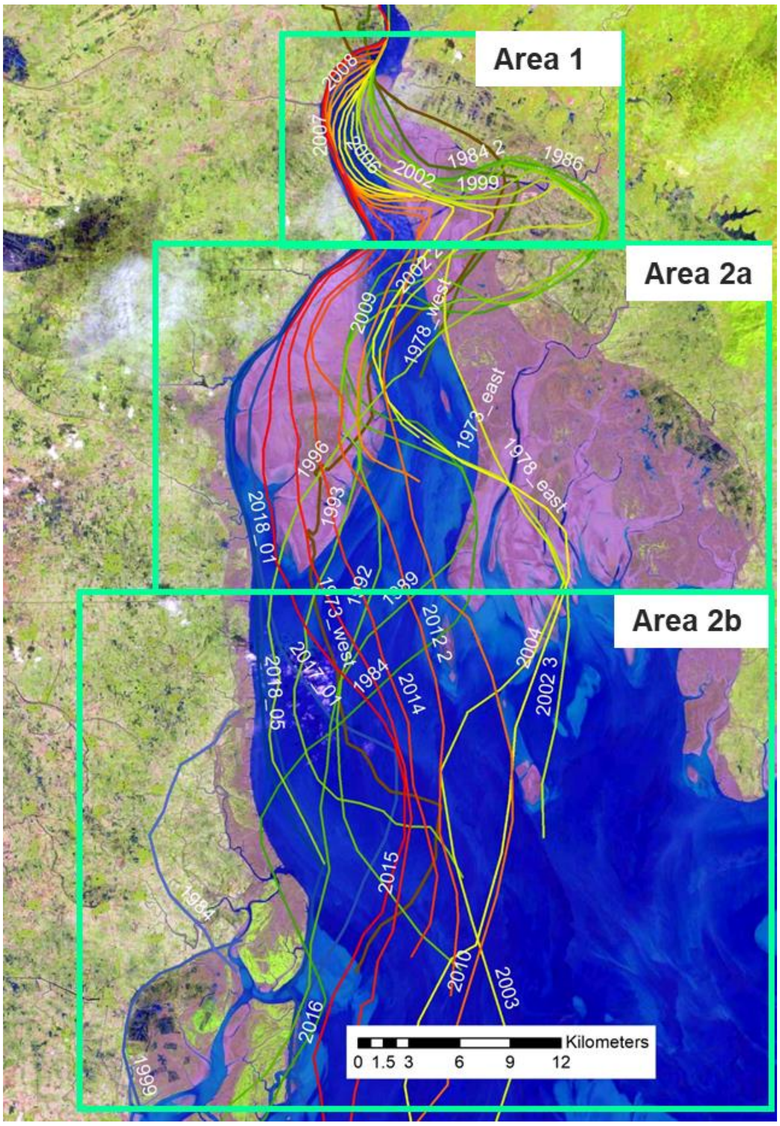


Figure 2.8 Three areas with distinctly different coastal erosion and migration of the channels (image Nov. 2018)

The morphodynamics have largely been assessed by means of satellite imagery, that was available from 1973 to 2018. Most of the images clearly display the position of the tidal channels, the tidal flats and the adjacent inhabited areas.

★

The position of the bank of the main channel at the limits of the estuary has been mapped. Plotting the position of these banks in one map, gives a good picture about the movements of the main channel over the decades. It also provides insight in any cyclicity and periodicity in channel migration.

Based on the results two areas have been distinguished (figure 2-8) with markedly different behaviour:

- Area 1: Unidirectional migration of the channel;
- Area 2: Channel migrates in both directions.

A further distinction has been made in area 2, based on the developments of the channels in the last five years. In the northern part of area 2 (area 2a) a center channel has developed recently (in 2017) and the importance of the channel on the west bank has decreased since then. In the southern part (area 2b), however, the major channel remains at the western shoreline of the estuary.

The background image in Figure 2.8 is the most recent satellite observation available: for November 2018. The channel that has caused the extreme erosion in Bago region in area 2A, is rapidly disappearing from the maps. this will probably lead to much less erosion on short term which is good news for land owners in this area. For fishermen who depend on good access to the Gulf, this development might be less favorable.

2.5 Coastal erosion resulting from unidirectional meander migration in area 1

The channel margin at the west bank for the period from 1984 to 2012 is shown in Figure 2.8. The position of the west bank in Area 1 has shifted from east to west, experienced as coastal erosion (black arrow). The largest changes have occurred in the southern half of the area, where initially in 1984 an east facing meander was present, that has disappeared because of the migration of the inner bend of that meander. Observations on satellite images prior to 1984 do show the presence of an east-facing meander (Figure 2.9) The most extreme development was the cutoff of the channel meanders in 2002 (location at black star). During the wet season in 2002 within a period of 6 months the two meanders have connected over the remainder of land that separated the two. The entire Area 1 then changed in a west facing meander.

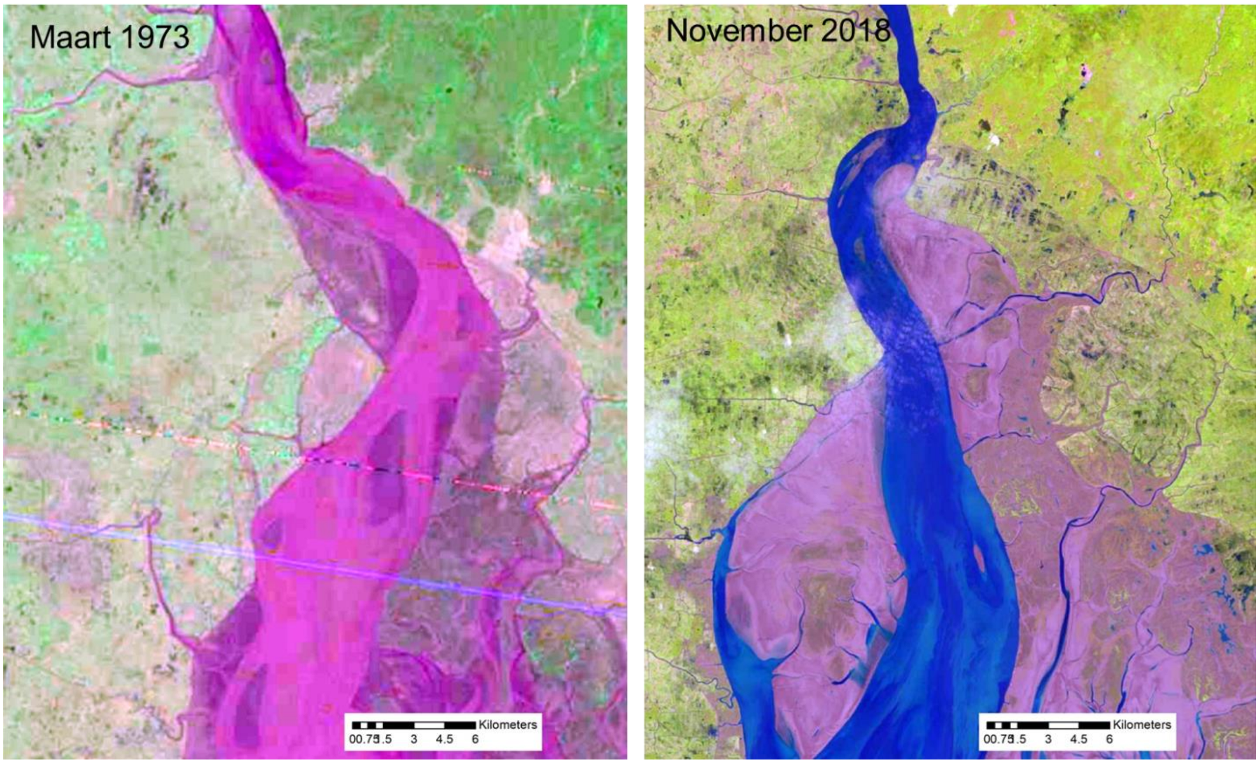


Figure 2.9 Satellite images of the Sittaung estuary from 1973 (left) and 2018 (right).

In the north of Area 1, the position of the west bank of the channel has remained stable at one point over the period of 1984-2018. This point forms a ‘hinge point’ for the position of the channel over this time-frame, as the entire channels seems to be attached to this point. However, older satellite images show the channel at the location of this ‘hinge point’, so the stability of this point is not guaranteed. During the field survey, it became evident that this location is not solid but potentially erodible (photo below). The fixed position of this hinge point from 1984-2018 has been crucial for the development of the channels in the entire estuary and therefore for the erosion of the shorelines. Future changes in the position of this hinge point may result in significant changes of the tidal channels in the entire estuary. Monitoring of this point and possibly safeguarding its position with local protective measure is therefore deemed vital for the management of the shorelines in Bago Region and Mon State.

View of the western shoreline of the Gulf of Mottama near the river mouth.

In the south of Area 1, the end-point of the meander has eroded to the west until 2010 and has remained seemingly stable since. The seemingly stable position of the last years is simply the result of a lower rate of erosion. During the September field visit, this location appears to be rapidly eroding again (photo below). With regard to the future erosion of the shorelines the position of this end point must be monitored, as it serves as a 'hinge point' for the development of the channels further to the South (in Area 2).

View of the western shoreline of the Gulf of Mottama, near Ah Lan Pya (29 September 2018). The steep, nearly vertical bank and the slumped blocks are evidence of the main erosional mechanism of the bank (slope collapse) that results from the ongoing landward migration of the tidal channel.

The process of meander migration is typical for river dynamics. Sediment from the outer bend of the meander, where erosion occurs, is deposited on the inner bend. The meander in Area 1 is in an estuary, with a clear influence of tidal flow, especially during the dry season and the mechanisms for the erosion of the meander is more complex than in pure fluvial systems. The complexity is expressed in the migration of the east-facing meander to the west. This development with erosion in the inner bight is the opposite of meander migration in rivers. The processes that seem to govern the migration of the meander in the situation of the last 15 years are landward sediment transport in flood phase and deposition of the sediment in sandbars in combination with outer bank erosion by ebb flow, that is enhanced by growth of the sand bars. These two mechanisms work in the same direction and have and will result in erosion in the west-facing outer bend of the meander.

2.6 Coastal erosion resulting from bidirectional channel migration in area 2

Area 2 is located south of the end point of the meander of area 1 (near the village of Nat Yao Kan; see second photo in Section 2.5). Area 2 is characterized by rapid changes in the position of the major tidal channel. In Figure 2.10 two extremes are shown, with in the left satellite image the situation in 2002 with the major tidal channel on the eastern side of the estuary; and in the right satellite image the situation in 2013 with tidal channel on the western side of the estuary. In both cases the main tidal channel lies directly adjacent to inhabited land, albeit on different sides.

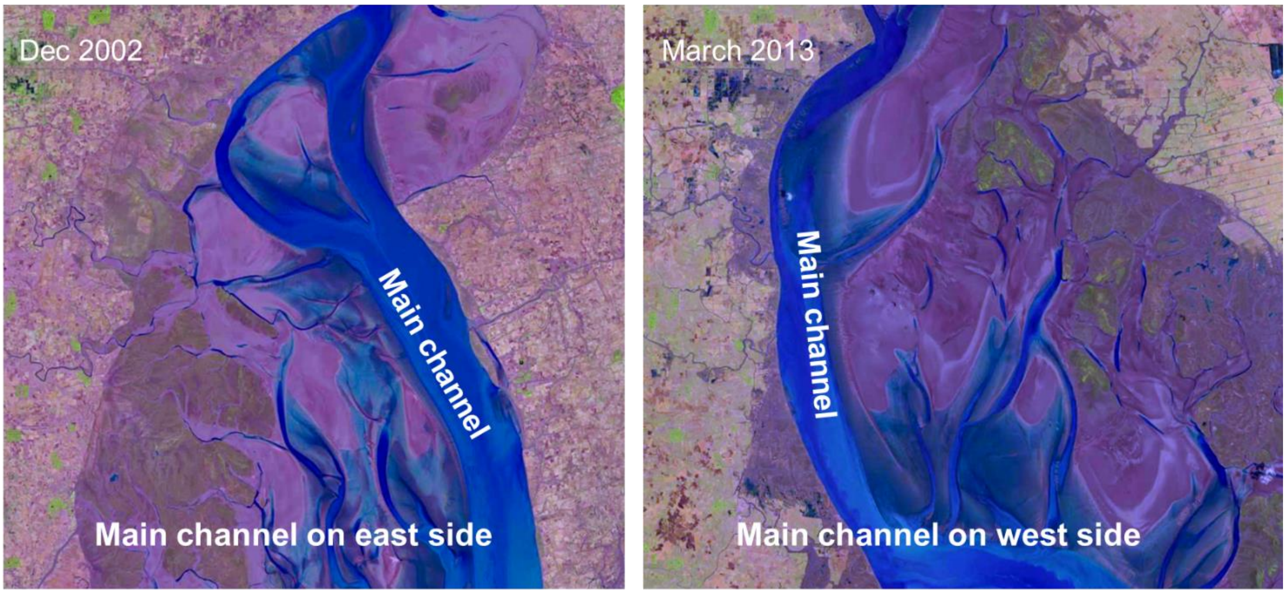


Figure 2.10 Satellite images of the Sittaung estuary from December 2002 (left) and March 2013 (right)

During the transition of the main channel from its position on the western to the eastern bank, a new channel or the migrating channel itself, will be in the center of the estuary. This is clearly visible in the recent satellite image from April 2018 in the right of Figure 2.11. Note that the main channel in the center is not the original channel that has shifted position, it is an entirely new channel that has formed in the center position.

The development of this new central channel was first observed in 2017. On the western side the original main channel is still present, but it is rapidly silting up starting from its northern end. How fast this process of channel abandonment goes, can be seen when comparing the satellite images of May and November 2018 (Figure 2-12). Within only five months the northern part of this channel - the channel that has caused the extreme erosion in the last years – has almost completely silted up, meaning that the tidal flow along the shoreline is much less than before.

Because of the back and forth movement of the main channel positions in Area 2, illustrated with the three black arrows in Figure 2-8, it is more difficult to interpret the satellite images than for Area 1. Furthermore, the number of meanders in Area 2 has also changed over time.

Based on an analysis of the satellite images and the results from the numerical model, the different channels have been classified channels as either ebb or flood dominated. The residual sediment transport was identified from the numerical model outcome. During the flood phase of the tides, the analysis shows that sediment is transported in landward direction and deposited in bars. The ebb- flow results in erosion on the outer bank, that is enhanced by the growth of these bars.

Over the past years the migration of the western channel has resulted in severe loss of inhabited land. The future developments will be dominated by the shift of the major tidal channel to the center position in the estuary and the abandonment of the old tidal channel (already clearly visible in Figure 2-12). The loss of the function of the old channel will eventually mean that its landward migration will end. This holds for the northern half of area 2, while in the southern half the main channel is still firmly located adjacent to the shoreline.

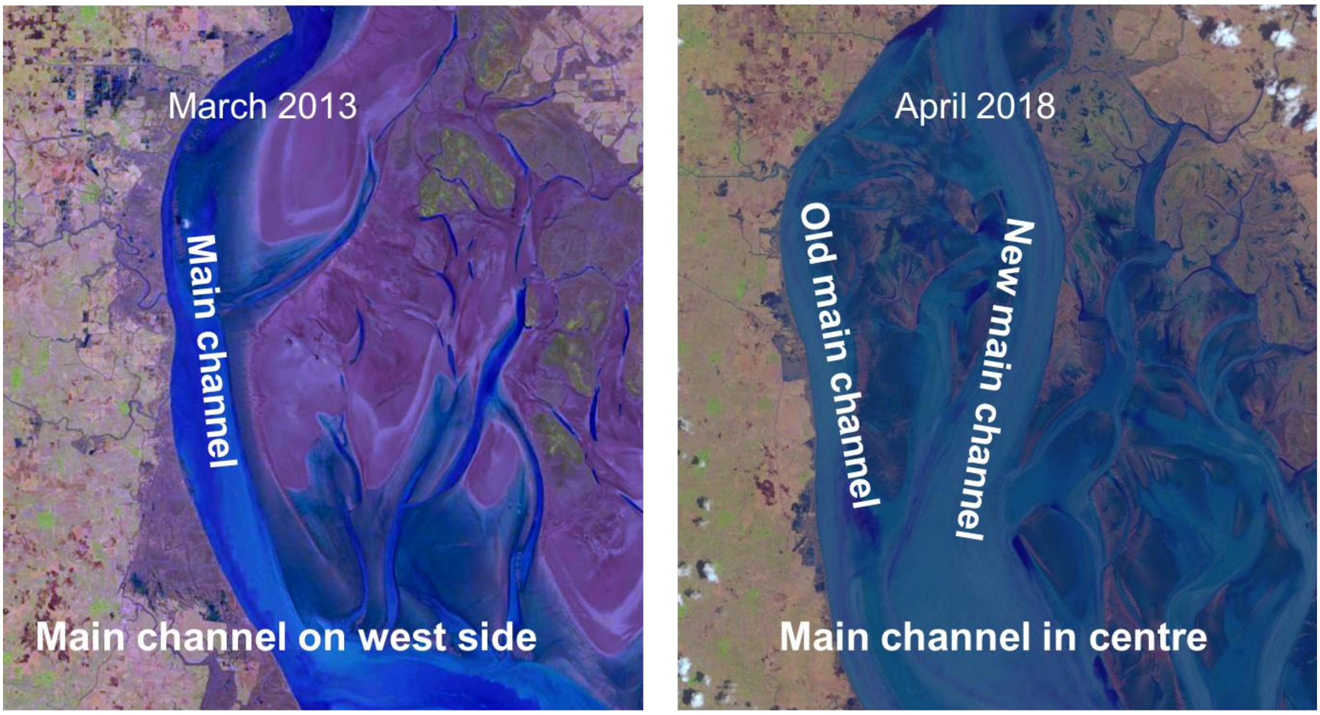


Figure 2.11 Satellite images of the Sittaung estuary from March 2013 (left) and April 2018 (right).

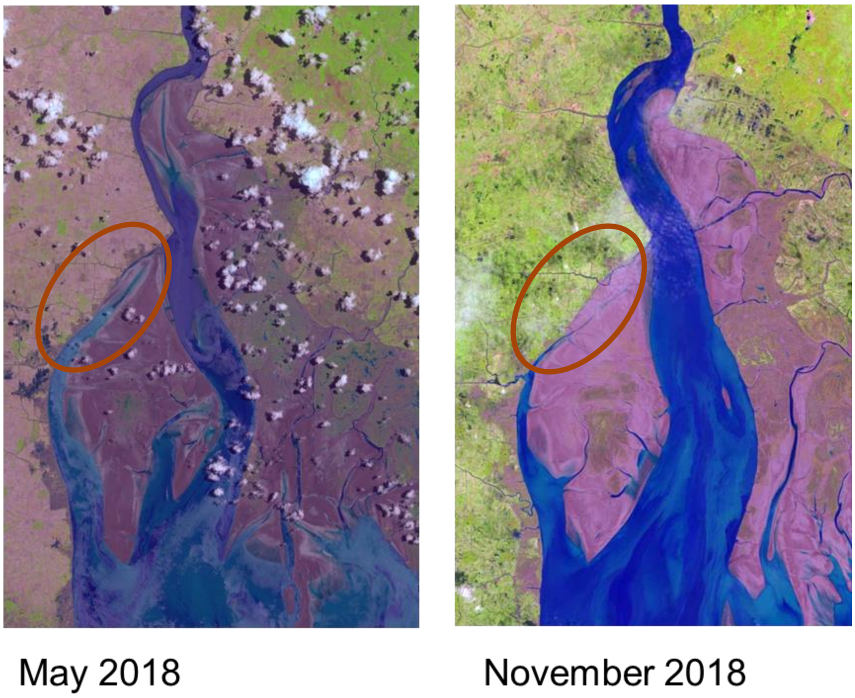


Figure 2.12 Satellite images of the Sittaung estuary from April 2018 (left) and November 2018 (right).

2.7 Comparison with other estuaries

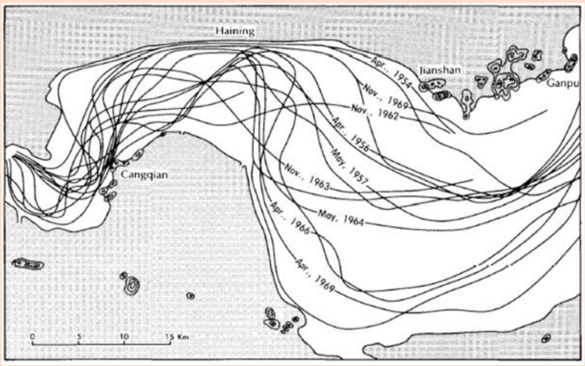
The characteristics of the Sittaung estuary have been compared with a dataset of estuaries worldwide, to identify how this system differs from other estuaries. The only estuary that resembles most with the Gulf of Mottama is the Qiantang Estuary in PR China (see text box below).

The characteristics of the Sittaung estuary have been compared with a dataset of estuaries worldwide, to identify how this system differs from other estuaries. A comparison of the tidal prims and cross-sectional area from the Sittaung estuary shows that its channels are very small and shallow, with an exceptional high width/depth ratio and that tidal prims are too large for the channel dimensions. This results in high flow velocities in the channels, well above 1 m/s as has been observed in the field.

Textbox Qiantang Estuary

Located on the coast of the East China Sea, the Qiantang Estuary is a 282-km long convergent (funnel-shaped) estuary. The upper reach is dominated by river flow, where the sediment is predominantly composed of gravely coarse sand and the morphology is basically stable. The lower reach downstream, also well known as Hangzhou Bay, is dominated by tidal currents. The middle reach is, depending on the season, controlled by both the river flow or tidal flow. During the high flow season, the river flow dominates, erodes the bed and transports a large amount of sediments seaward. During the dry season, the estuary is tide dominated and sediment is exchanged with the downstream Hangzhou Bay. Because the flood current velocity is twice that of the ebb current velocity, the flood current dominates resulting in deposition within the middle reach of the estuary [Xie et al., 2018]. The area is well-known for its high tidal bore. The estuary is constantly being ‘fed’ with fine sediments originating from the nearby Yangtse River; sediment that is being transported into the estuary because of the large flood dominancy which is also reflected in the occurrence of the tidal bore.

In the middle reach of Qiantang estuary, an elongated sand bar is found. The bed morphology around this sand bar shows strong seasonal and inter-annual variations due to this seasonal variability in discharge, the strong tidal current, the wide and shallow bed, and the fine bed materials. These changes cause the main river channels to shift resulting in periodical erosion and accretion on the northern and southern bank (from Chen Jiyu, 1990].



Since the 1960s, a large-scale coastal embankment has been built on both sides of the estuary for the purposes of flood defense and land reclamation. So far, more than 1000 km^2 land has been reclaimed and the width of the estuary has been narrowed, especially in the middle reach. The reclamation resulted in an increase of 0.1–0.2 m/s in tidal velocities. The increasing velocities induced more erosion in the channels, causing them to expand in width and depth. Outside the channels, increased sedimentation is observed. This phenomenon could be attributed to the fact that a decreasing tidal flat area enhances flood dominance, so that even more sediment carried by flood currents are deposited [Xie et al., 2017]. This explains why, contrary to some other global examples, the flats in the Qiantang estuary have not largely disappeared.

The relatively shallow channels in the Gulf of Mottama can either result from an overload in sediment caused by constant reworking of soil stored temporarily in land, or from the presence of erosion-resistant layers in the subsurface (like clay). The latter hypothesis can be tested with a geological investigation of the top 10 to 15 meters of sediments by use of hand coring. The cores can be collected from land-sites (or the tidal flats) where in the recent past a tidal channel was located. The analysis of the cores should focus on the presence of erosion resistant materials in the deeper segments (see Appendix A for more detail).

The specific setting of the Sittaung estuary in the funnel-shaped Gulf of Mottama leads to amplification of the tides and flood-dominance of the tidal flow, which in turn results in the entrapment of large loads of sediment in the estuary, chocking existing channels and thus inducing the development of new channels.

The local channel width was also used to estimate typical meander amplitude, based on a dataset with fluvial-tidal meanders worldwide (Leuven et al., 2018b). Meander amplitude is relevant is this case, because it indicates the maximum extent of erosion by outer bend erosion. Based on a typical channel width of 3 km, it is expected that meander amplitude is about 17 km (Leuven et al., 2018b). This neatly falls within the present-day estuary. However, the 95% confidence interval based on 75 estuaries worldwide is much larger and indicates that over longer time spans (decades, centuries) the *entire coastal plain* may be subject to meandering by tidal channels.

Rice fields being lost to the sea (photo taken on 29 September 2018 north of Ah Lan Pya, near Kywe Te)

3 PREDICTION OF COASTAL EROSION

3.1 Forecast of coastal erosion

From the previous Chapter 2 it follows that the development of new channels and the abandonment of older channels introduces a stochastic factor in the evolution of the estuary, which has a direct impact on the location and intensity of the coastal erosion. For the forecast we assume that the difference in behavior between area 1 and area 2 remain the same for at least the next five years, based on the historical difference between these areas. The recent development of the new center channel in area 2 has changed the confluence of the channel in area 1 and 2 (or vice versa) and this may affect the future developments in area 1 as well.

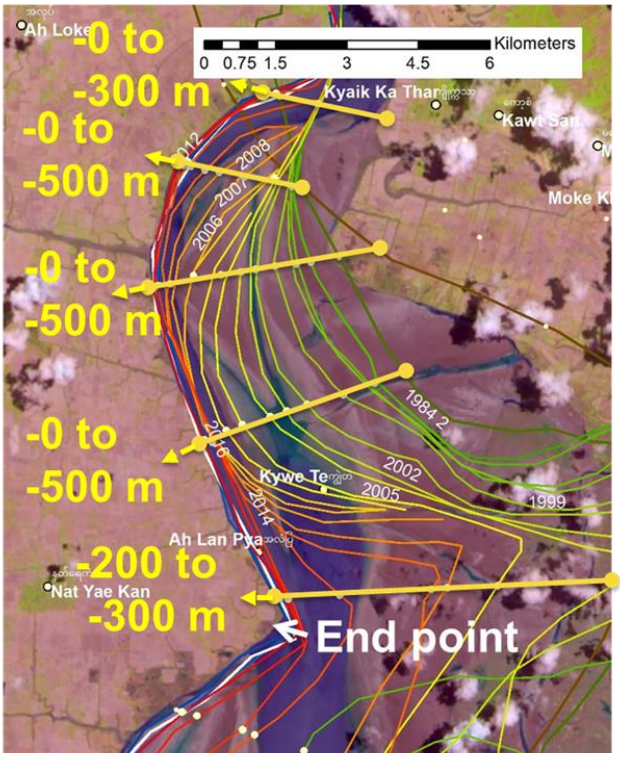
The large-scale and long-term developments of the shorelines of the estuary, over more than 10 years or longer, cannot be based on a description of the physics or on extrapolation of the observed trends. However, the overall characteristics of the estuary, in combination with ground rules from observations of estuaries around the globe, present useful insights for the longer term. These ground rules suggest that over longer periods (50 to hundreds of years) the *entire coastal plain* may be subject to erosion by migrating channels. At the eastern side of the estuary the bedrock of the hills limits this migration. At the western side there is no physical limitation to the migration. Visible remnants of meanders in the landscape suggest that indeed the estuary has reached to the maximum extent somewhere in historical times. Dating these meanders by historical or geological research, will provide more information on the recurrence of large-scale reworking of the coastal plain. The important message for the coastal-zone management of the estuary is that over longer periods of ten to hundreds of years a very large area is prone to erosion from the Sittaung estuary.

For the period of up to five years an extrapolation of the trends in combination with observations on the morphological changes is used to predict the extent over which erosion may occur. Even for this relatively short time span the expected changes are presented with a large bandwidth, that is in line with the observed changes in the evolution of the shoreline. A detailed presentation of the forecasts is provided in Appendix A to which is referred.

3.1.1 Bago state area 1. Unidirectional meander migration

Erosion on the western bank of the estuary is expected to continue at a slow but steady rate for the coming 5 to 10 years, due to the continued migration of the existing channel meander. The extent of the future erosion in this area is determined by:

- The position of the stable point in the north;
- The erosion at the end point of the meander in the south;
- The overall development of the channel pattern in Area 1 (and the connection with the main channel in Area 2).



The orientation of the meander bend is restricted by the presence of the stable point in the north of Area 1, because the meander bend does not and cannot migrate northwards (upstream). If the stability of this point would change, the migration could continue further to the north and to the west. We expect the stable point in the north to remain there for the coming five years, but this should be monitored as it is a key element for the extent of shoreline erosion in the entire estuary.

For the last few years the meander in Area 1 has also been bound in the south by the seemingly fixed point (see photos in Section 2.5). In combination with the stable point in the north, this puts a limit on the extent of the meander bend. With the gradually erosion of the southern end point, this restriction is gradually lifted. Eventually the orientation of the channel system may shift from a west-facing bend to an east-facing band that is lined up with the main central channel in Area 2. Observations on satellite images prior to 1984 (presented and discussed in Section 2.5) show the presence of an east-facing meander in Area 1 that continues in a south-running central channel in Area 2.

The observed rates of coastal erosion that form the basis for extrapolation, have been derived from the position of the channel bank for a number of transect perpendicular to the shoreline. Close to the stable point in the north, near the village of Ah Loke some erosion is possible in the coming five years but given the position close to the stable point it is likely to remain limited to tens of meters. South of Ah Loke the position of the shoreline has remained stable over the last 6 years, but recently (September 2018) erosion was observed in the field. At this location frequent shifts from stable to erosive occur, that are possibly related to sand bar developments associated with the earlier mentioned Bedload convergence Zone in Area 1.
To the south of Area 1 the recent stabilization, from 2005, has in 2016 turned into erosion again. Future erosion in the coming +5 years is likely, with a possible rate up to 50-100 m per year. Further south, close to the end point in the south some 200-300 m more land loss may occur in the next five years.

The development of the shoreline in the southern part of Area 1 is not only related to the development of the meander, but also relates to the development of the channels in Area 2. The channels in Area 2 connect with the channel in Area 1. The switch to the center channel in Area 2 may result in a reorientation of the flow and of the major channel in Area 1 and therefore in a slowdown of the erosion along the west bank.

3.1.2 Bago State area 2. Bidirectional channel migration: west - east switching

The area is split up in a northern part (Area 2a), and a southern part (Area 2b) (see Figure 1-3). The erosion in Area 2a has been the result of the presence of the tidal channel on the western side of the estuary. The observed development of a center channel and the simultaneous abandonment of the west channel is likely to result in the reduction of the erosion rates, possibly to zero. The abandoned channel will likely develop into tidal flats, as observed during earlier cycles of erosion in the estuary. New land is expected to develop.
In Area 2b the erosion also has been the result of the presence of the tidal channel on the western side of estuary. In contrast to area 2a to the north there are no indications that this tidal channel will lose its function soon. Erosion of this area is therefore likely to continue, at similar rates as observed earlier. This may result in the loss of a stretch of inhabited land that is up to 8 kilometers wide.

Area 2a
Near the village of Nat Yae Kan in the northern part of the estuary the recent sedimentation in the northern part of the channel has resulted in low flow velocities. The rate of costal erosion here has reduced after 2016 and reaches up to 100 m till last year. The erosion may continue in the next few years, perhaps with a maximum other 50 to 200 m. New land however, is expected to develop from sedimentation in the channel after this period. This also holds for the area near Kha Lat Su.

Near Koke Ko & Ka Pin the rate of erosion for the past 8 years has been higher than in the northern sections of Area 2a. This retreat occurs despite the sedimentation in the channel further north. The recent rate of coastal retreat has been around 1 km per year. Near Ngwe Taung the observed rate of coastal retreat has been even higher at 1.250 m per year. These rates of erosion are likely to get smaller when the western channel continues to lose its hydraulic function, which is the likely scenario for the coming years. It is therefore unclear what the coastal retreat in this cross section will be. The observed high rates are not likely to continue, as this will outpace the limited coastal retreat to the north. The upper limit for the maximum coastal retreat in this area would be another 500 - 1000 m, but even this maximum is subject to great uncertainty.

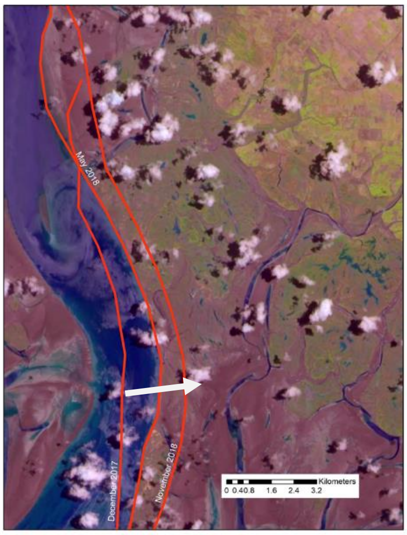
Area 2b
The area near Kan Taw is located at the bifurcation of the tidal channel. The tidal channel in the south splits into the western channel that is losing its function and the central channel that is taking over its role. The tidal channel here is the major active channel in the estuary. The migration of this tidal channel has resulted in coastal retreat with a recent rate over 1.600 m per year. The erosion of another 8 kilometers of inhabited land in the next 5 years is possible. However, when the channel losses its function, or shifts to a more central or eastern location the rate of erosion can reduce and the development could even reverse as has been observed in the past. This also holds for the area further south near War Taw and Aung Meik Thar.

The presented values of possible loss of land are extreme for area 2b, but such extreme rates of retreat have been observed in this area in the past 45 years (since 1973).

3.1.3 Shoreline of Mon state

The Mon side is likely to experience coastal erosion in the near future (in Area 2), due to the switch from a western to an eastern position of the main tidal channel. Initially the erosion will affect the tidal flats that are present in front of the inhabited land.

Horizontal retreat is expected to be very intense (in m/y), likely more than 1 km per year, which has already occurred in 2018 as shown in the picture aside. The three red lines indicate the location of the eastern bank of the central channel. Between December 2017 and November 2018, this bank has already moved 2 km to the east (indicated with the white arrow). Eventually, within years, erosion of currently inhabited land is likely to occur.



3.2 Vulnerable areas

The forecast of the coastal erosion from the previous Section indicates which areas are most vulnerable for coastal erosion in the next five years. Given the extreme rate of morphological changes (in dimensions and in speed) and the unpredictable nature of the dynamics, it is not realistic to pinpoint future positions of the shoreline to exact moments in time.

The (un)certainty of the prediction varies along the shorelines, as it depends on the nature of the changes. In Figure 3.1 the uncertainty in the position on the Bago shoreline is indicated by the bandwidth between the two lines.

The area between the current shoreline and the line that indicates the minimum erosion in the next 5 years is very likely to erode in the coming 5 years. The area between the two lines is likely to erode in the next 5 years.

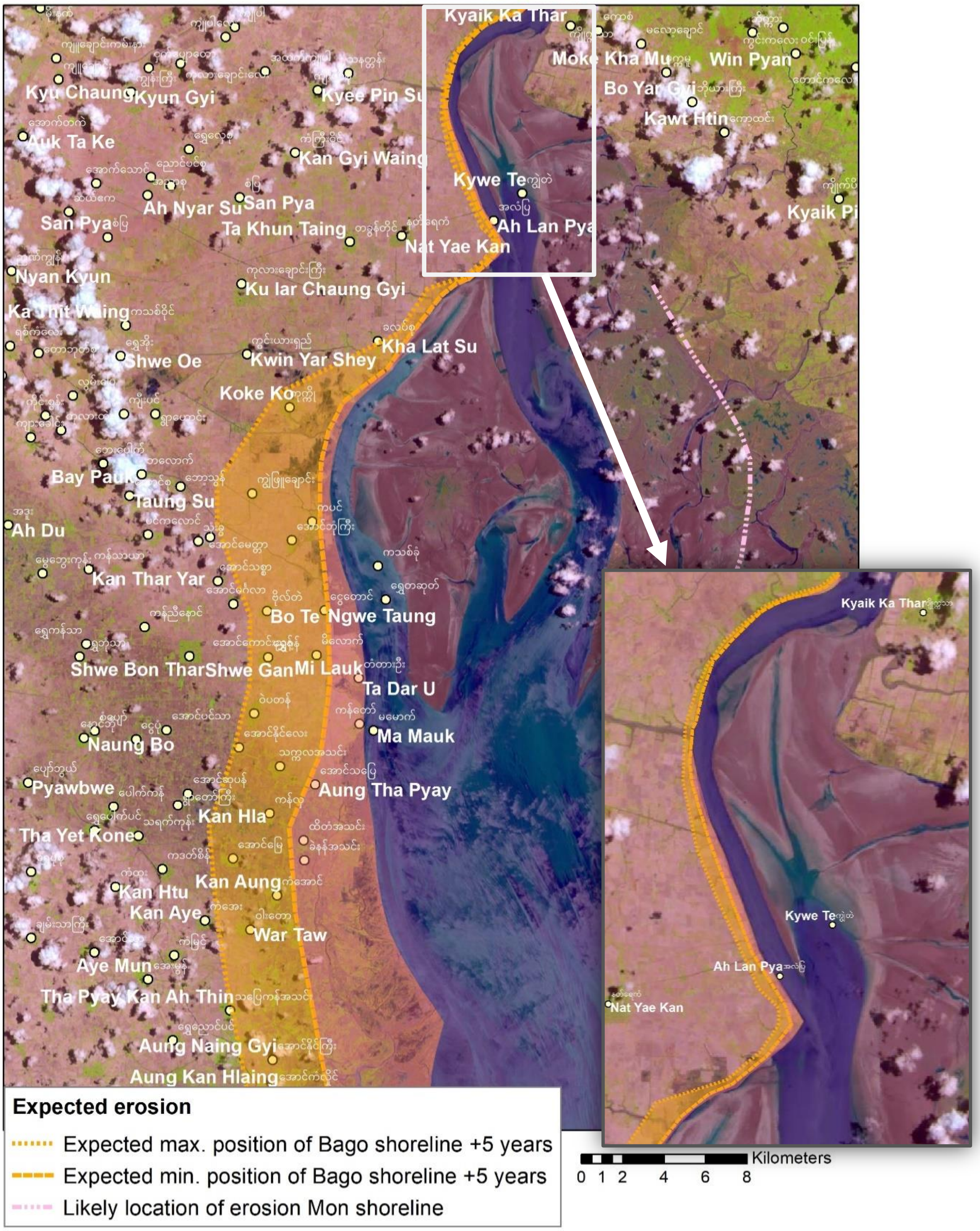


Figure 3.1 Vulnerable areas of the Bago shoreline. The inset shows the detail of the northern area (box).

4 POTENTIAL MEASURES, INTERVENTIONS AND ADAPTATION STRATEGIES

4.1 Overview of measures and interventions

To stop or reduce the coastal retreat and associated land loss, a diverse set of potential solutions is available in the toolbox of coastal engineers. These have been described in Appendix D to which is referred.

Coastal defense measures can be subdivided into the following three groups:

I. The zero-option: do nothing;
II. Measures to take away the cause of the erosion (called interventions); and
III. Measures to counteract the erosion or to alleviate the effect of coastal erosion (called structural measures).

The first group, the do-nothing option, does not necessarily mean that nothing should be done. non-structural interventions such as defining a setback line, communication about what can be expected, spatial planning, integrated coastal zone management; are all activities that fall within this category.

For all measures it is necessary to know the causes of erosion, which in this case is related to the (free-mode) meandering of the tidal channels. The passage of large tidal bores causes high levels of turbulence along the shoreline but are not the cause of the erosion. So, measures that aim to take away the cause of the erosion will need to control the migration of the western channel that currently runs close to the western (eroding) shoreline. This can be achieved by:

- Increase the height of the tidal flat on its east side. By doing so, the tidal prism of the channel decreases (less water is required to inundate the flat), and so will the flow velocities in the channel reduce;
- Increase the flow resistance on top of the tidal flat, for example with vegetation, which may have a similar effect as increasing the height; and
- Close the southern entrance of the channel with an artificial dam, to block the north-going flood flow.
-

Interventions (Appendix E)	
A. Deepening of the center channel Deepening of the center tidal channel encompasses dredging of the center channel over the full length of the estuary. A dredge volume of at least 20 million cubic meters of sediment is required. The ratio behind deepening of the center channel as shown in Figure 4-1, is that this allows for the tidal currents to enter and leave the estuary via this easy-access route. This would relieve the western channel and reduce the erosive tidal flows there.	**B. Increased height of western tidal flat** An increase in the height of the tidal flat results in a reduction of the ebb-flow from the flats. This reduces this component of the tidal flow that is directed towards the shoreline. An intervention to raise the tidal flat with 0,5 m would require roughly 15 million cubic meters of sediment.
C. Vegetation on western tidal flat Stimulating the presence and growth of vegetation on the tidal flats aims at the same effect as intervention B, albeit more indirect. The presence of the vegetation itself reduces the flow over and on the tidal flats, because of the increased roughness. Furthermore, the vegetation will enhance the sedimentation and will in turn lead to a reduction of the tidal flow from the flats towards the shorelines. The surface area of the tidal flats is large. Stimulation of vegetation over a significant part of their extent would require at least a thousand hectares of vegetation.	**D. Full closure of western channel** Closing of the western channel as indicated in Figure 4-2 at the south side of the channel, will reduce the flow through this channel and therefore reduce the erosion. Closing of the channel would require dumping of tens of millions of cubic meters of sediment.

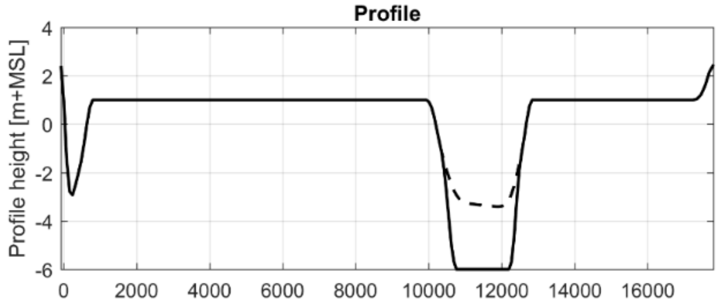


Figure 4.1 Cross section in the numerical model for intervention "A", with deepening of the central channel (dotted to solid line)

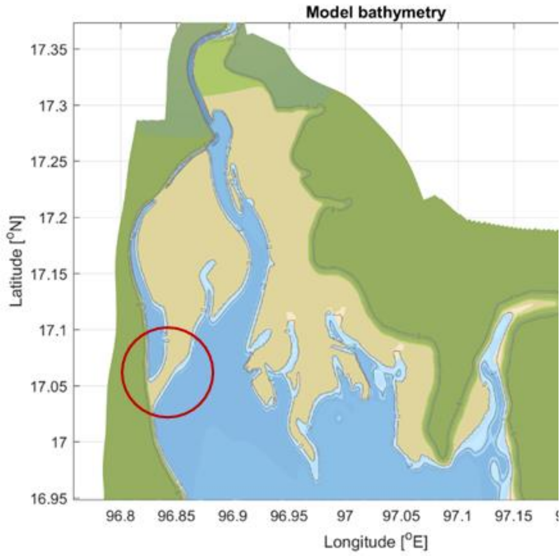


Figure 4.2 Map with intervention "D", with full closure of the western channel indicated with the circle.

These four types of system interventions have been analyzed with the numerical model; the results are given and discussed in Appendix E.

Structural measures to counteract the erosion can be grouped in three:

- Direct protection of the shore;
- Hard structures perpendicular to the shore; and
- Artificial nourishment.

All three concepts can either be temporary- or permanent measures, depending on the level of urgency and available resources to create properly designed protection schemes. A description of each category is presented below.

Structural Measures for coastal protection

Four categories of measures have been distinguished, based on their orientation and material

1a. Direct protection of the shore along the banks of the estuary

Direct protection of the shore above the low-water mark can be provided by some layer of resistant material. This layer can for example be a simple textile cloth, a series of sand bags, a bulkhead in the form of gabion nets or a rock revetment.

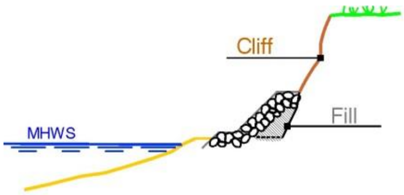
Geotextile Bags

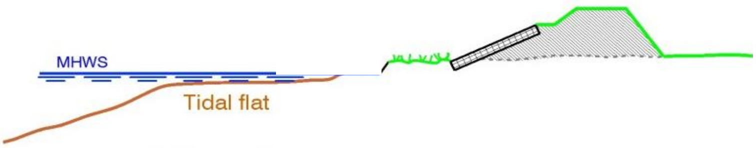
GeoTubes

Timber Structures

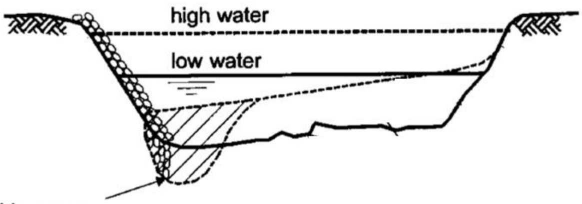
Gabion Mesh Boxes

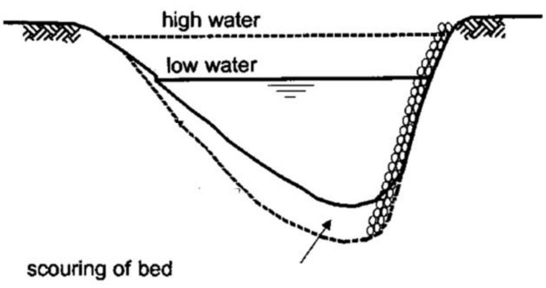
Rock revetment



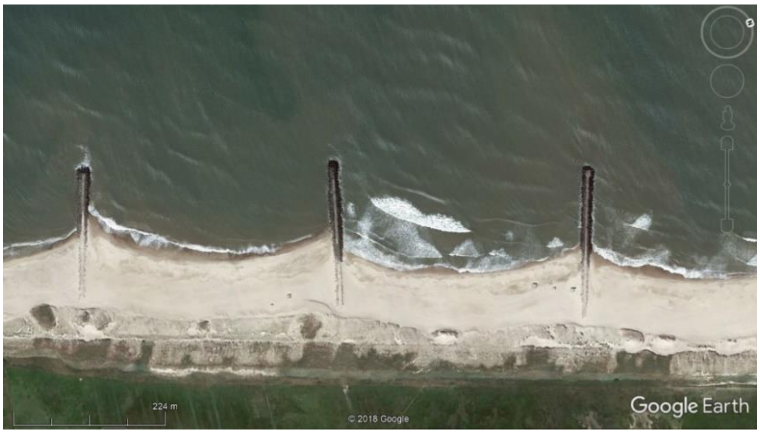


1b. Direct protection on the slope of the channel along the banks of the estuary
Direct protection against the migration of the tidal channel can be achieved by a layer of erosion-resistant material, rubble, rock, concrete units, from the top of the bank along the slope of the channel.





2. Hard structures perpendicular to the shore
The principal objective of these structures (groynes) is to decrease the eroding forces by reducing the flow velocities along the shore. On exposed coasts groynes are normally built as rubble mound structures. However, other materials, such as timber can also be used. Spur-dikes are perpendicular structures used in rivers to confine flow to the center of the river for navigation purposes and with an effect on the erosion as well by deflecting river currents away from the shore.



3. Artificial nourishment
This method includes restoring sand in front of the shore where it is used to compensate for the sand lost due to the beach erosion. The sand can be supplied either from land by normal excavation equipment as well as from water through a ship or a barge. This intervention does not take away the cause of the erosion and therefore the nourished sand will be eroded by the currents. Consequently, frequent re-nourishing will be required.

4. Building with Nature type mangrove development
Mangroves can form a natural protection against coastal erosion. The roots systems trap mud and reduce the subsequent erosion. The mangroves reduces the impact of storm surges on the hinterland. Initial start of mangroves in areas where they have been reduced can be facilitated by the use of permeable structures that reduce the impact of waves and currents on the seedlings while enabling the inflow of water and sediment. Permeable structures can be made from local available wood or bamboo.

Costs and design considerations slope protection

Technically speaking, any shoreline erosion can be stopped with a revetment. In this case, such revetment must be designed to stop a rapidly migrating tidal channel, which means that it should be constructed deep enough, with sufficient (underwater) toe protection. Considering the depths of the tidal channel, we expect that the toe structure must be at around MSL-8 m, possibly deeper.

The construction of such a slope protection is practically not possible under tidal bore conditions with flow velocities easily exceeding 3 m/s. Therefore, a sufficiently deep (more than 12 m - from MSL+4 m down to MSL-8) and sufficiently wide (depending on slopes at least 70 m) trench should first be excavated at a sufficiently safe distance from the shoreline. This distance depends on the construction time needed and the local erosion rate – probably a few hundred m at least (this zone will still be lost to the sea). The excavation of such a trench requires an excavation volume of at least 1000 m3 per m shoreline length, which obviously is a very costly activity on its own (estimated at 10 kUSD/m).

An alternative for a slope protection that does not require such massive excavation is a sheet pile. However, the earth-retaining height of such sheet pile would be at least 12 m (probably more), which would make this extremely expensive (ca. 200 kUSD/m) and hardly constructible given the required heavy equipment in relation to the expected local soft soils.

The slope protection that can be constructed inside the excavated trench, must be able to survive under extreme (design) conditions: flow velocities up to 3 to 4 m/s and significant wave heights up to several m (during cyclones). Because of the extreme flow velocities relatively heavy rock must be used, probably heavier than 500 kg, which will require special heavy equipment for placement.

Wave heights of several m will probably ask for concrete armour units, such as X-blocs, as rock alone can then no longer satisfy the design requirements. Costs for such a structure will be high; for example, the costs of a 1500 m long breakwater in the Black Sea using X-blocs was ca 60 k USD/m (with less extreme design flow velocity).

If both rock and concrete armour units are not feasible as protection layer, then grouted rock would be an alternative revetment cover. It is a solution that is already being applied along eroding river banks elsewhere in Myanmar. The grouting is done with concrete, not with asphalt because of the high temperatures in Myanmar, which requires a concrete plant on site. Grouted rock may work along relatively unexposed river banks, but not in a situation with high waves during cyclone attack. Moreover, the expected soft soil would probably lead to setting of the ground, resulting in bursts in the surface layer that will jeopardize the whole structure. This would mean that the revetment with grouted rock will need to be put on piles, clearly increasing the costs considerably. A rough estimate of these costs is between 20 to 60 thousand USD per m shoreline. These costs also depend on the additionally required infrastructure such as road construction (to get the equipment and materials on site), land purchase and ground excavation (to be able to build the revetment in a trench under better conditions).

Extent of the measures

The spatial scale at which measures can be successfully applied is the scale of the erosive channel elements: the channel meander in Area 1 and the erosive channels in Areas 2a and 2b. This scale holds for all measures shown here.

Local protection works, that aim to protect local values (village, religious places) will not be successful, as the erosion will continue in the unprotected stretches. Eventually, a locally protected area will be eroded from the sides or even from behind, meaning that in the best case (with measures surrounding the area on all sides) it will end as an island within the estuary.

Figure 4.3 Part of the western shoreline of the Sittaung estuary, with extent of alongshore protection against erosion.

It is important that also the entrances to the various tidal creeks are protected, because if these locations continue to erode, the protected shoreline can be attacked “from behind” jeopardizing the whole protection scheme. Closing the tidal creeks instead would not be a good idea as they also function as drainage canals in the wet season.

Successful protective measures will therefore have to be applied over stretches of 10 to 20 kilometers of the shoreline and be well engineered in a way that the structures can survive under maximum tidal bore conditions.

Storm surge barrier?

One rather extreme measure was mentioned during the consultations: the closure of the entire Gulf of Mottama with a barrier across the entrance of the estuary (from west to east for example from Ma Mauk on the Bago side to Pauk Taw on the Mon side). Obviously, such barrier will need to have an opening for the drainage of the Sittaung river discharge. With an estimated design river discharge of 5000 m^3/s this would ask for an effective ‘opening’ of at least 2500 m^2. Assuming a depth of 8 m and 70% relative openings, this asks for a bridge or gated sluice structure of some 450 m in length. Heavy bed protection will be required in the opening and both up- and downstream areas (some 500.000 m^2).

The design of the whole barrier (closed dam sections and gated openings) will be quite a challenge under the extreme hydraulic conditions that can occur, but actually constructing it will be extremely difficult and surely extremely expensive (without any attempt to calculate these, we expect costs to be well above 1 billion USD).

Moreover, the impact of such closure barrier on the ecosystem, notably crossing a Ramsar Convention protected site, will be dramatic (loss of flat areas to mention one aspect). We, therefore, do not expect that such barrier would be acceptable after a more thorough socio-economic cost/benefit analysis, or environmental and social impact assessment.

4.2 Trade-off matrix

A rather straightforward trade-off matrix has been developed to compare the various measures and interventions for the following set of six qualitative criteria:

- Effectiveness: Does the measure/intervention prevent further coastal erosion, and what is the spatial extent of the measure/intervention?
- Local implementation capacity: Can the measure/intervention be produced and build locally, or do specialist equipment and/or building materials have to transported to the Sittaung estuary?
- Environmental impact: What effects do the measures/interventions have on the local and regional environment? Do the measures influence the ecosystem services provided by the estuary, including fisheries, soil improvement, etc.;
- Costs: What are the costs of the measure/intervention, in terms of the investments needed for the construction (Capital expenditures) and the operational costs for surveillance, maintenance, etc (Operational expenditures).
- Benefits: What are the benefits of the measures/interventions in terms of protected values and investments.
- C/B ratio: Do the costs weigh up against the benefits?

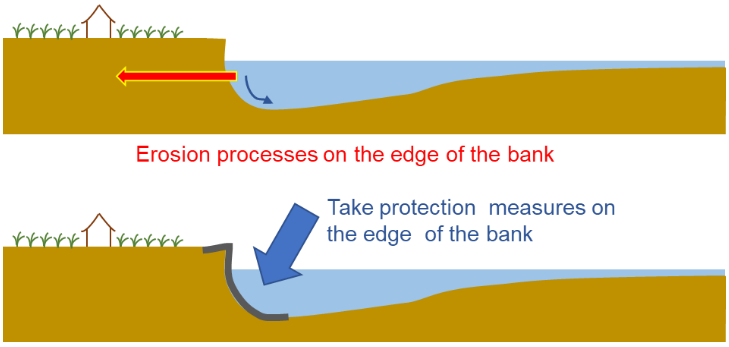
This table blow gives the qualitative scores per criterion and is followed by an explanation of the scores per measure and intervention. In this Table "-" stands for negative score, "0" for neutral score, and "+" for positive score ("--" and "++" are extra strong scores); n.a. stands for not applicable. The – minus score in the column "local implementation capacity" means a lack of capacity, while the + means that the capacity is available.

Measure / Intervention	Effectiveness	Local implementation capacity	Environmental impact	Costs	Benefits	C/B ratio
0. Do nothing	0	n.a.	n.a.	0	-	+
1a. Bank protection	0	+	0	$$	-	--
1b. Slope protection	+	-	0	$$$	+	-+
2. Groynes	-	-	0	$$$	-	--
3. Nourishment	0	-	-	$$$$	-	---
4. Mangroves	-	0	+	$	-	-
A. Channel dredging	--	--	--	$$$$	--	----
B. Heightened flat	+	--	-	$$$$	0	--
C. Vegetated flat	+	+	0	$$	0	-
D. Channel closure	+	--	-	$$$$	+	-

Qualitative scores for the structural measures

1a. Bank protection: The protection of the bank is above the low water line and does not deal with the erosion by the severe tidal flow. The effectiveness of bank protection is therefore regarded neutral (there are no adverse effects and so the score is not negative). Bank protection can be constructed locally, without specialist skills and largely with locally available materials. The measure has a small footprint and the environmental impact is therefore limited. The costs of this measure are average. Production of this measure is labor intensive, but with limited costs for materials (given that locally available material is used). Because this measure is not effective, the loss of inhabited land will continue, including the loss of all economic values and activities on this land.

1b. Slope protection: Protection of the slope can stop erosion by the tidal channels and is therefore regarded as (potentially) effective. Successful slope protection requires rock or concrete elements that are not readily available locally. Furthermore, the construction of slope protection on the very steep slope may require specialist equipment, because onshore construction of a falling apron type measure may not result in the required coverage of the entire slope. The measure has a small footprint and the environmental impact is therefore limited. The costs of slope protection are very high because a large amount of material (rock, concrete) is required, that is not locally available and will be extremely difficult to transport to site (no roads, shallow waters). The benefits are positive, as this measure can effectively protect inhabited land.



Schematic cross-section of the inhabited shore and erosion by the channel in the estuary (top), with slope protection (below).

2. Groynes: Groynes in this case will be less effective as they cannot stop the migration of a tidal channel. It is even more likely that they work counter-productive because of scour generated at the tips of the groynes where flow velocities will even increase. The extra turbulence generated by these groynes will also take more sediment from within the groyne cells and by doing so aggravate the coastal erosion.

3. Nourishment: Nourishment requires very large volumes of sediment to be placed along the shoreline to balance the erosion. Because the measure does not stop the erosion, but mitigates the effect, it is regarded neutral. Nourishment is not a viable option because of the nature of the coastal sediments (clay) and the cause of the erosion (large scale tidal channel migration). With 5 m/d shoreline retreat over a distance alongshore of at least 5 km and assuming a vertical eroding profile height of 4 m; a total nourishment volume of some 100,000 m^3 clay per day would be required: a totally impossible challenge. This measure has a largest footprint as has impact in the borrow area and on the location of the nourishment, thus resulting in a negative environmental impact.

4. Mangroves: The successful creation of mangrove habitat in front of the shorelines is not an effective measure, because the mangroves do not prevent the shore-line erosion by the migrating tidal channel (successful shoreline protection by mangroves is possible in situations where waves, storms and subsidence cause coastal retreat). The required materials are relatively cheap and local labor might be sufficient, making the costs of this measure relatively low. Successful creation of mangrove habitat has various benefits, for the natural environment (wildlife and for the local economy, increase in fish stock). Because this measure is not effective the loss of inhabited land will continue, including the loss of all economic values and activities on this land.

Qualitative scores for the system interventions

A. Channel dredging: Deepening of the tidal channel will result in an enhanced intrusion of the tidal flow in the estuary. Although the pressure may be relieved from the channel that cause the erosion of the shoreline, the adverse effects upstream, in terms of raised water level and increased erosion by far outweigh any positive effects. Furthermore, because of the abundance of sediment in the estuary, the life-span of the dredged channel is years at most (it silts up rapidly). The overall score on effectiveness is therefore very negative. Dredging large volumes of sediments from the channel does require heavy dredging equipment that is not locally available. The enhanced tidal intrusion and the disposal of the dredge spoil can have large and negative effects on the ecosystem of the estuary.

The dredge spoil may be used to for interventions on the flats and in the western channel, thus creating additional effects for the estuarine dynamins. However, the environmental impact is therefore considered very negative. The costs of the dredging operation easily exceed tens of millions of dollars and are judged very high. There are no additional benefits of the channel, it is for instance not likely that a stable shipping channel can be created. The overall balance between costs and benefits is extremely negative for this intervention.

B. Heightened flat: Increasing the height of the tidal flats will reduce the flow from the tidal flat that is directed towards the western shoreline and thus reduce the migration of the channel and the coastal erosion. The difference that the heightened tidal flat makes on the residual flow is shown in Figure 4.4 (derived from computer model). The upstream directed transport in the channel will increase and the downstream transport along the flat increases, effectively reversing the current situation. Given the impact on the residual transport, the intervention is therefore deemed effective.

As with the previous intervention, there is no local capacity for the implementation, because heavy dredging equipment is required to raise the tidal flat. The environmental of this intervention is negative, because the tidal flat habitat will deteriorate due to the coverage with sediments and the borough area will also deteriorate. The costs of the dredging operation easily exceed tens of millions of dollars and are judged very high. The heightened tidal flat can be claimed for agricultural use earlier then in the case of the natural development and this is a benefit of the intervention. This is judged neutral as this hamper other ecosystem services provided by the natural tidal flat. The overall balance between costs and benefits is negative for this intervention.

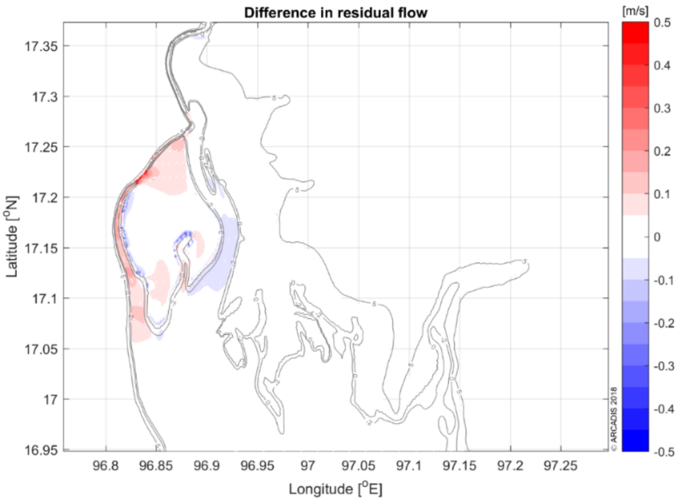


Figure 4.4 Difference in the residual flow as a result of the heightening of the western tidal flat.

C. Vegetated flat: Vegetation on the high tidal flats can effectively enhance the sedimentation and thus create a situation like intervention B, without directly bringing sediment to the tidal flats. The measure is considered effective, based on the outcome of the model simulations shown in Figure 4.5. The flow over the tidal flat is reduced, as a result of the roughness introduced by the vegetation. The result is very similar to the intervention B shown in Figure 4.4.

Boosting the vegetation may be achieved in various ways, with local labor. The local implementation capacity is therefore considered positive. The environmental impact is limited with this 'Building with Nature' type intervention, that enhances natural developments. The costs of this intervention are average, because the surface over which vegetation must be enhanced is large. The benefits of this intervention are considered positive, because the intervention is effective. The overall balance between costs and benefits is still slightly negative for this intervention, because the absolute costs are still high in comparison to the values that are protected.

D. Channel closure: Closure of the channel (Figure 4.2) is an effective intervention to reduce the flow through the western channel (see model output in Figure 4.6). It should be noted that the closure dam must be properly engineered to avoid that it erodes rapidly and breaches after some time. Local capacity for this major dredging operation is limited and the costs are very high. In line with the other dredging operations the environmental impact is regarded negative. As the intervention is effective, the benefits are judged positive. The overall balance between costs and benefits is negative for this intervention, because the costs are very high in comparison to the protected values.

For the interventions B and D the borough area for the sediments have to be selected with care, to prevent negative developments, like the enhanced intrusion of the tides associated with the deepening of the tidal channel.

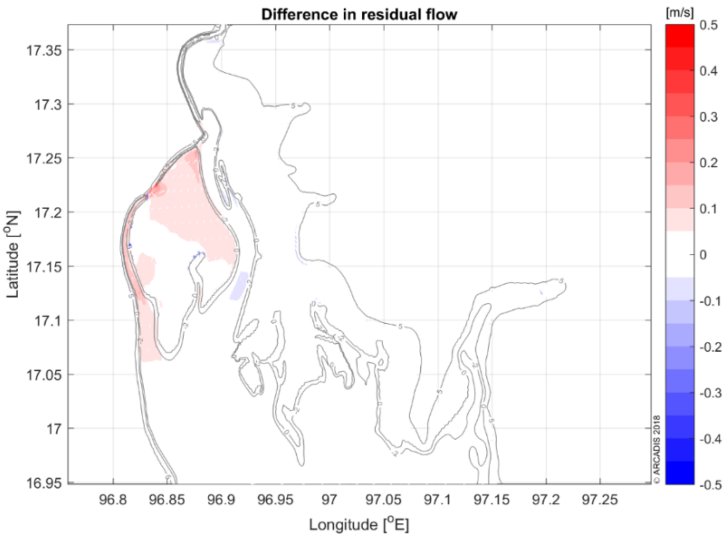


Figure 4.5 Difference in the residual flow as a result of the added vegetation on the western tidal flat

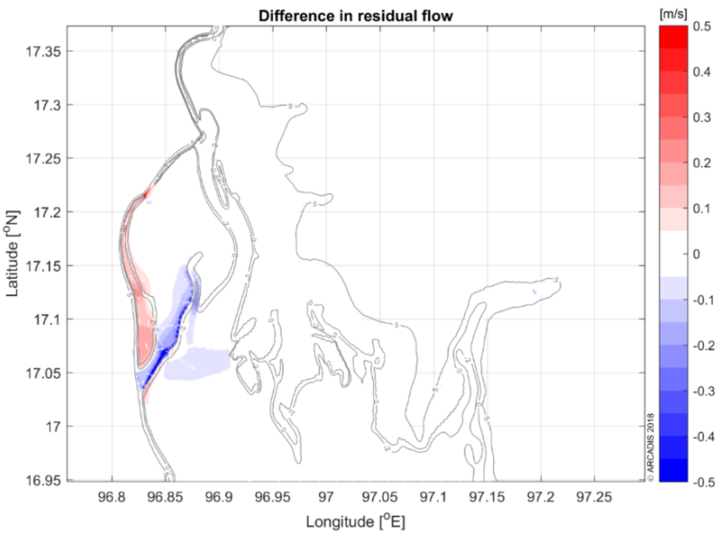
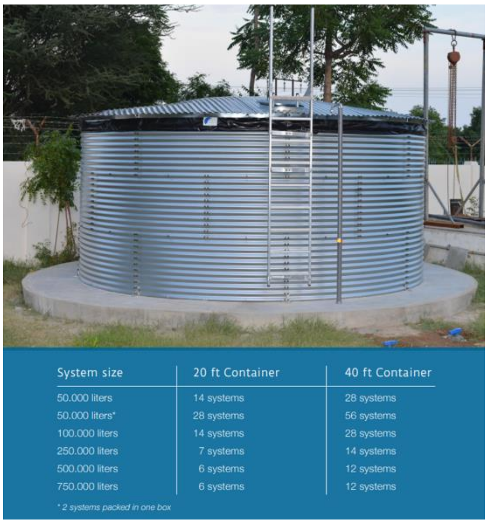


Figure 4.6 Difference in the residual flow as a result of the closure of the western tidal channel.

4.3 Adaptation strategy

The trade-off matrix of the measures shows that none of the structural measures or interventions are attractive from a cost/benefit aspect. The costs for the protective measures simply do not outweigh the benefits in terms of protected values, as only limited economic values are currently present. In terms of adaptation strategies this means that only one adaptation pathway remains viable: adapting to retreat as a special follow-up of the zero-option.

Adaptation to retreat has been common practice for centuries along the banks of the Sittaung estuary in the Bago and Mon states. The inhabitants move when the shorelines approach their land and houses. Crops and wood are harvested as much as possible and all transportable materials are being removed and recycled.



System size	20 ft Container	40 ft Container
50.000 liters	14 systems	28 systems
50.000 liters*	28 systems	56 systems
100.000 liters	14 systems	28 systems
250.000 liters	7 systems	14 systems
500.000 liters	6 systems	12 systems
750.000 liters	6 systems	12 systems

* 2 systems packed in one box

The down-side effect is that there is hardly any infrastructure in the flood plain, such as roads or adequate water reservoirs, which hampers local economic development. Appendix D shows some examples of so-called flexible infrastructure that can be considered to increase the adaptive capacity of the local communities. These types of measures will also be useful in times of accelerated weather extremes and therefore would fall under the category Climate Adaptation Measures as well. The flexible infrastructure examples have been grouped into:

- Roads;
- Drinking water supply;
- Housing; and
- Assets (e.g. hospital, agriculture).

Prices for such measures differ, from hundred to several hundred USD for water tanks and the flexible adaptations for houses and other buildings, to several thousand USD for bespoke flexible houses, hospitals and buildings. Construction of roads is be the most expensive adaptation measure at ten of thousands of USD per kilometer, depending on the building materials. Roads will have additional benefits for the economic development of the region. Further reference is made to Appendix D.

Adaptation strategies should preferably be associated with organizational, legal and financial regulations to facilitate community resettlement. A system of financial ‘solidarity compensation’ for farmers who are forced to relocate can be envisaged. Governance at national, regional and local level will have to allow for the societal dynamics associated with adaptation strategies.

4.4 Impact of accelerated sea-level rise

Accelerated global sea-level rise is predicted because of global warming. The increase in sea level will also impact the Myanmar shorelines, including the Gulf of Mottama and the Sittaung estuary. Based on the geological analysis, it is likely that the Gulf of Mottama have already been exposed to high rates of *relative*[2] sea-level rise, as a result of the subsidence of the subsurface in the region. Accelerated global sea-level rise will add to the regional effect of subsidence and result in even higher rates of *relative* sea-level rise. The flooding of the coastal plains, that happens regularly during the wet season and during high tides means that sediment is deposited there. Most of the sediment is deposited in a zone of several hundred m wide measured from the shoreline. The coastal plain thus has capacity to “follow” the accelerated relative rise of the sea level.

The amount of (fine) sediment available in the Gulf of Mottama and the Sittaung estuary is very large and all that sediment is available for sedimentation on regularly inundated land and tidal flats to follow the rise in water levels. For the entire coastal plain to follow the rise in sea-level, the high rates of deposition occur close to the shorelines. Migration of the channels over the coastal plain, with the adverse effect of loss of land and livelihood, does have the advantage of delivering sediment over a very large area. The migration of the channels therefore facilitates the rise of the coastal plain that is required to follow sea-level rise.

Based on the abundance of sediment and a comparison with other estuarine and tidal system, a build-up of the coastal plain and estuary at rates up to at least 4 cm/y seems likely. This means that for the next 50 years, if the sea level rise does not exceed such rate of 4 cm/y, no changes in the morphodynamic behavior of the Gulf of Mottama is expected.

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[2] Relative sea-level rise is the combined effect of the rise of the water level and the lowering of the land due to subsidence.

It is unlikely that an accelerated rise-in sea level will influence the already extreme dynamics of the shoreline and the tidal channels. The driving forces of the migration of the channels are hardly influenced by the gradual sea-level rise. Climate change may result in an even more peaked river discharge during the rainy season. Although much of the flood waters will be accommodated in the coastal plain, the increase in peak discharge may result in additional channel migration in the upstream regions of the estuary. Changes in the sediment yield of the river as a result of climate changes or following antropogenic interventions, may have a similar effect in migration rates and avulsions. An increase in the upstream migration and avulsions could even lead to shift of the entire river belt to the west that would affect a large inhabited area. Monitoring of the developments is essential to recognize such potential system-wide changes, and this may lead to local measures to protect critical points.

4.5 Monitoring as an integral part of the coastal zone management

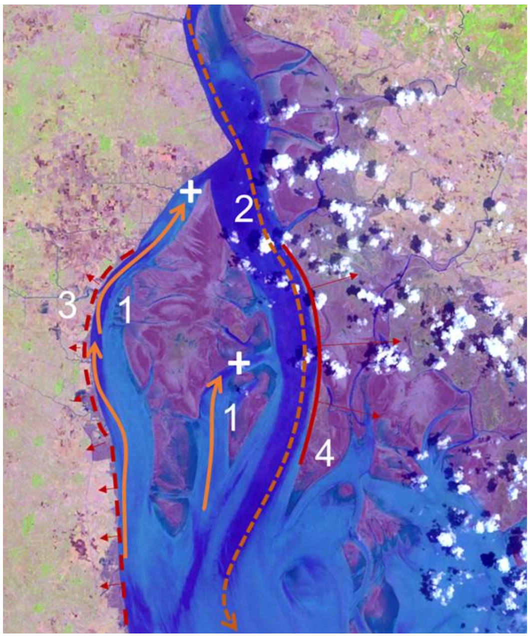
An essential part of coastal zone management is the monitoring of the morphological developments. For the extreme changes on the Bago and Mon shorelines the importance of up-to-date monitoring is even greater. The availability of recent satellite images in the public domain allows for yearly actualization of the developments of the shorelines and the tidal channels. The analysis of the satellite images is relatively easy, and does not require field measurements that are complex, time consuming and relatively expensive in this environment.

Appendix G gives guidance on how such satellite data analyses can be done by Myanmar experts themselves. It is worthwhile to designate the yearly update of the monitoring to institutions and even make specific persons responsible for this task. A government authority or the universities of Bago and Mawlamyine may be best equipped and best suited for this task. Each year a report should be updated, with the most recent positions of the shorelines, the changes in the shoreline positions, the position of the tidal channels and of the critical points and an update forecast of the developments. Ideally the analysis and reporting would be supervised (at least for the first 3 to 5 years) by an expert or review panel. The yearly reports on the position and developments of the shoreline can be directed to the Bago and Mon government bodies with a responsibility in the adaptation strategy.

5 DISCUSSION

5.1 Causes for the coastal erosion

The horizontal shoreline retreat along the Bago coast in the Gulf of Mottama has been more than 5 m/day or 1 km/year at some locations. Although extreme, this kind of erosion is part of the natural shoreline dynamics, showing periods of very rapid land growth as well as land retreat. The coastal erosion of the shorelines of Bago Region and Mon state result from the natural dynamics of the channels of the Sittaung estuary. The governing processes are the currents and sediment transport that result from the tides and -in the rainy season- the river floods.



The coarser bedload sediment (sand) is transported upstream in the estuary and results in the formation of sand bars in the so-called bed-load convergence zone. The meanders migrate as a result of the combined effect of currents that erode the channel banks (“bank pull”) and flow from the bars (“bar push”).

The very shallow nature of the tidal channels facilitates rapid channel migration. Although it remains unclear what causes the shallowness of the channels, it is likely to be caused by the presence of an erosion-resistant deposit in the subsurface (which can be studied with a drilling program).

Satellite image with an indication of the major processes governing coastal erosion by the migration of the channel in Area 2.

The direction of the migration of the channel determines the location of the erosion: migration to the west results in erosion of the Bago shoreline and erosion to the east results in erosion of the Mon shoreline. The direction of the migration and the erosion does change in periods of 10 to 15 years in the southern part of the estuary. The change in direction seems to repeat, but the frequency does not allow to identify a clear cycle with a fixed duration. In the northern part of the estuary the migration of the channel and the erosion of the shoreline has prolonged over a period of at least 30 years.

5.2 Forecasts & bandwidth

The changes in tidal-channel position and migration have been erratic and mechanisms that explain the differences are difficult to identify. The erosion of the shorelines is therefore unpredictable, especially over periods longer than a few years. For the prediction of the shoreline development in the next five years the observations have been extrapolated with the large-scale channel dynamics in mind. Over prolonged periods (20 to 50 years) a much larger area is prone to erosion by the migration of the channels. The entire coastal plain may in fact be subject to erosion at this time scale.

Area 1.
In the northern area the erosion of the western shore is expected to continue for the next five years, leading to a maximum coastal retreat of several hundreds of m. This erosion is not likely to occur along the entire shoreline, but the exact location of channel migration shifts and is hard to pinpoint.

Area 2.
Recent developments (since 2017) in the southern part of the estuary show the development of a new tidal channel in the center of the estuary, that seems to take over the role of the migrating channel on the western shore. Within one to a few years the erosion on the western shore is expected to stop. The amount of expected maximum erosion is 0 to 100m in the northern part of this area for the

next few years and gradually increase when moving to the south, where erosion may still reach a distance of 1 km. Erosion further to the south of Area 2 (south of the sand bar that is developing off the coast), of the eastern shore can be expected with migration of the central channel to the east. Further to the south there is no development of a central channel and the erosion of the western shore is expected to continue. The erosion in this part of the estuary may continue for some years at the current extreme rates of over 1 km/year.

The effects of accelerated sea-level rise will be limited for the Sittaung estuary and its shorelines. There is an abundance of sediment available in the system that allows for buildup of the coastal plain and estuary at rates up to at least 4 cm/year. The already extremely dynamic nature of the estuary and its shorelines will not change due to the effect of accelerated sea-level rise.

Climate change may result in an even more peaked river discharge during the rainy season. Although much of the flood waters will be accommodated in the coastal plain, the increase in peak discharge may results in additional channel migration in the upstream areas regions of the river, which could lead to a shift of the entire river belt to the west ultimately affecting a large inhabited area. Monitoring of the developments is therefore important to recognize such system-wide changes well in time.

5.3 Adaptation strategy: managed retreat

A number of structural measures and system interventions to combat coastal erosion have been examined and compared. Measures and interventions to effectively stop or reduce the erosion of the shoreline do need to tackle the migration of the channels. This can be achieved with ‘hard’ measures on the channel slope and bank, with ‘hard’ referring to rock, concrete or other solid materials. Alternatively, ‘soft’ solutions, meaning interventions with sand or mud may be used.

‘Hard’ protective measures that protect the full channel slope and bank, can take the form of a horizontal rock riprap apron (generally known as a ‘falling apron’). Such measures need to stretch over the entire length of shoreline (i.e. over lengths from 10 to 20 km) that need protection and the flow conditions do require considerable rock dimensions. A ‘soft’ intervention to reduce the migration of the tidal channel is for example the full blocking of the southern entrance to the channel with dredged sediments. Such an intervention will require the dredging and dumping of nearly 20 Mm^3 of sand and mud and would require a major engineering effort in this setting.

The costs of possibly effective structural measures and system interventions have been compared with their potential benefits, in terms of protected values and this yields the conclusion that the costs outweigh the benefits. Adaptive use of the land i.e. managed coastal retreat and increased adaptive capacity of the communities, is a viable alternative. This may be facilitated by the use of mobile infrastructure and accommodations (housing, schools, water tanks).

Monitoring of the actual development of the shorelines, tidal channel and critical points is a key element for any (adaptive) strategy for the Bago Region and Mon State, given the rapid and unpredictable changes that occur in the estuary. Interpretation of the publicly available satellite images in combination with observations in the field will provide up-to-date information that allows adequate management decisions. A yearly analysis by two designated specialists from the regions is suggested.

The following is recommended:
- Focus on a strategy of managed-coastal retreat for the Gulf of Mottama shorelines;
- Facilitate managed-coastal retreat with investments in reusable and transportable housing, schools and infrastructure;
- Monitor the tidal level with respect to a national datum; and
- Monitor the yearly developments of the shorelines and the tidal-channels and update the predicted coastal retreat, in order to inform the inhabitants on the time window for reallocation.
- To further the understanding of the system behavior, take core samples at a few locations (Appendix A) and determine the presence of erosion resistant materials in the deeper segments.

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COLOPHON

DEALING WITH COASTAL EROSION IN THE GULF OF MOTTAMA

CLIENT
HELVETAS Myanmar

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