2017

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Mars P. Tan
The University of Notre Dame Australia

Publication Details
Tan, M. P. (2017). Sedimentation dynamics of the Cagayan de Oro river catchment and the implications for its coastal marine environments [Doctor of Philosophy Science]. The University of Notre Dame Australia. https://researchonline.nd.edu.au/theses/165

Sedimentation Dynamics of the Cagayan de Oro River Catchment and the implications for its coastal marine environments

Mars Platino Tan, S.J.

School of Arts and Sciences,
University of Notre Dame Australia

Supervising Professors

Dr Rene Rollon (University of the Philipines)
Dr Tolentino Moya (University of the Philippines)
A/Prof Dylan Korczynskyj (University of Notre Dame Australia)

This thesis is submitted in fulfillment
of the requirements for the award of the degree
of Doctor of Philosophy in Environmental Science

November 2017

Declaration of Authorship

This thesis is the candidate's own work and contains no material which has been accepted for the award of any degree or diploma in any other institution.

To the best of the candidate's knowledge, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

08 July 2016

Candidate's Name Date

Acknowledgements

The completion of this thesis would not have been possible without the assistance of many generous and kind individuals and institutions both in the Philippines and in Western Australia. Unfortunately, it is impossible to remember all of them.

First and foremost, my sincere gratitude and appreciation to my academic supervisors, Dr Rene Rollon and Dr Tolentino Moya of the University of the Philippines, whose expertise in and passion for science research have guided me well through the complexities of my thesis until its completion; to Dr Dylan Korczynskyj of the University of Notre Dame Australia, whose professional mentorship from beginning to end has provided me with the key support from writing to logistics; to Dr Olive Cabrera of the University who assisted me in the Physical Oceanography part of my study; to Dr Erik Paling of the University of Western Australia, for his scientific critiques that no doubt have improved different aspects of my study; to Dr Michael O'Leary of Curtin University, who mentored me in the initial phase of my study; to Mr. Mark Sabines, of Xavier University (Philippines), who graciously tutored me on the intricacies of SWAT modeling; to Dr Caroline Jaraula of Curtin University, for her helpful inputs in my thesis proposal; and to Dr Augustine Doronila of the University of Melbourne, who helped me find my way to the University of Notre Dame Australia.

In the collection, analyses, and presentations of the massive amount of both field and secondary data, I am truly thankful to James Borcillo, my indefatigable research assistant and companion, who took on all kinds of odd jobs for the research work; to the present and former staff and volunteers of the McKeough Marine Center (XU), namely, Czarmayne Escoro, Marriane Macapilet, Ria Ramos, Janice Rivera, Julie Acero, Fra-and Quimpo, Jun Aranzo, Daniel Linog, Warwin Sabasaje, Friday Atilano, and Ariel Talavera; to the former Director of the Engineering Resource Center (XU), the ever reliable research colleague and friend, Engr. Dexter Lo, and his staff and volunteers, namely, Mr Jan Taat, Engr. Gerry Apor, Shaira Baang, Jeff Vallente, Meldy Comandante, and Rengie Bagares; to Dr Ester Raagas of the Kinaadman Research Center (XU), for the statistical work; and to Janna Batillo, Camille Bollozos, and Menche Lazarte, for their help in modeling works (SWAT & DELFT3D). For the facilities and equipment, I sincerely thank the Chairs/Directors of the McKeough Marine Center, the Biology Department, the Geo-Informatics System Center, and the Engineering Resource Center of Xavier University

I truly appreciate the enormous help and support of several people from the University of Notre Dame Australia: Dr Marc Fellman, Director of the Research Office; Ms Lorraine Mayhew, Administrative Assistant; and Dr Julia Alessandrini and Dr Kate Howell, former and present Higher Degree Research Education Coordinators, respectively. Several persons from the University have given me support in various ways: Ms. Jackie Stevens of the Notre Dame Library; Ms Victoria Li of the International Students Administration; Dr Sarah McGann, Dean of the School of Arts and Sciences and her academic colleagues, namely, Dr Angeline O'Neill and Prof Chris Wortham; Richard King of the Academic and Enabling

Support Office; and the staff of the University library. Also, my sincere gratitude to Prof. Peta Sanderson, Pro Vice-Chancelor Research and International, for her full support and encouragement.

Back in the Philippines, various local communities and government institutions have accommodated me to conduct on-site field work and have provided me with valuable secondary data: Barangays Macabalan and Bonbon; the Parish of Talakag; the communities of Miarayon, Nangka, Taguanao, and Tikalaan in Bukidnon; the Bureau of Soils and Water Management; the Cagayan de Oro City Planning and Development Office; the Cagayan de Oro River Basin Management Council; the Department of Environment and Natural Resources-River Basin Control Office; the Department of Public Works and Highways-Region 10; the Philippines Atmospheric, Geophysical and Astronomical Services Administration in Cagayan de Oro City and in Malaybalay City, the Macajalar Bay Development Alliance, and the Manila Observatory in the Ateneo de Manila University.

Several people have played key roles behind the scenes to enable me to do my writing and to complete the thesis, for which I most grateful: To Fr Roberto Yap, SJ, President of Xavier University, who approved my study leave and, in addition to the herculean task of running the University, generously "held the fort" for me as Acting Rector of the Jesuit Community in the Xavier University; to his predecessor, Fr Jose Ramon Villarin, SJ, President of the Ateneo de Manila University, who likewise served as the superior of the community, in my absence; to my Provincial Superiors, Fr Jose Cecilio Magadia who approved my studies abroad and to Fr Antonio Moreno, SJ, for his encouragement and his kind understanding to free me from all regular ministries and duties so I could steadily focus on my writing; to all my Jesuit brethren at Xavier University and the Loyola House of Studies for substituting for me in various tasks and for their prayers. In the editing of my thesis, I truly appreciate the help of my brother Jesuits, Fr. Louis Catalan, Fr Manuel Francisco, Fr Eric Genilo, Fr. Gabriel Gonzalez, Fr Robert Rivera, Fr Albert Alejo, and Fr Walter Ysaac. I also thank the staff of the Loyola School of Theology Library, where I spent my daily routine of thesis work for many months.

Writing the thesis has been made bearable because of my friendships with several individuals who, in their own ways, have provided me much help and inspiration: My ever generous host family in Perth, Dr Hector and Ms Aurora Divinagracia and their son, Gerry, who took me in as part of the family; my second Jesuit family in Nedlands, Fr Joseph Sobb, Fr John Prendiville, and Fr Hari Suparwito; the community of All Saints Catholic Chapel in Perth, particularly the late Fr Tiziano Bogoni; Theresa Pike and her family; Margaret de Ornelas and Frances Dennis; and Msgr. Michael Keating of the St Mary's Cathedral. In the Philippines, I benefited much from the invaluable assistance of my academic colleagues and friends, Dr Libby Abesamis, Dr Hilly Quiaoit, Ms Gertrude Garcia, Ms Elaine Villanuz, and Ms Elizabeth Enerio.

For the scholarship grants and funding support, I am indebted and truly grateful to the Government of Australia, the University of Notre Dame Australia, Xavier University, and the Philippine Province of the Society of Jesus.

Last but not the least in this long list, are the members of my own family, from whom I found loving inspiration and drew much encouragement throughout the long arduous yet fulfilling journey towards the completion of my PhD thesis: My father, Oscar (deceased) and my mother, Lucia (deceased); my sisters Corazon, Olivita, Brigide and Ma. Leizel; my brother Donderex; and my beautiful nieces, Dea Zelene and Deance Jaira.

Finally, I thank the Almighty God who has sustained me during my lowest moments, guided me through the crucial decisions I had to make, awakened in me confidence in myself and in the goodness of others, and kept me focused on the ultimate meaning of my study.

Ad Majorem Dei Gloriam

Abstract

Declines in coastal environment condition can often be attributed to land-based activities in the uplands. This may be the case in some parts of Macajalar Bay, where river plume is observed almost daily. This present study aims to demonstrate the erosion-sedimentation process along the Cagayan de Oro River Catchment to its river mouth, and its implication for the marine coastal habitats. Highlighted in the study are the various natural factors that have influenced the erosion-sedimentation process: its volume; direction; and effects on the coastal habitats.

In the uplands, to account for the influence of catchment spatial heterogeneity and local rainfall on run-off rates and sediment yield, the Soil Water Assessment Tool (SWAT) model was employed. The model predicted high (15 > 50 t/ha/yr) to very high sediment yields (>50 t/ha/yr) in a few sub-catchments and slight to moderate yields (0 > 15 t/ha/yr) in most sub-catchments. However, during heavy and prolonged rainfall events, a number of sub-catchments became highly prone to erosion, due to existing large cultivated lands and very steep slopes. On normal rainfall days, the model predicted continuous transport downstream of slight to moderate amounts of sediments which could have implications for coastal marine environments within the river mouth vicinity.

In the bay, the Delft3D model was employed to investigate the direction and location of total suspended sediment distribution. The model predicted coastal current circulation and sediment dispersal patterns in the months of April to May and December to be predominantly east and southeast. Based on the simulation results, most of the flowing suspended sediments were trapped at the river mouth (average discharge: 30-50 mg/L; extreme discharge: 1200-1600 mg/L), while some were dispersed east of the opening. The amount of dispersed sediments in inshore waters varied according to the river discharge conditions: low to average

discharge (~113.49 m3/s) amounted to minimally higher-than-normal total suspended solid (TSS) concentrations in ambient water (10-30 mg/L), while extremely high discharge (~1245,33 m3/s) resulted also in high-TSS concentrations (200-500 mg/L). Given that most sediment particles were predicted to be concentrated at the river mouth (e.g., with shallow depth water and mudflat presence), sedimentation may have influenced mangrove establishment and growth. Likewise, there may have been an association between river-sediment plume and the present ecological conditions of both corals and seagrasses.

To determine any relation between river sedimentation and marine coastal habitats, the existing distribution, composition and abundance of each coastal marine habitat were scrutinised using satellite images, historical maps, previous related studies and Chapter 3 results on river plume extents and concentrations. Analysis results revealed that river sedimentation reinforced by human intervention has contributed to land changes at the river mouth, either through accretion (~35.21 ha) or through erosion (~5.10 ha). Formation of new land forms has in turn contributed to mangrove colonisation, albeit slow, either through natural growth (~4.5 ha) or through human plantation (~2.0 ha). With regard to corals and seagrasses, their natural locations and distributions in Macajalar Bay have most likely been influenced by salinity and sediment concentration levels. As to their composition and abundance, massive corals dominate sites furthest from the river mouth but no clear association between seagrass abundance and river-borne sediment encroachment. At best, the results imply that sedimentation in the catchment does have implications for the distribution of the three major coastal habitats within the river's vicinity.

Based on the major findings of the study, specific rehabilitation and management measures were recommended to address erosion-sedimentation issues in the uplands, the coastal areas and the coastal marine habitats while taking into account existing government plans and projects. Four key management principles, namely, integration, sustainability, precautionary and adaptive (Boesch, 2006) were used as basis for the integration of the recommended management measures.

Limitations of the study in each chapter were recognised. In the catchment, the model simulated sediment data showed poor agreement with the observed data, and the validation results were weak. Thus, longer data collection period is recommended for future monitoring and modelling studies. In the sediment transport near the river mouth, there was disparity between model and measured suspended sediment concentration data. It is recommended for future studies that several collections of samples be done following different stages of river flow to approximate the value of model simulated data. As regards the coastal marine habitats, the study results can be strengthened by long-term information on the distribution, abundance and diversity of coral reefs and seagrass meadows within the river mouth vicinity.

Chapter 1: Introduction

Sedimentation dynamics of the
Cagayan de Oro River catchment and the
implications for adjacent marine coastal environments

1.1. From Catchment to Coastal Issues

1.1.1. Catchment Land Issues Affect Coastal and Marine Environments

The degradation of water catchments due to increased land-based activities (e.g., mining, deforestation, poor agricultural practices and urban development) has taken a toll on coastal environments and ocean resources globally (Gabric & Bell, 1993; Goldberg, 1995), Chia & Kirkman (2000) as cited in Sien CL 2001, GESAMP Report (2001) as cited in Gray et al., (2002). From 1997 to 2004, annual cover loss based on regression analysis of a subset of coral reefs (n= 476 reefs) in the Indo-Pacific Region was 72% (Bruno and Selig, 2007). In addition, 29% of known seagrass cover, since initial recording began in 1879, has been destroyed in different parts of the world (Waycott et al., 2009). In a recent satellite mapping of world mangrove distribution, 35% of mangrove forests are estimated to have been lost from 1980 to 2000 (Giri et al., 2011).

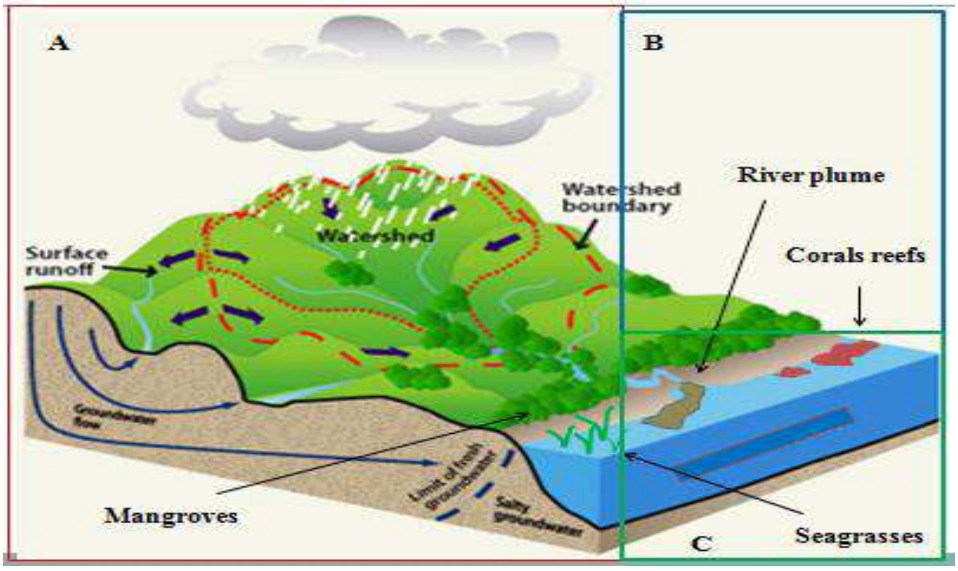


Figure 1.1: Ridge-river-reef (catchment-to-coast) continuum showing three landscape systems covered by the sediment transport route: A—catchment and river; B—coastal processes; C—coastal communities along coast and underwater. (Base illustration of Ridge to Reef from Google 2015)

The heavy impact on these coastal marine habitats is attributed to one of three major environmental problems—pollution, habitat degradation and exploitation of natural resources—or a combination of them. The catchment to coastal natural connectivity facilitates the transfer and eventual deposition of upland sediments and other materials in the coastal areas (see Figure 1.1). The pollution problem is a combination of all these coastal water pollutants that further endanger ecosystems and human populations living along the bay area (Islam & Tanaka, 2004; Camargo & Alonso, 2006).

Habitat degradation can be direct, as with the destruction of marine habitats through coral extraction, the conversion of mangrove forests into fishponds, the smothering of seagrass due to excessive sedimentation, and destructive fishing methods. Degradation can also occur indirectly, such as through the alteration of normal environmental conditions that adversely affect fish survival and coastal habitat growth (Baran, et al., 2001; Gabric & Bell, 1993; Ming et al., 1994; Talaue-McManus, 2000).

Excessive extraction of resources occurs in both catchment and coastal/bay areas. Examples in relation to catchment areas include mining, quarrying, logging and the over-harvesting of mangroves that results in increased soil erosion and land degradation (Lal, 1989; Billi & Rinaldi, 1997; Sidle et al., 2006).

1.1.2. Conditions of Coastal and Marine Environments Affect Human Population

Community experiences in both local and global contexts confirm that the lives and living conditions of coastal people are linked to their immediate natural environments (De Souza et al., 2003). Concomitantly, the productivity and quality of coastal and marine waters—particularly that of the upland environment—is connected directly to vegetation cover and the stability of river catchment/s (Catterall, 1993; McKergow et al., 2003). Well-managed coastal ecosystems provide valuable services and protective functions to the environment and human communities. In addition, coastal zones host the maritime industry, fisheries, agriculture and tourism vital to the economic development of cities or regions.

In the study area, coastal resources comprise a large part of the total financial income for government and local residents. For example, the Philippines fishing industry produced 2.54 million tonnes of fish from the aquaculture sector, 1.37 million tonnes from the municipal sector and 1.24 million tonnes from the commercial sector (Bureau of Food and Aquatic Resources [BFAR], 2010). In 2010, the country ranked fifth among the world's fish product producing countries (www.bfar.da.gov.ph/profile). In terms of value, the fishing industry has contributed P221 billion (US$5.13 billion) to the Philippines economy, with the aquaculture sector having the highest production of P83 billion (US$1.93 billion), followed by the municipal (P77.8 billion/US$1.81 billion) and commercial sectors (P60.46 billion/US$1.40 billion (www.bfar.da.gov.ph/profile).

In contrast, the increasing coastal population exerts the compounded effects of destructive activities in both catchment and coastal sites; consequently, this reduces the productivity of natural ecosystems upon which they depend (Talaue-McManus, 2000; Bennett et al., 2001). The most affected are artisan fisher-folk and coastal communities, due to the loss of livelihood, food shortages, poverty and poor health.

1.1.3. Addressing the Catchment to Coastal Ecological Issues

The ridge-river-reef model approach will be used in this study to investigate erosion-sedimentation along the catchment to coastal continuum. Natural factors that influence the sedimentation process from catchment to coast will be examined.

1.2. Overview of the Ridge-River-Reef Model

1.2.1. Ridge-to-Reef Management Model: A New Approach to Address Catchment and Coastal Environmental Issues

The continuing increase in coastal area populations and coastal residents' heavy dependence on marine resources pose a serious challenge to finding more effective marine ecosystem management approaches (Creel, 2003; Duda & Sherman, 2002). Conservation efforts confined to coastal and marine environments have proven insufficient (Ruddle et al., 1992;Berkes et al., 2000; Richmond et al., 2007). Despite bay-wide rehabilitation programs operating in several places, upland terrestrial run-off continues to threaten the bay. In fact, increased unregulated land-based activities in catchments have coincided with the decline of marine habitats and resources in adjacent bays. Environmentalists and natural resource managers therefore realise they must shift from a 'piece-meal' to a more integrated catchment and coastal/bay approach (Clarke & Jupiter, 2010).

The ridge-river-reef approach is an ecosystem-based management method that aims for effective coordination regarding the use and management of land and water resources from upland sources to the sea. It has been adapted and practised by several international environmental groups, such as the Global Forest Coalition, the International Union of Conservation of Nature (IUCN), Nature Conservancy, the United Nations Environment Program (UNEP), the United States Agency for International Development (USAID), the World Association of Food Chains (WAFC) and the Worldfish Center, to assist developing countries improve their catchment, coastal and marine resources management practices. The approach links catchment and bays with water as the connective element, and emphasises the support role of catchments to protect and enrich river and coastal ecosystems.

In the Philippines, the ridge-river-reef connectivity concept is relatively new. In many local areas, natural resource management practices such as marine protected areas (MPA), community-based coastal resource management (CBCRM) and indigenous people-conserved areas have been established for about 40 years (Pomeroy, 1995; Lowry, et al., 2005; Alcala & Russ, 2006). Only in recent years have leaders and local communities acknowledged the ridge-river-reef model is a more effective management model. This acknowledgement is based on their common experiences addressing environmental and social issues in both coastal and upland areas (Canoy and Quaioit, 2011). The ridge-river-reef model overarches the entire catchment and coastal/ocean continuum, assessing interconnected issues and harmonising management practices so they become more effective and sustainable. The concept has been validated locally as an effective management approach when two or more environmental components are needed to address common needs. In each natural component (or ecosystem), though, the stakeholders should maintain and continue to upgrade their own effective conservation practices.

Similar to the situation in many developing countries, ridge-river-reef ecosystem-based management in the Philippines has been implemented in the local setting by local government units and offices with strong support from international organisations. These programs include:

- From Ridge to Reef: An Ecosystem-Based Approach to Biodiversity Conservation and Development in the Philippines (2011 to 2013), with Mt Malindang, located in Misamis Occidental (Philippines), as the site on which the program is focused (http://worldagroforestry.org/regions/southeast_asia/philippines/).
- Sustainable Ridge-to-Reef Approach in Surigao del Norte, under the activity cluster of the Conflict Activity Resource and Asset Management Program (COSERAM), local government units and private groups (http://coseram.caraga.dilg.gov.ph).

- Ridge-to-Reef Ecosystem Management Approach for Sustainable Development, with the Bukidnon watersheds and the Macajalar Bay as the focus sites (Quiaoit, 2011).

Local people's collective learning from (and sharing in) the ridge-river-reef approach challenges all advocates and stakeholders to revisit previous strategies and commitments to address problems in accordance with nature's complex yet integrated systems and processes (Canoy and Quaioit, 2011).

1.2.2. Challenges to the Ridge-River-Reef Approach

While the ridge-river-reef ecosystem-based management approach offers an integrated solution to both catchment and coastal environmental problems, it has its own challenges. Due to the huge geographical area the model encompasses, and the complexity of ecosystem relationships, local communities are often better able to handle problems with assistance from external groups who provide technical expertise, training capabilities, materials and equipment, and financial support. In many cases, local communities do not have sufficient resources and/or capabilities to handle problems, especially when the environmental issues are already significant.

It is no wonder that ridge-river-reef projects supported by international conservation groups are usually found in developing countries. Nonetheless, a growing awareness and increasing initiatives within local governments and communities regarding the application of this approach are evident in several localities, particularly in the Philippines (Canoy and Quiaoit, 2011). Another challenge to the ridge-river-reef approach is the lack of community understanding regarding cause and effect processes in natural systems. The underlying science is often not well understood or appreciated by many, including resource managers. In addition, the interaction processes among systems are complex and the environmental factors involved often unpredictable. For example, the available scientific information is frequently inadequate to explain the causes of certain environmental anomalies observed within a locality; each local natural setting may be unique and have dynamics that differ from other ecosystems.

Thus, the science of the ridge-river-reef model needs further dissemination to educate people who are involved in it. For example, Cagayan de Oro City has experienced four extreme weather conditions and massive flooding within the same number of years. Despite this, many residents still do not fully understand the direct connection between floods and catchment conditions. Upland communities do not attribute bay sedimentation to increasing catchment land-based activities due to the long distance (~100 km) to the bay. Along the coast of Macajalar Bay, residents witness sediment plumes flowing out of the river mouth almost daily, yet they discard the idea of bay pollution, reasoning that the bay's large size and natural flushing capability are enough to reduce the sediments' harmful effects on marine resources.

1.2.3. The Science of the Ridge-River-Reef Model

Although the ridge-river-reef model has become popular as a resource management model, the science behind it (an essential aspect of the approach) is less well known. Understanding the science is crucial, as it presents a complete picture of all the interrelationships among various factors in each landscape system. Established science-based models and formulae are very useful for simulating actual processes and interactions, and producing simulated results at an acceptable accuracy level. Models can also create scenarios and predict potential problems, forming the basis for appropriate response measures on the ground.

An adequately represented ridge-river-reef model can provide information that will guide catchment and coastal resource managers towards choosing the best measures to address a particular environmental problem. Such knowledge can also support various resource management goals, including programs relating to biological conservation, catchment and reef health, reliable water supplies, economic and social sustainability and disaster-risk reduction, run by local government and communities.

At present, only a few research programs address environmental problems within an integrated and interconnected ridge-river-reef context. Three major natural components are considered as one integrated unit: ridges or uplands, the river or transport path and the reef or bay, which includes coastal marine habitats (see Figure 1.2).

1.2.3.1. Ridges or sub-catchment areas.

Studies on ridges mainly involve two major environmental factors: climate patterns or weather conditions and the physical characteristics of the catchment/sub-catchment—specifically, the relationship between rain and water run-off processes, and that between rain and soil erosion within a catchment. Variations in water run-off, soil erosion and transport rates are influenced by changes in rainfall patterns (Römkens et al., 2002; Shamsuddin et al., 2014) and catchment characteristics (Niehoff et al, 2002; Bartley et al., 2006; Hartemink, 2006). Several models have been developed to simulate rainfall run-off processes (Beven &Kirkby, 1979; Todini,1996) and estimate soil loss in the catchment, including:

- Wischmeier and Smith’s (1978) universal soil loss equation (USLE)
- Laflen et al.’s (1997) water erosion prediction project (WEPP)
- Renard et al.’s (1997) revised USLE (RUSLE)
- Neitsch et al.’s (2011) soil and water assessment tool (SWAT).

1.2.3.2. The main river channel and its tributaries.

Research has examined the dual roles performed by rivers in the ridge-river-reef connectivity in relation to transport paths. First, rivers are subject to the effects of catchment features and processes (Allan et al., 1997; Ibisate et al., 2011); second, rivers influence sediment plume behaviour in the bay (Milliman & Syvitski, 1992; Ma, 2009). Regarding the first role, the catchment's topographical characteristics, vegetation cover, soil conditions and rainfall intensity influence the responses of the river's dynamics (e.g., total discharge, water level, river velocity and suspended sediment concentration). As for the second role, the river's characteristics—such as a channel's topography, morphology, water depth, total discharge and sediment load—affect the river plume's initial profile and direction in the bay.

1.2.3.3. River mouth and coastal waters.

Several previous studies have examined coastal plume concentration pathways and surface-water current motion patterns. Appropriate methodologies in various studies showed specific influence on the river flow movement and direction by each bay forcing factor.

River flow behaviours near the river mouth and offshore have been studied in the laboratory (John, 1964; Horner-Devine et al., 2006) and through numerical modelling (Chao & Boicourt, 1986; Kourafalou et al., 1996).

To understand plume characteristics and predict the flow direction, field and laboratory analyses have been conducted to determine the key role of each factor: riverine force (Milliman & Syvitski, 1992; Kourafalou & Androulidakis, 2013), wind force (Geyer et al., 2000; Lentz & Largier, 2006; Choi & Wilkin, 2007), circulation current (Jay & Smith, 1990), tidal action (Petrenko et al.,2000), waves (Wright et al, 2001) and sea/ocean topography (Liu et al., 2002; Gille et al., 2004). Models developed to determine current direction and sediment transport movement in the bay (Allard etal., 2008) have enumerated several transition models that include the Delft3D in their respective features and enhancements to address specific needs and requirements.

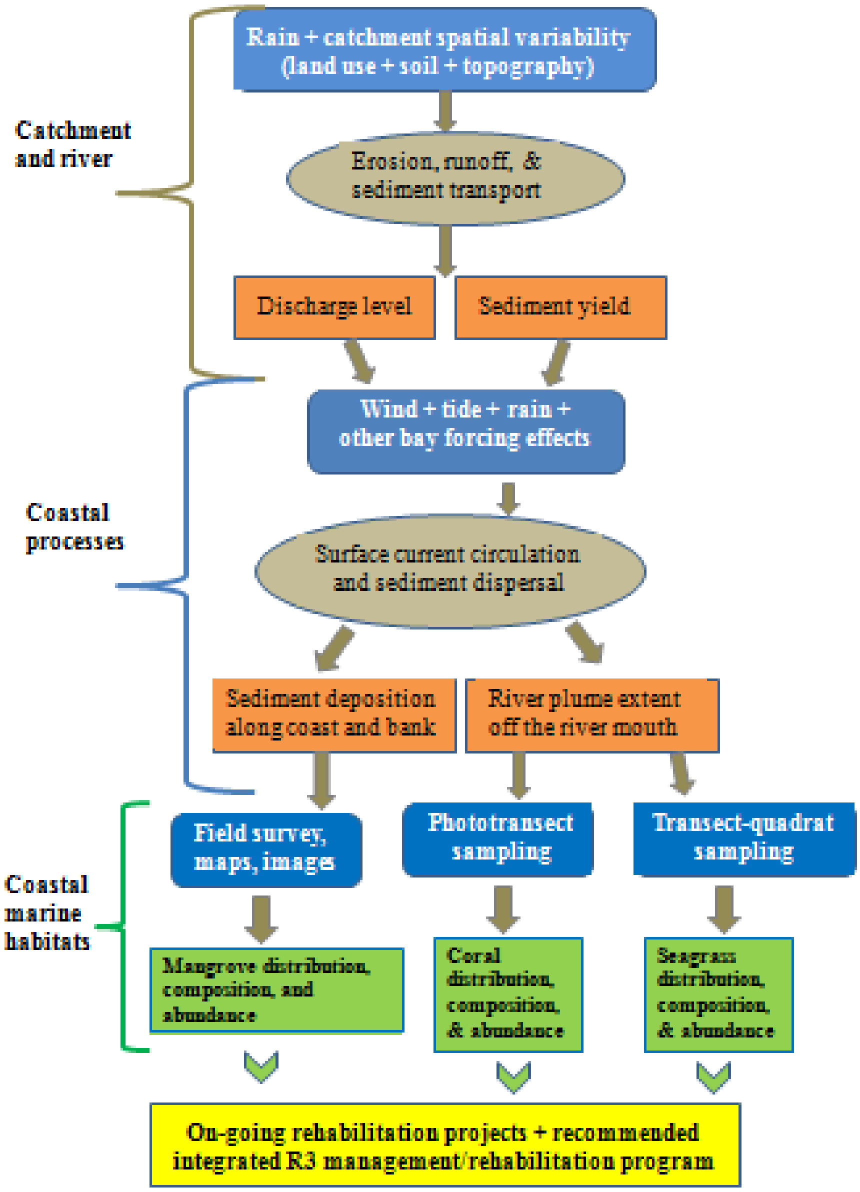


Figure 1.2: A schematic diagram of the present ridge-river-reef study showing sediment transport along the three main landscape systems: 1) catchment and river; 2) inshore waters; and 3) coastal marine habitats found along the coast and underwater. Independent variables and methodology used (blue colour); resulting processes (gray colour); effects on sediments and water (orange colour); coastal marine habitats' profiles (green colour); recommended R3 management program (yellow colour).

1.2.3.4. Major coastal marine habitats.

Many studies have examined the effect of organic and inorganic sedimentation on coastal ecosystems such as corals, seagrasses and mangroves through physico-chemical and biological variables, including turbidity, salinity and temperature. Similarly, several studies on corals (Rogers, 1990; Vermaatl, 1999; Fabricius, 2005) have shown various adverse effects of sediments on corals' reproduction, growth and survival including the reefs' structure and function. Further, studies in seagrasses (Fortes, 1988; Duarte et al., 1997; Erftemeijer & Lewis, 2006) have also demonstrated different growth responses of seagrasses to sedimentation effect and other stresses. The relationship between mangroves and sediment deposition has also been examined (Duke et al., 1997; Duke & Wolanski, 2001; Thampanya et al., 2002).

1.3. Macajalar Bay and the Cagayan de Oro River catchment

1.3.1. Sedimentation at the Cagayan de Oro River Mouth and Macajalar Bay

Sedimentation is a common problem in many coastal and marine environments, both locally and globally (Syvitski etal., 2005). Sedimentation's harmful effects on the coastal ecosystems should not be understated (Thrush et al., 2004), and its impacts on the economy and lives of human coastal populations cannot be overlooked (Newcombe & Jensen, 1996). Due to widespread and constant sediment influx, coastal managers and local populations are often left with no effective recourse to address the sedimentation problem.

Sedimentation in Macajalar Bay has been occurring for many years, as this area is the natural sink of the Cagayan de Oro River catchment (see Figure 1.3). However, in recent years, sedimentation is believed to have worsened due to the catchment activities of both the increasing upland and urban populations, and the frequency of extreme rainfall events. Previous studies have also pointed to a decline in the numbers of fish caught in the bay and to the degradation of corals and seagrass communities (Atrigenio et al., 1998; Quiaoit et al., 2008).

1.3.1.1. Mangroves, corals and seagrasses at the river mouth and its vicinity.

A few seagrass and coral areas thrive off the Cagayan de Oro River mouth, despite their proximity to the river mouth and its sediment plumes. While local residents claim that both coastal habitats existed before their arrival, the present issue is whether the extent of these habitats has been affected by increased sediments from the upland regions. Regarding the mangroves, the large remaining forest in Bonbon is an integral part of the river mouth environment. It has undergone changes over time. River sedimentation may have influenced riverbank and coastal morphological changes, as well as mangrove distribution.

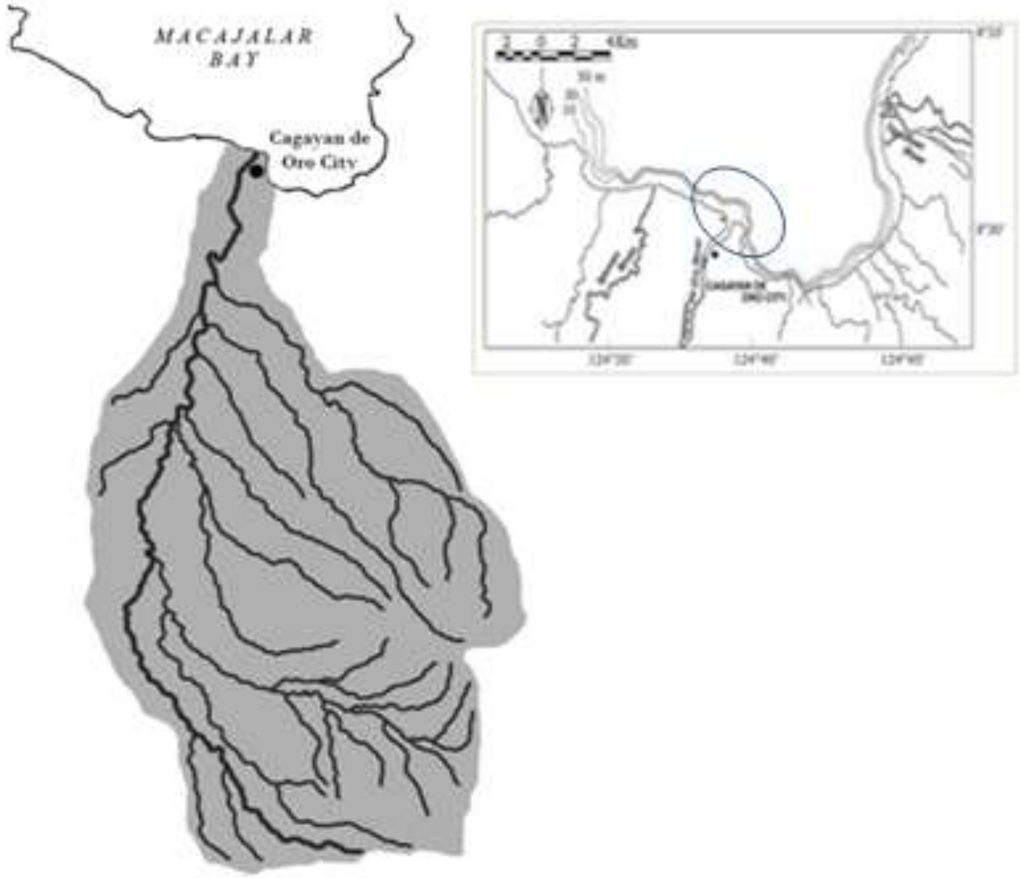


Figure 1.3: DENR (Department of Environment and Natural Resources)-delineated Cagayan de Oro River catchment with the Cagayan de Oro River draining into Macajalar Bay. Located at the river mouth (encircled) are three coastal marine habitats (mangroves, corals and seagrasses)

1.3.1.2. The river mouth.

Observations (of the author) suggest that the river plume, which normally affects the river mouth, extends further eastward and westward from the coast on different days. Thus, the plume’s structure and concentration vary from time to time. It also changes in its extent and direction in relation to the bay’s forcing variables. Due to the shallow channel and morphological changes along banks and adjacent coasts, heavy deposition occurs at the river mouth. In fact, a large mudflat lies on the west side of the river mouth. Dredging has been a daily activity at the mouth area during sampling period. Dredged materials are stockpiled on the Bonbon coast for different purposes, including construction and land filling. Mangroves and other vegetation grow on the west side (Bonbon) of the mouth (one and a half km back upstream), while built-up and residential areas exist on the east side (Macabalan).

1.3.1.3. The Cagayan de Oro River.

The Cagayan de Oro River plays an important role in transporting sediments and other constituents from the uplands to the lowest part of the catchment (see Figure 1.3). It has four major tributaries that drain the eastern side, where the headwaters are located, and several smaller rivers and streams on both sides of the catchment. From the headwaters to the bay, the river traverses rugged terrain upland and cuts across a densely populated city before draining into Macajalar Bay. Its relatively deep upstream channel (1 to 5 m) allows it to carry large volumes of discharge after rainfall. Downstream near the river mouth, the channel's gentler slope and shallower depth (0.5 to 3 m) weaken flow velocity.

1.3.1.4. Ridges and sub-catchment areas.

The relationship between rain and run-off is influenced by a site's spatial variation over time, as with the Cagayan de Oro River catchment, which has experienced a rapid increase in the human population, along with an expansion of land-based activities, particularly large-scale land cultivation, mining activities, timber poaching, quarrying and logging (Ecosystem Alliance, 2015). The area has also experienced frequent extreme rain events, such as the three recent typhoons namely, Washi (Dec 16, 2011), Bopha (Dec 12, 2012) and Haiyan (Nov 8, 2013), that resulted in massive flooding in the city and nearby towns. Rehabilitation of the Cagayan de Oro catchment is imperative (Paragas et al., 1997), but first it requires identification and prioritisation of the sub-catchments potentially most vulnerable to erosion.

1.3.2. Addressing the Severe Erosion-Sedimentation Problem

Addressing sedimentation near the Cagayan de Oro River mouth poses major challenges due to the lack of baseline data and the complex interrelationships among causal factors. First, to quantify the amount of sediment loss in the catchment, various environmental variables such as rainfall amount, catchment slope, land cover/use and soil conditions are needed as prescribed inputs for analysis. Second, the locations of sediment plume dispersed in the bay are not easily determined, as the forcing factors (river discharge, wind regime, tidal action and sea floor bathymetry) affect the flow simultaneously. To predict sediment dispersal patterns and impact locations, these variables should be available in the analysis as model inputs. Third, the influence of river-derived sediment plumes on the coastal environment and its resources should be based on empirical data and results. As no direct correlation exists in studies that have examined sedimentation levels and the marine habitat's ecological condition, the available data, such as maps, images and actual observations are at best adequate for suggesting associations or implications.

The ridge-river-reef ecosystem-based model is thus an apt framework to demonstrate the interplay among factors within each landscape system, particularly their effects on the sedimentation process. Due to the number of factors that simultaneously influence the sedimentation process, appropriate modelling tools are required for analysis. In the catchment area, the effects of various factors on erosion and sediment transport have been examined using the SWAT model (Arnold & Allen, 1996). In the bay, the forcing factors that influence river plume flow patterns have been analysed using the Delft3D model (http://oss.deltares.nl/web/delft3d).

1.3.3. The Study's Objectives

The current study aims to demonstrate the erosion-sedimentation process, focusing particularly on the various factors affecting the erosion-run-off process in the catchment and the sediment load transport in the bay, and its implications for the river mouth-coastal environment. Specifically, the study seeks to examine the following:

(1) Upper catchment—to determine the effect of a catchment's physical features, its land-based activities and management practices, and its local rainfall seasonality on soil erosion and run-off using the SWAT model (see Chapter 2).

(2) River—to quantify the volume of river discharge and suspended sediment concentration in the channel in relation to rain input (see Chapter 2).

(3) River downstream and coast—to locate the sites where suspended sediment concentration is highest and most persistent using the Delft3D model (see Chapter 3).

(4) To assess the distribution, composition and abundance of existing coral, seagrass and mangrove communities from direct sampling and historical maps in relation to the sedimentation in the Cagayan de Oro River (see Chapter 4).

Recommendations will also be made to the local government, communities and other stakeholders regarding management and rehabilitation measures for the entire continuum, based on the research results and the four key management principles. These principles are integration, sustainability, precautionary and adaptive approaches.

1.3.4. The Study's Scope and Limitations

Sediment dynamics in the catchment begin with soil erosion and its overland transport. Accordingly, an analysis was conducted concerning the interactive effects of erosional and run-off factors on the sediments. The sediment yield of each sub-catchment is presented to highlight erosion-prone sites and to confirm the upland sources of downstream sediments. No examination was undertaken of sediment dynamics within the river system. Instead, this study focuses on an important sedimentation issues within the river mouth and its coastal marine environments. These issues concern the implications of sedimentation dynamics for the coastal marine environments, and in particular the three existing habitats of mangroves, corals and seagrasses. In the study, the approach to sedimentation dynamics mainly focuses on the suspended sediment concentration in river and coastal waters, and also on sediment load transport and direction within the study sites.

Due to very broad coverage of the study sites, time constraints, inadequate secondary data and limited human and financial resources, some of this study's specific limitations are identified in each chapter.

1.3.5. The Study's Significance

This study contributes to the existing body of knowledge regarding the factors and/or conditions that influence sedimentation processes along the continuum from catchment to coast. It is the first to be conducted in the Cagayan de Oro River catchment area and the Macajalar Bay. Therefore, it may serve not only as a baseline study for succeeding research in the same catchment area, but also as an example to be followed for similar Philippine environments or ecosystems.

The study's results and findings will also further strengthen the Cagayan de Oro River catchment and Macajalar Bay's present management policies and practices. The data obtained from this study can also address specific needs. For example, sub-catchments identified as 'erosion hotspots', or sites highly vulnerable to erosion can be recommended as priority sites for further assessment and areas for applying more effective conservation and rehabilitation measures. Given the limited time and resources available, this is a very useful strategy if the entire catchment area is to be rehabilitated. Further, understanding the factors and conditions that contribute to sedimentation is essential to formulate effective mitigating measures. Finally, data concerning the ecological profiles of three major coastal habitats in relation to upland-derived sediments and other stressors will comprise an important input for integrated coastal management intervention within the ridge-river-reef continuum.

1.3.6. The Study's Overall Framework and an Overview of Each Chapter

This study focuses on the sedimentation process: the generation, downward transport, and concentration/deposition of terrigenous materials from sub-catchments down to the river channel; then at the river-coastal area where mangroves are found; and finally the underwater habitats of coral and seagrass communities (see Figure 1.4). The study sites include:

1) The Cagayan de Oro upper catchment where rainfall events were monitored.
2) The Cagayan de Oro River main channel where measurements of total river discharge and suspended sediment concentration (SSC) were conducted; and
3) The Cagayan de Oro River mouth and its vicinity where river-borne total suspended sediment concentration (TSS) data were collected, and where the distribution, composition and abundance of existing coral, seagrass and mangrove communities were assessed in relation to the presence and potential influence of sediments from the Cagayan de Oro River catchment.

Chapter 1 provides a general introduction of the thesis. It describes catchment and coastal connectivity as an environmental issue affecting human communities globally. In particular, it focuses on local issues in the Philippines, with the Cagayan de Oro River catchment area and its coastal marine environment within Macajalar Bay. The chapter introduces the ridge-river-reef approach as an appropriate framework for research and for applying measures to address coastal area sedimentation problems caused by land-based activities in the uplands. It also reviews the previous research on each major ridge-river-reef model component.

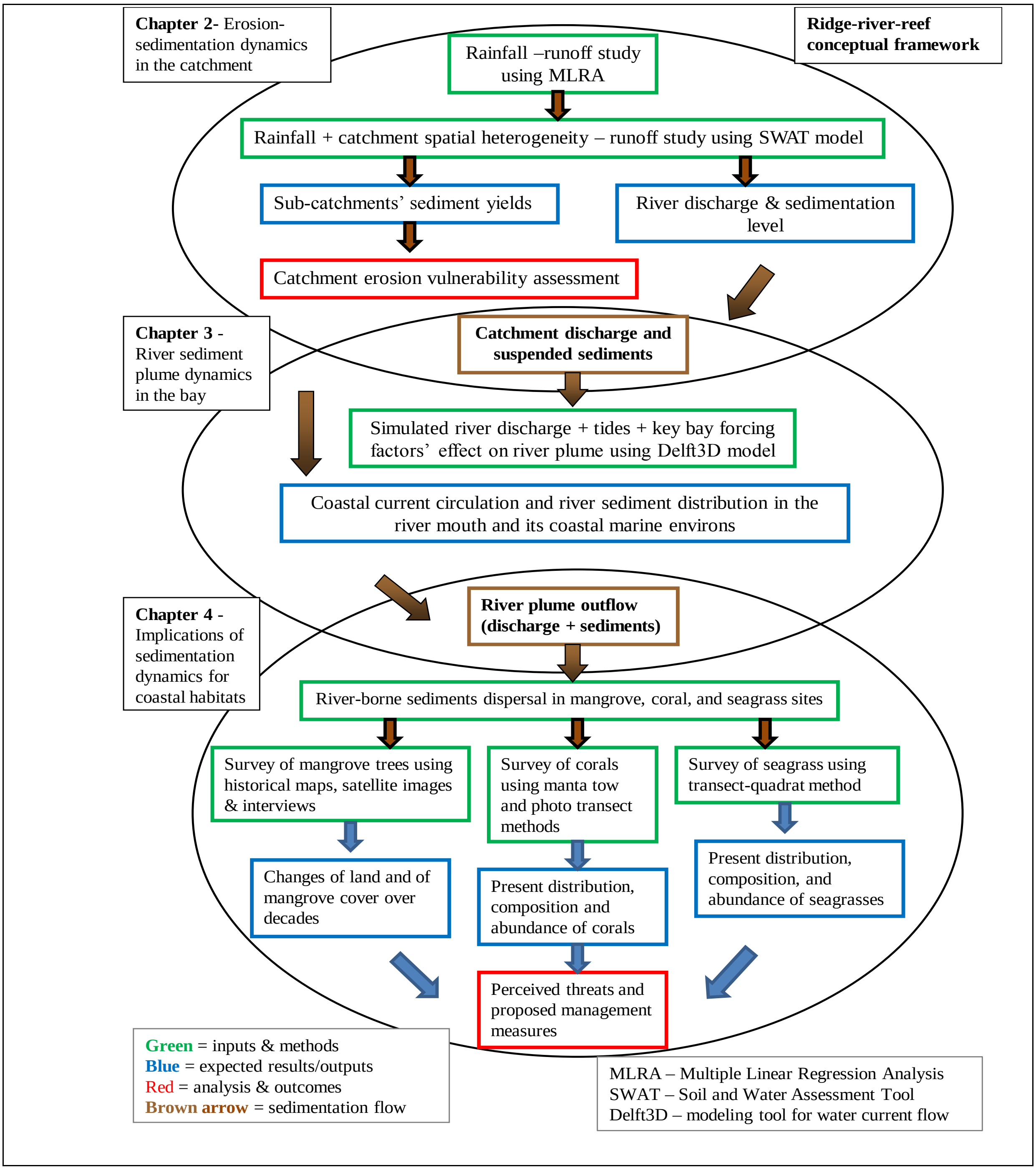


Figure 1.4: A conceptual framework of the present study showing the flow and connectivity of the three main chapters through sedimentation dynamics. Each chapter contains the inputs, methods, expected results/outputs, analyses, outcomes and proposed management program. The overlapping sections connect the chapters.

Chapter 2 begins with the erosion process that occurs in the uplands. It focuses on the influence of the Cagayan de Oro River catchment's spatial heterogeneity, management practices and local rainfall seasonality on soil loss and river discharge. The chapter first examines the rainfall variation in selected monitored sub-catchments and uses multiple linear regression analysis (MLRA) to correlate rainfall data with the corresponding river measurements taken during a ten-month sampling period. Following this, the chapter introduces SWAT as a modelling tool to examine the role of specific sub-catchment physical features (e.g., topography and soil), land management practices (e.g., land use and land cover) and rainfall factors affecting run-off and sediment flow. Statistical measurements such as the Nash and Sutcliffe efficiency (NSE) (Nash & Sutcliffe, 1970) and the PBIAS(%) models (Gupta et al.,1999) evaluate the model's performance. Chapter 2 highlights the identified 'erosion hotspots' or priority sites in the catchment requiring urgent government and local community rehabilitation programs.

Chapter 3 describes the behaviour of upland-derived sediments driven by various forcing factors and conditions as they reach the river and coastal waters. The first phase of the study describes the TSS and salinity concentrations of both Macabalan seagrass and Bonbon coral sampling sites, based on measurements collected once a month for eight months. The study's second phase employs the Delft3D model to simulate the extent of river sediment plume flow and the bay's coastal current circulation patterns. It also identifies the key factors that influence the dispersal and fate of river sediments at the river mouth and offshore. Finally, it presents normal- and worst-case weather scenarios affecting river discharge and the sedimentation implications for seagrasses, corals and the adjacent human communities.

Chapter 4 examines the relationship between river-borne sediments and the condition of each of the three coastal habitats. Each habitat's ecological profile is described in terms of its geographical distribution, composition and abundance. The chapter compares historical maps and satellite images of the river mouth showing mangrove cover to ascertain physical changes over time resulting from sedimentation. It also examines satellite plume images, simulated maps and observed TSS and salinity results to determine the extent of river plume encroachment on seagrass and coral communities. Ecological profiles of coastal habitats are assessed and then examined in relation to sedimentation using the related literature as a reference. Finally, the chapter presents future scenarios for both coral and seagrass communities, based on the threat of continuing sedimentation from the uplands.

Chapter 5 details the key management principles, as well as specific management and rehabilitation measures for the entire ridge-river-reef continuum, based on the study's major findings. It identifies the key factors that influence ridge-river-reef sedimentation, while highlighting the connectivity of the erosion-to-transportation process with the concentration or deposition of terrigenous materials at the river mouth and offshore. The chapter borrows four key management principles (integration, sustainability, precautionary and adaptive) from Boesch (2006) as a basis for integrating the recommended management and rehabilitation measures. As on-going management plans and activities already exist, it is hoped that the actions recommended here will both reinforce and bridge certain gaps in the existing plans and strategies of local government and other groups.

Chapter 2

Key catchment factors affecting the erosion-sedimentation dynamics of the Cagayan de Oro River catchment

2.1. Introduction

2.1.1. Catchment Erosion and Sedimentation as Environmental Issues

Soil erosion, sediment transport and sediment deposition are typical hydrological processes in any river catchment and are governed by a range of factors and their interaction. The main factors of catchment physical features are described well in the USLE (Wischmeier & Smith, 1978): catchment elevation range, slope, soil condition, land use/cover and management practices, and conservation efforts. Moreover, rainfall variables, which include amount, intensity, frequency and spatial distribution also influence erosion and its subsequent run-off rate (Nearing et al., 2005). Rainfall's soil erosion capacity(or 'erosivity') (Renard et al., 1997) changes according to the amount and intensity of rain. Therefore, rainfall can be a quite significant factor in areas that experience typhoons (Smithers et al., 2001; Ulbrich et al., 2003). Rain erosivity is higher if rainfall is more intense, and even more so when it is prolonged, resulting in higher soil loss (Dabral et al., 2008; I. a. A.-T. Pal, 2008).

Further, these natural factors and conditions may pose serious environmental problems when aggravated by human activities (Sadori et al., 2004; Buytaert et al., 2006). For example, erosion and sedimentation due to increased land-based activities in upland areas have caused coastal environment and ocean resource degradation across the world (Hedges & Keil, 1995; Dagg et al., 2004; Daoji & Daler, 2004;; Thrush et al., 2004). Zhide & Yuling (2010) noted a similar effect from sediments in low-lying area rivers, causing flooding in several major rivers globally. Local climate change that results in drought or heavy rains worsens the impact of run-off on human communities, initiating acute problems: food shortages, water-borne diseases and irreversible ecosystem destruction (GESAMP, 2001).

2.1.2. The State of Catchment Areas in the Philippines

Catchment areas in the Philippines are considered to be in a critical condition: 2.6 million hectares are threatened due to destructive land-based activities such as deforestation (Paragas et al., 1999). Northern Mindanao (where the Cagayan de Oro River catchment is located) has suffered a similar fate due to the improper use of upland areas and also because of the catchment's high slopes (>18%). Erosion is a grave threat to both the catchment area and lowlands during strong and prolonged rains. Accelerated upland erosion and subsequent sedimentation can increase the risk of disastrous river flooding (Macklin & Lewin, 2003), extensive river water pollution (Verstraeten et al., 2002; Fu et al., 2003), and severe physical land degradation (Lal, 1990; Southgate, 1990; Taddese, 2001).

In the Cagayan de Oro River catchment, these existing risks have been heightened by increased upland land-based activities with known adverse impacts on the catchment and its river system. Logging, mining, quarrying and vast agricultural plantations could result in increased erosion and sediment deposition in the river (Bons, 1990; Douglas et al., 1992; Brown et al., 1998; Chukwu, 2008;). Around 61% of the catchment is cultivated for annual and perennial crops (The Ecosystem Alliance, 2015). Agricultural land practices have led to the deforestation of sizable catchment areas. Moreover, multi-national corporations have expanded their large mono-crop plantations (e.g., pineapple, bananas and corn). Mining and quarrying are also present and active in the catchment area. Moreover, local communities are growing in number and many have settled along the riverbanks (DENR—River Basin Control Office, n.d.). Even in the absence of typhoons, moderate rains can result in accumulated impacts on the river and bay, albeit gradually (Moss & Green, 1983; Renard et al., 1991). River sediments are transported through the channel to the river mouth, where final sediment deposition occurs (Marcus & Kearney, 1991). Sediments that persist in the bay form a plume cover with detrimental effects on marine ecosystems and organisms (Newcombe & Jensen, 1996; Fabricius, 2005; Orth et al., 2006). However, some sediments are too heavy to reach the river opening and so become part of the river bottom topography (Dietrich & Smith, 1984). Over time, sediment deposits accumulate on the bottom, possibly changing its topography and creating new flow paths (Church, 2006). These shallow parts of the channel increase the risk of riverbank overflow, and the subsequent flooding of adjacent communities (G. E. Williams, 1971; Macklin & Lewin, 2003). The Cagayan de Oro River catchment has experienced extreme high rainfall events in recent years, including 2009, 2011, 2012 (Faustino-Eslava et al., 2011; Rasquinho et al, 2013), 2013 (typhoon *Yolanda* with the international name *Haiyan*), and 2014 (typhoon *Seniang* with the international name *Jangmi*). All abnormal weather conditions occurred in the dry months of November, December and January. The two worst events occurred in 2011 with typhoon *Sendong ((*international name *Washi*) and 2012 with typhoon *Pablo* (international name *Bopha*). These storms brought heavy rains and caused massive flooding in Cagayan de Oro City and its surrounds. The physical features of the sub-catchment have a significant effect on the rate of surface-water run-off and the movement of associated sediments (Poff et al., 1997; Allan, 2004; Soulsby et al., 2006). Consequently, thickly forested sub-catchment areas provide high surface-water flow regulation. Where little vegetation exists, a site becomes more prone to erosion, which is exacerbated by heavy rains (Johansen et al., 2001; Twine et al., 2004).

A well-managed and protected river catchment supplies lowlands adequately with water for various uses. If the catchment itself is stable and productive, water-related disasters become less of a threat to communities, even during heavy rains in the uplands. In any disaster management planning, it is always wise to devote more resources and energy for disaster preparedness and mitigation measures before an event rather than for relief and rehabilitation work after an event (Carter, 2008).

2.1.3. Objectives and Significance of the Research Study Described in this Chapter

This study focuses on the interactive effects of erosion and sedimentation by rainfall intensity, with the physical attributes and land management practices in the Cagayan de Oro River catchment. Both the physical attributes and land use/land cover in the catchment are considered important factors that influence rainfall run-off processes (Soulsby et al., 2006); these processes can be accelerated by human activities (Sadori et al., 2004; Buytaert et al., 2006) and by extreme weather conditions (Leigh et al., 2013). Specifically, this study aims to determine the influence of seasonal rainfall and the catchment's physical features on discharge volumes and suspended sediment loads in the Cagayan de Oro River. It will do this through using the SWAT model (Neitsch et al., 2011). Through the study's results, potential sources of high-sediment yield will be identified and labelled as 'erosion hotspots' for immediate rehabilitation.

Moreover, this study hopes to contribute information and knowledge to disaster prevention programs, focusing upon a balanced and sustained river catchment.

2.1.4. Using the SWAT Modelling Tool to Attain the Objectives

This study uses SWAT as a river-catchment scale model. This model was deliberately chosen as it can predict the effects of land and water features and of management practices on water and sediments in large complex catchments with different soils, land use and management conditions over long periods (Nietsch et al., 2005). The SWAT model has been used extensively in several countries to investigate the effects of rainfall and land management practices on catchment run-off and sediment yield (Santhi et al. 2001b; Jayakrishnan et al., 2005; Zhang et al., 2007; Rostamian et al. 2008; Alibuyog et al., 2009b). The model has the capability to analyse non-point and point sediment sources over a large spatial scale, such as the Cagayan de Oro River catchment. The model is referenced in the literature (Gassman et al., 2005), and previous studies are easily available online (CARD, n.d). It requires a minimum amount of data to simulate very large catchments and various management strategies. Moreover, it can integrate a comprehensive land surface with river/stream channel processes. It is capable of simulation at yearly, monthly, and daily time-points over short and long periods.

2.1.5 The Study's Scope and Limitations in this Chapter

Given the very broad coverage of the catchment study site, and the limited time and resources, this study will focus on and limit its scope to the following research concepts and related methods:

1) Examination of erosion in the catchment area as source of downstream sediment.
2) Sedimentation dynamics along the main river channel are not accounted for in the modelling study. Succeeding chapters will examine sedimentation dynamics only within the river mouth area and its coastal marine vicinity.
3) River data were collected at a site along the Cagayan de Oro River where waters from all the catchment's major and minor tributaries meet.
4) Using readily available government geographic information system (GIS) maps on land use/cover (National Mapping Resource Information Authority) and on soil types (Bureau of Soils and Water Management) as data inputs for the SWAT modelling.

2.2. Materials and Methodologies

2.2.1. Rainfall Run-Off Study

To measure catchment rainfall amounts in the Cagayan de Oro River area, rain gauges were installed in four selected sub-catchments and monitored daily for ten months. During the same period, the parameters of the Cagayan de Oro River, such as water level, flow velocity and discharge were also measured daily. For an initial insight into run-off and sediment yield, correlation relationships between sub-catchment rainfall and river parameters were analysed using the MLRA (McIntyre, et al., 2007). Further, the SWAT model (Neitsch et al., 2011) was employed to account for the influences of each sub-catchment’s land features and its management practices on the rain-river relationship. Observed rainfall and river data were input to build the model, while additional rainfall, catchment and weather data were gathered from secondary sources to complete the prescribed inputs needed to run the model. The SWAT model simulated the catchment processes (e.g., run-off and sediment transport) and estimated the run-off volume and sediment yield of each sub-catchment.

2.2.1.1. Methodology Framework.

The methodology framework used in the study involved two main phases of work:

1) Collecting the daily measurements of actual rainfall amounts and river parameters (discharge and SSC) and analysing their cause and effect relationships using MLRA (Multiple Linear Regression Analysis).
2) Measuring the effects of catchment spatial heterogeneity and other weather variables on discharge and sediment output variations using the SWAT model (see Figure 2.1). Simulations were subjected to calibration and validation processes. Finally, the simulated results were evaluated using the NSE and the PBIAS (%) tests.

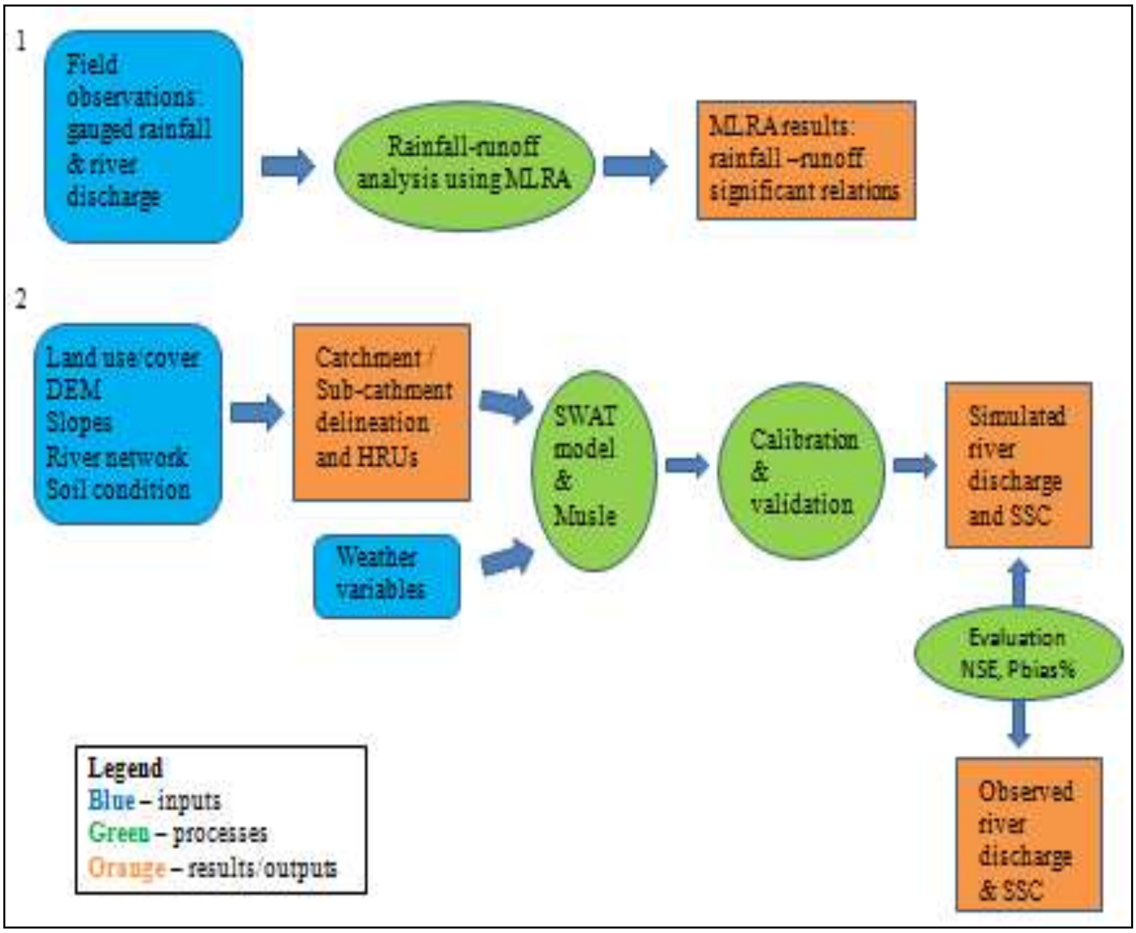


Figure 2.1: The methodology framework diagram shows two modelling works: 1) the lumped and the 2) distributed models. The first model investigated the rainfall-river level of correlation using the MLRA; the second model considered catchment spatial heterogeneity per HRU and other weather variables. The SWAT modelling work was subjected to calibration and validation, and finally evaluation against the actual data.

2.2.2. Study Site—Cagayan de Oro River Catchment

The specific catchment of interest in this study, the Cagayan de Oro River Basin, is located between latitude 7º 57´ N and 8º 31´ N, and longitude 124º 31´ E and 124º 52´ E. It straddles the provinces of Bukidnon and Misamis Oriental on Mindanao Island, Philippines (see Figure 2.2). The entire catchment covers an estimated area of 1,400.08 km^2 (140,008 ha). Based on the DENR delineation, the catchment has eight sub-catchments feeding into the ~90 km long main channel, the Cagayan de Oro River.

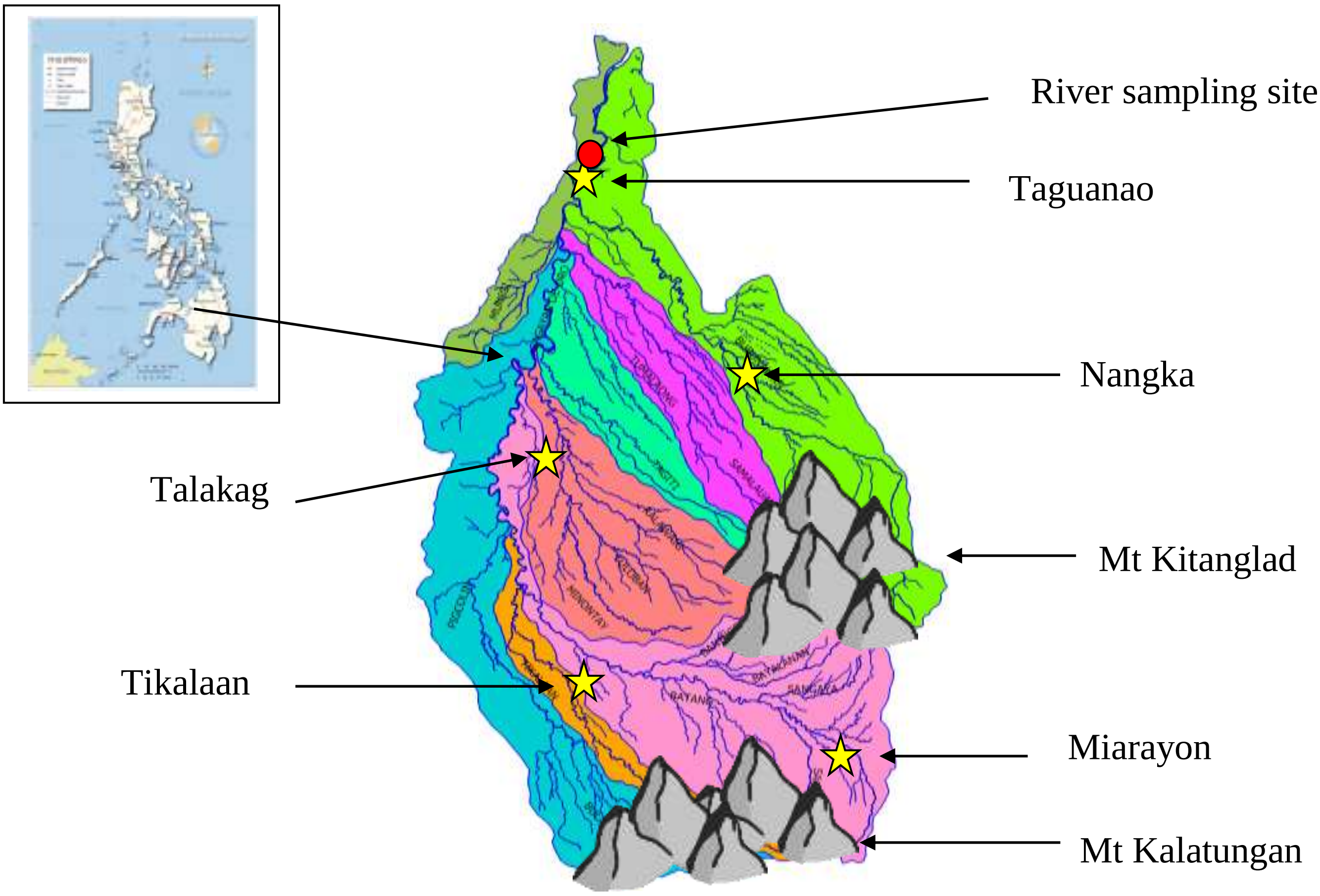


Figure 2.2: The Cagayan de Oro River catchment and its eight sub-catchments. Rain gauge sites used in this study are indicated by yellow stars. River-sampling site is the red dot. Rain gauge and river sites are around 100 m apart. Inset is the map of the Philippines showing the location of the study site (river catchment). Source: DENR, Philippines.

2.2.2.1. Climatology of the catchment.

The catchment's major seasons, wet and dry, coincide with two monsoons: the south western (SW) and north eastern (NE) monsoons, respectively. Weather abnormalities during the initial dry months of 2009, 2011, 2012, 2013 and 2014 were influenced by the NE monsoon wind, which prevailed in the months of December and January.

Generally, the entire country experiences two seasons: dry and wet. Based on the modified Coronas' classification of four climate types (Coronas, 1920), the Cagayan de Oro River catchment falls under Type III, with the rainy months (average: 361.70 mm/mo) from May or June to October, and the dry months from November to April (average of 112.30

mm/mo). However, a few recent events of high rainfall amounts on 2 January 2 2009, 17 December 2011 (*Washi*), 4 December 2012 (*Bopha)*, 8 November 2013 (*Haiyan*) and 29 December 2014 (*Jangmi*) justified the reclassification of November, December and January as transition months from a wet to a more pronounced dry season. This study considers the wet months as May to October, while the more pronounced dry months include February to April.

The climate varies slightly across the catchment, according to geographical location. Based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA, 2014), the southern part of the river catchment has wetter and cooler weather conditions: a short dry season from 1 to 3 months and a less pronounced maximum rain period based on the modified Corona's classification. Average temperature is 24 °C. Relative humidity varies from 80% in April to 88% in July. The northern part of the catchment exhibits a slightly drier and warmer climate (http://www.weatherbase.com). Here, the driest months are March and April, while July receives the highest monthly rainfall. The average temperature is 25.50 °C, while relative humidity ranges from 76% in April to 82.90% in December.

2.2.2.2. Catchment topography.

The Cagayan de Oro River's two headwaters are found in Mt Kitanglad and Mt Kalatungan, with elevations of 2,899 mASL and 2,286 mASL, respectively. Figure 2.1 shows decreases in the elevation height from ~2000 mASL to 30 mASL. The lowest portion of the catchment is home to Cagayan de Oro (city), where the Cagayan de Oro River passes the final portion of land before emptying into Macajalar Bay. The Cagayan de Oro River catchment is characterised by mountainous uplands and largely agricultural-use and mixed vegetation lowlands. Palanca-Tan (2011), using a 90-m solution digital elevation model (DEM), calculated that 40% of the catchment area is situated between 500 and 1,000 mASL, while the higher regions between 1,000 to 1,500 mASL comprise 22%; the highest (>1500 mASL) covers 9% of the catchment area. Lower regions between 200 and 500 mASL make up 23% of the area and the lowest part (<200 mASL) makes up 6% of the catchment area. The catchment area's average elevation is 828 mASL.

2.2.3. Collection of Rainfall and River Data

2.2.3.1. Rain gauge sites.

Five rain gauge sites were established in four of the eight sub-catchment areas (DENR-delineated map) to monitor rainfall (see Figure 2.2). Factors considered in the selection of rain gauge sites included: the study's preference for major sub-catchments; easy accessibility to the site from a major road; availability of local partners to assist in rain gauge monitoring. Therefore, within the pragmatic limitations associated with the ideal possible locations for rain gauges, placement was designed to represent the entire river basin as much as possible. Due to poor accessibility, no rain gauge site was assigned to the mid-eastern part of the catchment near Mt Kitanglad. The five sites located in four sub-catchment areas are referred to by the name of the local community or *barangay* in which the rain gauge was located: Miarayon, Tikalaan, Nangka, Talakag and Taguanao (see Table 2.1).

2.2.3.2. Rainfall measurements.

Daily rainfall collection was conducted from May 2012 to June 2013 and was determined as the measure of the rainfall amount between 6 am and 6 pm. Water collected during the evening was measured at 6 am on the following morning. Rainwater collectors were emptied every 12 hours, or as needed.

Table 2.1: Details of the locations of each rain gauge used in this study in context to the sub-catchments of the Cagayan de Oro River Catchment and the river sampling site at the Taguanao Bridge.

Rain gauge Sites	Coordinates of rain gauge sites (Lat N/Lon E)	Sub-catchment and its land area in ha (DENR-based)	Distance to Taguanao Bridge (km)	Elevations in mASL
Taguanao	8.42/124.63	Bubunawan 26,876	0.10	60
Talakag	8.30/124.74	Kalawaig 19,383	19	350
Nangka	8.25/124.61	Bubunawan 26,876.	18	481
Tikalaan	8.02/124.60	Tikalaan 7,527.	46	850
Miarayon	7.95/124.78	Batang 31,598	68	915

The rain gauge used was based on PAGASA standard measurements (Barcenas, 2012). The rain gauge consisted of an outer metal cylinder, with a height of 61 cm and a diameter of 20.30 cm. The inner cylinder was 50.80 cm high and 6.40 cm in diameter; it collected rainwater with a funnel. Rainwater overflow from the inner cylinder went to the outer container. A wooden stick calibrated in mm measured the amount of collected rainwater inside the inner and the outer cylinders. The rain gauge was placed on top of a slightly elevated concrete mount in an open space and was fenced to keep it safe from stray animals.

To augment the rainfall data collected from gauged sub-catchments, rainfall data in strategic non-gauged catchment sites were collected from satellite-based source.

2.2.3.3. River study site.

The river-sampling site was located in *barangay* Taguanao, along the Cagayan de Oro River (see Figure 2.2) under a 12 m high concrete bridge. The river cross section is ~105 m wide and its normal depth during the dry season is 4.64 m (measured at the foot of the bridge). The study site is approximately 7 km from Macajalar Bay, where the river discharges. After the Taguanao Bridge going downstream, three more bridges are located before the bay. The present river-sampling site was chosen for two important reasons: first, it is located far from the bay and is out of range for tidal influences; second, it gathers water coming from all catchment tributaries. With this, the designated river parameters excluded seawater input: only rainwater had a potential influence on the river's responses.

2.2.3.4. River data measurements.

Measurements of the Cagayan de Oro River parameters began four months after rainfall measurement commenced. River data collection was conducted between 7:30 pm and 8:30 pm from Monday to Friday, beginning September 2012 and continuing until June 2013. A cross section of the channel was divided into three sampling points equidistant to each other and marked as 'right', 'centre' and 'left'. At each point, a sample of river water was conducted once for SSC and twice for water velocity. The river's height was measured from a fixed post marked with height measurements calibrated in metres. A Nansen water sampler (Rosa et al., 1994) was used to collect suspended sediment in water samples. Properly labelled 1 litre sample bottles were left to stand for 3 to 5 days, allowing the suspended sediments to settle. Clear water above the sediment was decanted. The remaining sediment/water mixture was filtered through 1µm paper using a vacuum pump. The collected solids were oven dried at 60 °C from 30 to 48 hours until the weight of each sample became constant (up to two decimal places).

To measure river water velocity, a current meter (2030 and 2031H Flowmeter) attached to a cord was lowered into the river water for 60 s. Velocity measurements were taken at each sampling point at two depths: 0.20 m and 0.80 m below the water surface (Carter & Anderson, 1963). Two-point depth measurements were then averaged as the sampling point's water velocity. For both water velocity and SSC, sample measurements were made at three different locations across the channel and then averaged as a composite value.

A bathymetry survey was conducted to measure the different depths across the 105 m wide channel. An echo sounder unit was attached to a slow-moving boat crossing the channel, which measured 166 depth points at two-second intervals between the points. The echo sounder partly filtered and recorded the sound's travel time through a microcomputer. A global positioning system (GPS) unit recorded the reading location at every pulse reception. Corrections were made in the depth readings, based on water fluctuations during the survey. From these measurements, the channel's cross section area was computed using the following formula:

$$D_{ave} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad \textit{(Eq. 2.1)}$$

$$A = D_{ave} \; x \; W \qquad \textit{(Eq. 2.2)}$$

$$Q = \; A \; x \; V \qquad \textit{(Eq. 2.3)}$$

Where D_{ave} = average depth (m) of the river

d_i = depth recording across the river

n = total number of depth recordings

A = cross sectional area (m^2) of the river

W = width (m) of the river

Q = river flow or discharge (m3/s) of the river

V = river velocity (m).

2.2.4. Statistical Analysis of Gauged Rainfall and River Data

A MLRA was used to understand the effect of seasonal rainfall amounts on each river parameter. Analysis results highlight the gauged site(s) that had a significant association with the river responses. The SWAT model was then employed to account for variability in catchment features and to identify specific land uses and factors that caused significant effects on run-off and sediment yield.

In the MLRA, a daily measurement operated as the unit basis in all three seasons: wet, transitional and dry. Each unit value of the daily rainfall amount from each sub-catchment corresponded with a daily value of the river parameter (e.g., water level, river discharge and suspended sediment). Pearson's correlations (PC) were used to determine whether any of the gauged rainfall values correlated with one another. Where a high correlation between sites' rainfall data occurred, the data were not included in the regression analysis. To remedy this, principal component analysis (PCA) was applied to convert closely correlated variables to uncorrelated variables before proceeding to regression analysis.

2.2.5. Application of the SWAT Model to Predict Run-Off Volume and Sediment Yield

MLRA results showed that relationships between rainfall values/river discharge and sediment yield measurements in either the dry or the wet season, or in both, were significant.

The SWAT model was employed to address two important objectives: to determine the influence of catchment spatial variability on run-off and sediment yield, and to estimate the sediment yield of every sub-catchment.

2.2.5.1. Description of the SWAT model.

The SWAT is a physical- and process-based model that requires specific information about weather, topography, soil properties, vegetation, land uses and management practices happening in the catchment (Neitsch et al., 2011). Using these data, the SWAT can model directly the physical processes associated with water and sediment movements and with crop and nutrient cycling. The SWAT is a daily and continuous time model capable of handling data series from long observation and collection periods. The model is designed to predict the impacts of land features and management practices on water, sediment, and chemical yields in non-gauged catchments. Model-generated results are useful to address environmental problems caused by the continuous and gradual effects from combined natural and anthropogenic sources. Specifically, the SWAT generates—in exact figures—the amount of run-off and sediment yield that can be converted into a spatial representation of sites and their respective sediment losses (in t/ha/yr), highlighting those that are critical.

The SWAT model's first configuration level is the entire river catchment (Arnold et al., 2012). The catchment (or watershed) is sub-divided into the next configuration level, comprising a number of sub-catchments. Each sub-catchment is further sub-divided into one or several hydrologic response units (HRUs). A single HRU is composed of homogenous land use, management, topographical and soil characteristics.

Simulating the hydrological process is divided into two routing phases: the land phase consisting of water, sediment, and chemical loadings movement overland until they reach the main channel; and stream routing, or the movement of water, sediment and chemicals through a river channel to the outlet. The erosion and sediment yield for each HRU is calculated using the Modified Universal Soil Loss Equation (MUSLE) (J. Williams, 1975). MUSLE uses run-off to simulate erosion and sediment yield. Sediment concentration in the stream is governed by two processes: deposition and degradation, which can be measured using stream power (Bagnold, 1977). Williams (1980) used Bagnold's definition of stream power to develop a method of measuring degradation as a function of channel slope and velocity.

The GIS interface for SWAT has been developed to enable appropriate support for the input of various spatial data sets and the model runs. Recent SWAT-GIS interfaces include the widely used ArcGIS SWAT (ArcSWAT) GIS interface (Olivera et al., 2006), AVSWAT for the Arc View 3.x GIS, and ArcSWAT for ArcGIS (Gassman et al., 2007).

For this study, the ArcSWAT version 2012 was employed to model the hydrological processes. This version provided the tools for the following necessary SWAT procedures: sub-catchment delineation, definition of HRUs and weather stations, data base editing, parameterisation, result simulation, and the calibration of key parameters.

2.2.5.2. The SWAT model procedure.

The SWAT model procedure used in the study is shown in Figure 2.3. GIS data prepared for model inputs included digital elevation model (DEM) raster files, stream networks, land cover and soil types. Using the DEM and stream network data, the entire river catchment was delineated into sub-catchments with river networks. To further classify a sub-catchment into smaller units, areas with similar land cover, soil type and slope class were grouped into one HRU, based on a specified threshold value for each class. Weather data obtained from actual observation and from secondary sources were selected and input into the model. Simulations were run using pre-processed data inputs for calibration and validation of the SWAT model. The water balance equation of the river catchment was calibrated first, followed by adjustments of selected key water and sediment discharge parameters.

Various dataset inputs were processed and reclassified for compatibility with the SWAT database code. To approximate accuracy in the predicted results, simulated catchment parameters were subjected to a meticulous calibration process within a given acceptable range of parameter values. Model predictions for a given set of assumed conditions were compared with the actual measured data of the same conditions. The proximity of predicted outputs to the actual conditions was evaluated statistically by specific indicators and tests. This was also a test for the model's capability at simulating the studied hydrological processes.

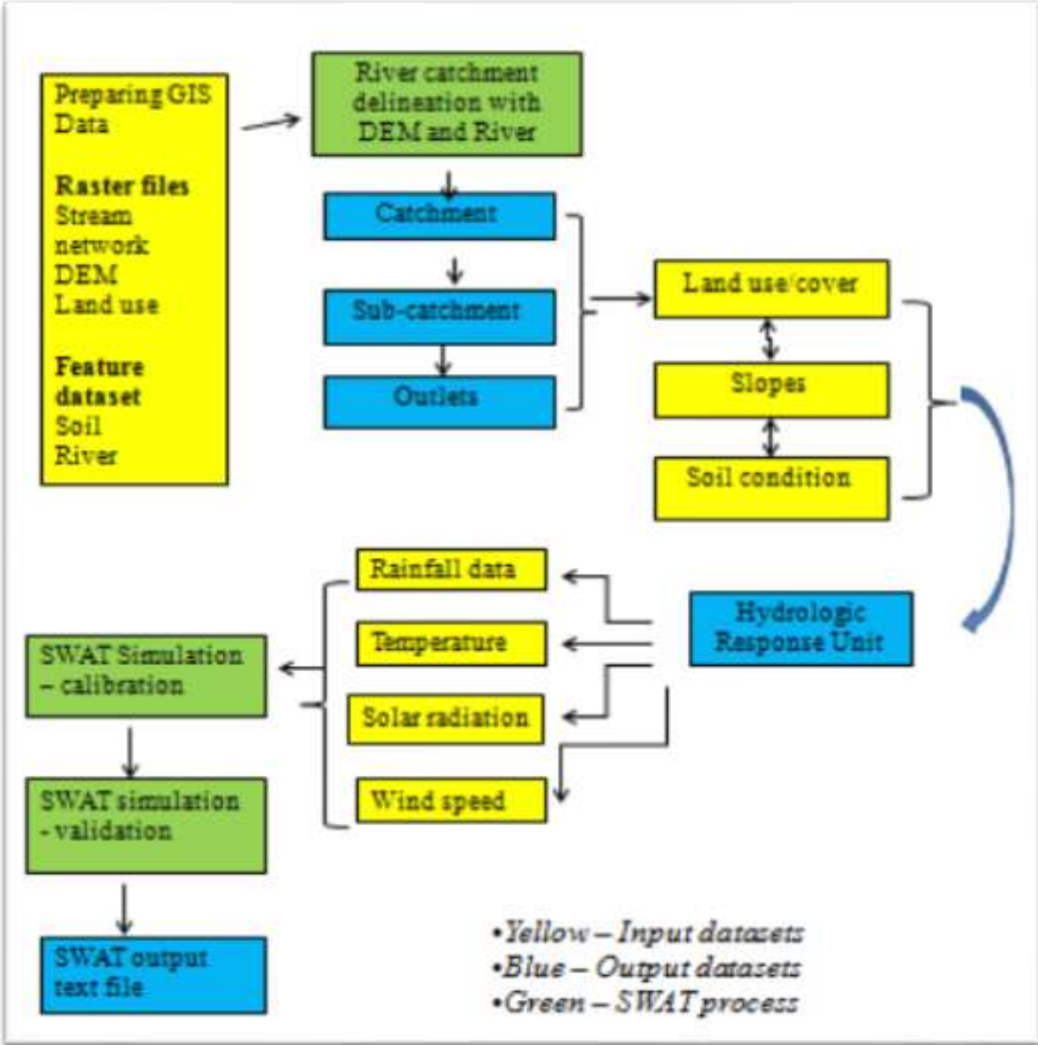


Figure 2.3: A schematic diagram of sets of procedures used in constructing the SWAT model to estimate river water discharge and SSC values from the Cagayan de Oro River catchment. The procedure involves three basic steps: 1) delineation of catchment boundary, sub-catchment and river network; 2) creation of HRUs; 3) model set up and run (e.g., select weather data, indicate simulation period, write SWAT files and run) (George & Leon, 2008).

A high statistical value suggests the model can perform efficiently to simulate the actual processes and conditions in the catchment. This gives a high level of confidence for modelling results and outputs' accuracy. After simulating the calibrated values, model validation is undertaken either temporally or spatially, with 'reasonably' accurate simulations. Accuracy here is relative to the goals of the research study (Refsgaard, 1997). Model validation involves applying the model to observed data (not yet calibrated) using parameters that have already been determined during the calibration stage.

For this study, the SWAT model was used to simulate observed rain and river relationships in the Cagayan de Oro River catchment using the prescribed dataset inputs. The relationship between observed and simulated values for both discharge and sediment yield was represented daily on a line graph. Individual sub-catchments and their corresponding sediment yield values were also represented on a map. The map highlighted the spatial locations of sub-catchments identified as high-sediment yielding sites and considered potential erosion-prone areas.

2.2.5.3. Preparation of the SWAT model inputs.

2.2.5.3.1. Spatial Datasets.

One required spatial dataset was derived from Advance Spaceborne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER DEM) (Abrams, 2000), which was used to delineate river catchment and sub-catchment boundaries. Another spatial dataset was a stream network (vector format), an input in the catchment and sub-catchment delineation. This was digitised from a 1:50,000 scale topographic map by the National Mapping Resource Information Authority (NAMRIA, n.d.).

Other spatial datasets in vector format included land use/cover (LUC) and soil data. LUC data were based on interpretations of advanced land observing satellite—advanced visible and near infrared radiometer type (ALOS-AVNIR2) satellite images taken from 2007 to 2010. LUC are accorded the following classifications: forest, pasture, range-brush, agriculture, built up and inland water. For LUC, the model used the values of oak trees for mixed forest, Bermuda grass values for pasture land, grain sorghum values, a warm season annual plant for generic agriculture land, and the values of little bluestem (a perennial plant) for brush land. Due to a scarcity of soil data from government offices, soil properties were generally classified into two types: clay and clay loam, based on the data map prepared by the Bureau of Soil and Water Management (BSWM, n.d.).

Table 2.2: List of SWAT model data inputs for delineation of the catchment and sub-catchments

Data type	No of stations	Unit	Date of available data	Sources (agencies)
Spatial data sets				
DEM	-	-	2010	NAMRIA
Stream/river	-	-	2010	NAMRIA
Land cover/use	-	-	2007-2010	NAMRIA
Soil types			2000	BSWM

BSWM—Bureau of Soils and Water Management
NAMRIA—National Mapping Resource Information Authority

2.2.5.3.2. Sub-catchment delineation.

To divide the river catchment into smaller sub-catchments, DEM and a stream network were needed to define the flow direction, model reaches, sub-catchment outlets and other catchment parameters (e.g., longest flow path, area, perimeter, reach dimension).

In sub-catchment delineation, a 1,000 ha threshold value was specified, which means that areas of less than 1,000 ha size inside the catchment were not read by the model and thus not delineated as one sub-catchment. A large threshold value would mean fewer sub-catchments were delineated, with a lower spatial variability for the catchment. Small threshold values would mean more sub-catchment areas and higher spatial variability. The model created 84 stream outlets, or 84 sub-catchments, inside the catchment.

2.2.5.3.3. Hydrologic response units.

A HRU is even smaller as a physical unit than a sub-catchment. A HRU comprises land and inland water masses of similar soil type, slope class, land cover/use and management practice (Arnold et al., 2012).

For an HRU definition, threshold values were set for each class/category included in the response unit. Multiple HRUs per sub-catchment was the chosen option. In land use, the threshold value was 10%, soil class was 5%, and slope was 20% per sub-catchment. This means that a single HRU was the result of combining three variables of similar characteristics, based on the threshold values set as the minimum requirements for inclusion. For land use, at least 10% of the sub-catchment with similar LUC was included by the model to comprise a single HRU. Similarly, for slope, at least 20% should have the same slope and soil type, with 5% of the same soil type to be included in a HRU. In total, 583 HRUs were created, which guaranteed a higher spatial heterogeneity in the catchment.

2.2.5.3.3.1. Land use/cover.

The land/forest cover map was generated using interpretations of ALOS-AVNIR2 satellite images. It is the latest land cover map of the Cagayan de Oro River catchment taken from an aerial survey between 2007 and 2010. The Cagayan de Oro River catchment map was extracted from the NAMRIA land/forest cover map of the entire country, based on the following set of coordinates: upper (x—659196.585; y—945029.729) and lower (x—710261.270; y—870218.642). Northern parts of the map beyond the Taguanao Bridge, the river-sampling site, were not included in the LUC map.

GIS-raster land cover data was input into the model. Spatial variations of the catchment were further enhanced by considering specific LUC found and identified within a sub-catchment. The SWAT provided the grid field classes: forest, shrubs, pasture, agriculture, built-up areas and inland water. The GIS land cover types were reclassified based on the six field classes prescribed by the SWAT database. The SWAT had assigned corresponding percentages for each LUC classification (see Table 2.3).

Table 2.3: SWAT-defined land covers/uses and their corresponding land areas in %

SN	Land cover/use	Area (hectare)	Total land uses /covers in %
1	Forest	46,114.07	32.92 %
2	Shrubs	21,048.10	15.02 %
3	Pasture land	21,538.62	15.38 %
4	Agriculture	49,780.67	35.54 %
5	Built up	622.77	0.44 %
6	Inland water	983.78	0.70 %

2.2.5.3.3.2. Soil data.

Raster format soil data were input into the model. Grid values comprised two types: clay and clay loam. Together, the two soil types make up the entire catchment area: 40% of the mostly lowland area has clay soil and around 60% of the largely mountainous portion has clay loam soil. The soil's physical attributes were typed manually into Microsoft Access and stored in the SWAT soil database. The database was linked to the soil map through the lookup table, which was also linked to the soil map.

2.2.5.3.3.3. Slope classes.

Aster DEM (50 m x 50 m) was input into the SWAT model. Slope was divided into five classes (see Table 2.4). Slope classes were reclassified according to the limits set for each class.

Each category (land cover, soil type, slope class) was reclassified based on the SWAT database code. Afterwards, all three reclassified layers in each of the topographically defined sub-catchment were overlain to define the HRUs within the sub-catchment.

Table 2.4: Slope classes that make up the Cagayan de Oro River Catchment with the assigned slope limits and their corresponding land areas covered in hectares and in percentages.

Current slope class	Lower limit (%)	Upper limit (%)	Area covered (ha)	Percent of each class
1	0	1	564.52	0.40%
2	1	10	39,381.37	28.11%
3	10	20	43,400.99	30.98%
4	20	30	21,970.63	15.68%
5	30	999	34,770.49	24.82%

2.2.5.3.3.4. Rainfall and other weather data.

Primary rainfall data came from five gauged sites within the Cagayan de Oro River catchment. To augment the gauged rainfall data on the eastern side, two more local rain stations were tapped. These were the Dahilayan rain station, which is located on the other side of Mt. Kitanglad, and the PAGASA Malaybalay station, the closest government weather station to the river catchment, located ~30 km to the east outside the study site (see Figure 2.4).

Additional rainfall data were also obtained from a satellite-based source, the Tropical Rainfall Monitoring Mission (TRMM) (Simpson et al., 1996), a joint United States of America and Japanese project to monitor tropical and sub-tropical precipitation (see Figure 2.4). The TRMM satellite used several space-borne instruments to measure rainfall data. Using geographical coordinates, TRMM weather data were taken from specific locations near the central catchment area where no gauged station had previously been installed. Meteorological dataset inputs were obtained from gridded global weather representations, called reanalysis datasets, of the National Centers for Environmental Prediction (NCEP) (globalweather.tamu.edu).

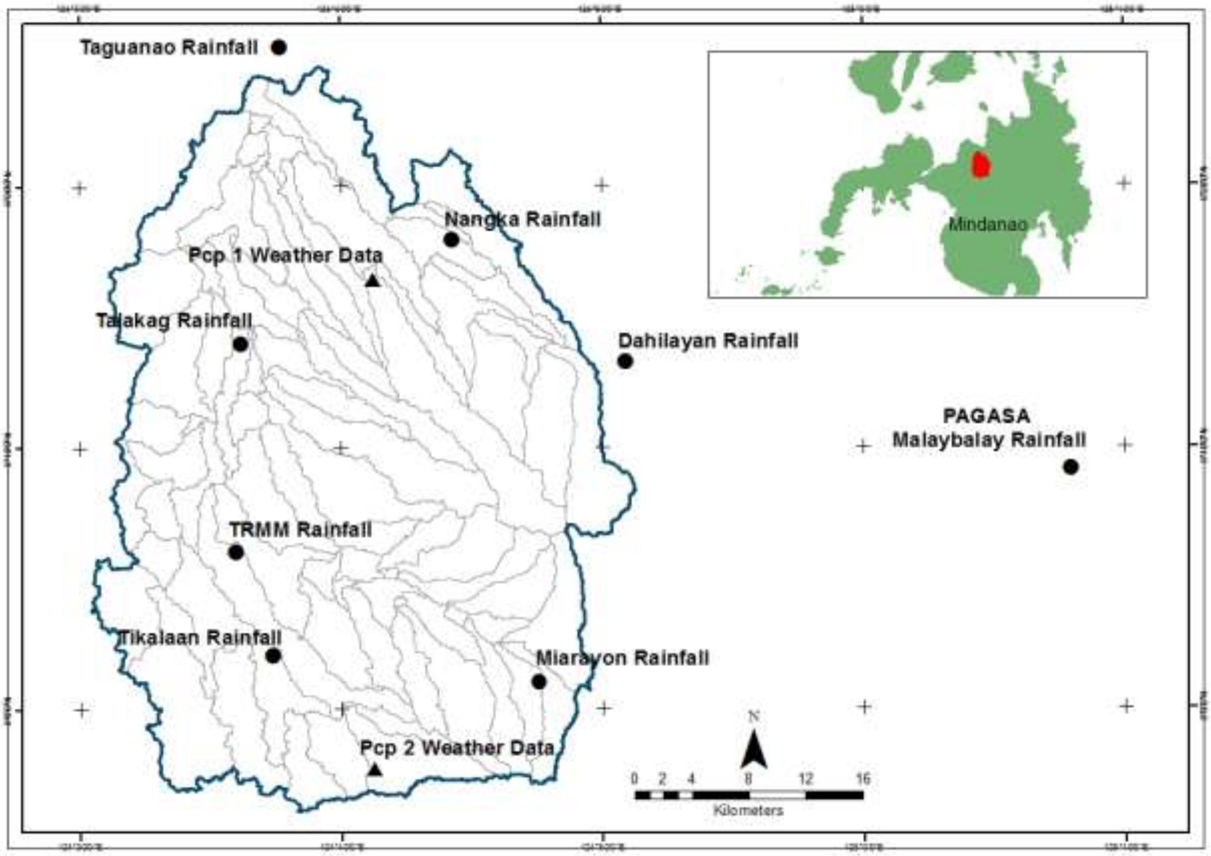


Figure 2.4: Eight rain gauge stations and two weather stations in the Cagayan de Oro River catchment, as sources of rainfall and weather data inputs for the SWAT model. No stations were assigned at the two peaks and their vicinities due to limited access to the sites.

For other weather data, two source locations were chosen to represent both the northern (lowlands) and the southern parts (mountains) of the river basin (see Figure 2.4). The weather data included maximum and minimum temperatures, wind speed, humidity and solar radiation. All weather data were sourced from the NCEP through climate forecast system reanalysis (CFSR), a model representing the global interaction between oceans, land and atmosphere of the Earth (Fuka et al., 2014). These data were compiled into the proper format prescribed by the SWAT model.

Overall, weather data in time-series were obtained from ten stations, both from the gauged sites and from secondary sources (see Tables 2.5a and 2.5b).

Table 2.5a: Rainfall data input for the SWAT model and their various sources.

Weather variable	Method & unit (mm)	Coordinates	Eleva-tion (m)	Frequency & Period	Sources of data
Rainfall	Rain gauge	8.4217/124.63	60	Daily; May 2012 to June 2013	Actual observation, Taguanao, Cagayan de Oro
	Rain gauge	8.2969/124.74	350	Daily; May 2012 to June 2013	Actual observation, Municipality of Talakag, Bukidnon Province
	Rain gauge	8.2500/124.61	481	Daily; May 2012 to June 2013	Actual observation, Nangka, Municipality of Libona, Bukidnon Prov
	Rain gauge	8.0197/124.60	850	Daily; May 2012 to June 2013	Actual observation, Tikalaan, Municipality of Talakag, Bukidnon Prov
	Rain gauge	7.9531/124.78	915	Daily; May 2012 to June 2013	Actual observation, Miarayon, Municipality of Talakag, Bukidnon Prov
	Rain gauge		600-700	Daily; May 2012 to June 2013	Dahilayan, Municipality of Manolo Fortich, Bukidnon Prov
	Rain gauge	8.1520/125.13	622	Daily; May 2012 to June 2013	PAGASA Station, Malaybalay site
	TRMM		600-700	Daily; May 2012 to June 2013	Southwest of the center

Table 2:5b: Prescribed weather data input for the SWAT model and their various sources.

Weather	Unit	Coordinates	Elevation (m)	Frequency and period	Sources of data and location
Temp max & min.	˚C	8.4333/124.45	180	Daily. May 2012 to June 2013	CFSR from NCEP, North
		8.1520/125.13	622	Daily. May 2012 to June 2013	CFSR from NCEP, South
Humidity	%	8.4333/124.45	180	Daily. May 2012 to June 2013	CFSR from NCEP, North
		8.1520/125.13	622	Daily. May 2012 to June 2013	CFSR from NCEP, South
Wind speed	m/s	8.4333/124.45	180	Daily. May 2012 to June 2013	CFSR from NCEP, North
		8.1520/125.13	622	Daily. May 2012 to June 2013	CFSR from NCEP, South
Solar radiation	MJ/ m^2	8.4333/124.45	180	Daily. May 2012 to June 2013	CFSR from NCEP, North
		8.1520/125.13	622	Daily. May 2012 to June 2013	CFSR from NCEP, South

CFSR—Climate Forecast System Reanalysis from NCEP
TRMM—Tropical Rainfall Monitoring Mission

2.2.5.4. Initialisation and simulation runs.

Due to the short period of data collection, 10-month data were replicated four times. The first three sets were used for initialising or conditioning the model for simulation. The SWAT model simulated the observed discharge and sediment yield from September 2012 to June 2013. The simulation process consisted of the calibration period from September 2012 to March 2013, and the validation period from April to June 2013.

2.2.5.5. Calibration of hydrological data.

The simulated hydrological balance reasonably approximated the actual apportioning of rainfall to water balance components (e.g., evapotranspiration, surface run-off, base flow,) before the calibration of water flow, sediments and nutrients was performed (Santhi et al., 2001a). Without a reasonably adequate model to begin with, the calibration process could be very difficult, as certain parameters might affect multiple processes, causing chain-reaction changes to the affected values (Arnold et al., 2012).

2.2.5.6. Calibration and validation of discharge and sediment yield runs.

The first run-off and sediment load phase included the calibration of key parameters and processes (see Appendix A) that control the amount of water and sediment loads in the river, such as evapotranspiration, surface flow, percolation and base flow. The second phase included the routes of discharge and suspended sediments along the stream and river channels to the bay. The calibration steps followed recommendations in the SWAT model (Neitsch et al., 2011). The validation phase was allotted to the three remaining months.

2.2.5.7. Model performance evaluation.

To evaluate the model's efficiency performance, this study used the split sampling technique, where observed discharge data were divided into two phases: calibration from

September 2012 to March 2013 and validation from April to June 2013. To improve the model performance of the discharge and sediment yield, a manual calibration technique was used to adjust select key parameters.

To test the model's efficiency as simulating the hydrologic process, two statistical indicator tests were employed: NSE and PBIAS (%). The NSE measures how sound the match is between observed and simulated data, based on 1:1 line. It is solved using the equation below:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{sim}\right)^2}{\sum_{i=i}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right] \qquad (Eq.\ 2.4)$$

Where Y_i^{obs} = ith observation for the constituent being evaluated
Y_i^{sim} = ith simulated value for the constituent being evaluated
Y^{mean} = mean of observed data for the constituent being evaluated
n = total number of observations.

The NSE's optimal value is 1.0, indicating a perfect match between the observed and simulated data. Values between 0.0 and 1.0 are generally considered acceptable. Values ≤0.0 are generally viewed as unacceptable, which means that the mean observed value has better predictive power than the simulated value.

The per cent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). The PBIAS (%) is calculated using the equation below:

$$\text{PBIAS \%} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) x\ 100}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \qquad (Eq.\ 2.5)$$

Where Y_i^{obs} = ith observation for the constituent being evaluated

Y_i^{sim} = ith simulated value for the constituent being evaluated

n = total number of observations.

The optimal value of PBIAS% is 0.0. Lower values indicate more accurate model simulation. Positive values suggest model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999).

2.2.5.8. HRU Analysis and Classification.

Each sub-catchment delineated by SWAT was examined and classified into four classifications, based on the amount of sediment yield generated in tonnes per hectare per year (t/ha/yr). Acceptable tolerable soil loss was pegged at 0 to 5 t/ha/yr, which is close to the value of 3 to10 t/ha/yr suggested by Paningbatan (1987) (as cited in Paragas et. al. [1999]). Soil loss from 5 to15 t/ha/yr is described as a moderate risk; from 15 to 50 t/ha/yr is high risk, and above 50 t/ha/yr is very high, requiring immediate intervention measures to rehabilitate the affected sites.

Finally, every sub-catchment of SWAT data output was examined for relationship patterns between the sediment yield value and the cluster's common key attributes and physical factors: curve number, length and steep of slope, and rainfall amount. The key physical attributes became the basis for describing each sub-catchment or cluster of sub-catchments and their sediment-yielding capacity. For a more thorough treatment of the data, the land use classification, the slope classes, the rainfall amount, and each catchment's spatial coverage were also examined.

2.3. Results

2.3.1. Rainfall Variations in the Cagayan de Oro River Catchment

Rain gauge data collection in five sites began in May 2012. All recordings ceased in June 2013. A comparison of the total monthly rainfall values among the five gauged sites during the 14-month sampling period are shown in Figure 2.5.

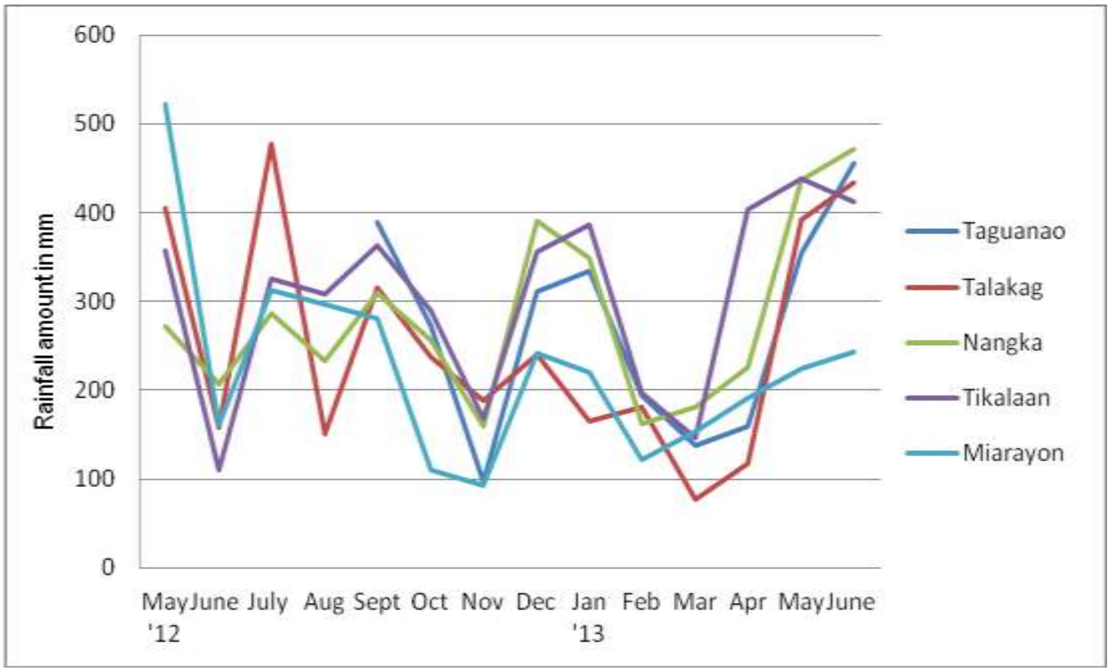


Figure 2.5: Monthly rainfall distribution in five gauged sub-catchments, the Cagayan de Oro River Catchment. Graph shows general similar temporal rainfall patterns in most of the gauged sites during the sampling duration.

2.3.1.1. Temporal variations of gauged catchment rainfall.

Generally, Figure 2.5 shows low rainfall totals in the wet months of June 2013 and August. Relatively low rainfall readings were also observed in November and the summer months of February to April. High monthly rainfall totals in most gauged sites were recorded in May, September, October, December and January. Certain abnormalities in weather patterns during the year (e.g., tropical depressions, typhoons and long spans of non-rainy days) affected each site's rainfall total for a particular season significantly. For example, the very high monthly total in December was mainly due to heavy rains resulting from an extreme rainfall event, Typhoon *Bopha,* while the low rainfall total in June 2012 could be attributed to no rainy days over a week at all the four gauged sites. The transition season had the highest rainfall variability (SD = 16.33) compared to the wet (SD = 9.47) and dry seasons (SD = 8.22). Among all the sampling months, November experienced low rainfall totals consistently at all sites.

Regarding seasonal variation, the rainfall input at all gauged sites was consistently high in the wet months of July, August and September (2012), May and June (2013). June (2012), October (2012), February, March, and April (2013) experienced relatively low rainfall inputs at all five gauged sites. Generally, the sampled months followed the regular pattern of seasonal rainfall variations, except for the normally dry months of December (2012) and January (2013), which recorded relatively high rainfall input at all sites.

2.3.1.2. Spatial variations in gauged catchment rainfall.

Catchment rainfall varied according to location. In general, the highest monthly rainfall average was recorded in Tikalaan, while the lowest was in Miarayon. However, Miarayon had the highest rainfall total (521.50 mm/month) in May, while Talakag experienced the lowest (77 mm/month) in March. The general pattern of monthly rainfall variations was observed as most pronounced in Talakag (SD= 129) and least pronounced in Nangka (SD = 99.5).

2.3.1.3. Statistical test for relationship significance between rainfall and river discharge.

The MLRA results indicate that, with the exception of Taguanao, all five rain gauge sites had significant effects on the Cagayan de Oro River discharge in both wet and dry seasons (see Table 2.6). However, only the recorded rainfall in Talakag had a significant effect on river discharge during both the wet (T = 2.09, p = 0.00) and dry (T = 1.40. p = 0.00) seasons. Daily rainfall in Taguanao had no significant effect on river discharge in the dry season and was not included in the MLRA's dry season data, as its daily rainfall values were highly correlated with those from Nangka. However, Nangka's results were included in the MLRA due to the rainfall's significant effect during the wet season.

Table 2.6: Seasonal gauged rainfall effect on the river discharge based on the MLRA.

Rain gauge sites	**Dry season**		**Wet season**		**Transition season**	
	Rc	*p* value	Rc	*p* value	Rc	*p* value
X_1:Taguanao site			0.03	0.06ns		
X_2:Talakag site	2.09	0.00**	1.40	0.00**		
X_3: Nangka site	2.55	0.00**	1.40	0.05*		
X_4: Tikalaan site	0.83	0.061ns	0.98	0.020*		
X_5: Miarayon site	1.35	0.027*	1.97	0.052*		
X_1 : Principal component 1 (described as function of the rainfall readings from five sites)					73.09	0.00**
MLRA adjusted R^2	0.71		0.21		0.75	
Final models	$\hat{y} = 68.59 + 2.09x_2 + 2.55x_3 + 0.83x_4 + 1.35x_5$		$\hat{y} = 99.91 + 1.40x_2 + 1.41x_3 + 0.99x_4 + 1.97x_5$		$\hat{y} = 168.92 + 73.09x_1$	

ns: non-significant;
*: significant, where $0.01 < \alpha < 0.05$
**: highly significant, where $\alpha < 0.01$

In the wet season, Miarayon had the highest effect on river discharge, resulting in an increase of 1.97 m^3s^{-1} discharge per mm of the site's rainfall amount. During the dry season, Nangka's influence on the discharge volume was the highest, with a 2.55 m^3s^{-1} increase of discharge for every mm of rainfall increase. Mean change values due to per mm changes in rainfall amounts in Talakag and Nangka contributed to higher additional discharges in the dry season compared to the wet season.

2.3.1.4. Statistical test for relationship significance between rainfall and suspended sediment concentration in the river.

The MLRA results indicated positive correlations between the rainfall values of two sites (Talakag and Tikalaan) and the river SSC during the wet season (see Table 2.7). Some positive association relationships were also exhibited during the dry season between the river SSC values and same site, Tikalaan and another site, Nangka. Thus, both seasons exhibited a similar influence on the rainfall and SSC value correlations in Tikalaan. Again, Taguanao was not included in the MLRA during the dry season.

In the wet season, Tikalaan exhibited the strongest effect on SSC, resulting in an increase of 2.39 mg after every mm increase in the rainfall amount. During the dry season, the influence of Nangka's rainfall resulted in an increase of 1.50 mg for every mm of increase in the rainfall value. Overall, the high mean change in SSC due to rainfall contributed to a higher increase of the SSC total in the dry season compared to the wet season.

Table 2.7: Seasonal gauged rainfall effect on the river SSC based on the MLRA.

Rain gauge sites	**Dry season**		**Wet season**		**Transition season**	
	Rc	*p* value	Rc	*p* value	Rc	*p* value
$\mathbf{X_1}$:Taguanao site			0.18	0.74 ns		
$\mathbf{X_2}$:Talakag site	0.29	0.22ns	1.29	0.05*		
$\mathbf{X_3}$: Nangka site	1.43	0.00**	1.09	0.13 ns		
$\mathbf{X_4}$: Tikalaan site	0.59	0.03*	2.34	0.00**		
$\mathbf{X_5}$: Miarayon site	0.26	0.50ns	0.83	0.54 ns		
$\mathbf{X_1}$: Principal component 1 (described as a function of the rainfall readings from five rainfall sites)					98.13	0.00**
Adjusted R^2	0.51		0.22		0.79	
Final models	$\hat{y} = 13.75 + 1.50x_3 + 0.706x_4$		$\hat{y} = 15.82 + 1.65x_2 + 2.39x_4$		$\hat{y} = 168.92 + 73.09x_1$	

ns: non-significant;
*: significant; where $0.01 < \alpha \leq 0.05$;

**: highly significant; where $\alpha \leq 0.01$

2.3.2. SWAT Biophysical Characterisation of the Cagayan de Oro River Catchment

SWAT simulation run outputs describe the biophysical characteristics of the Cagayan de Oro River catchment in a spatial representation.

2.3.2.1. Hydrologic response units.

HRUs are portions of a sub-catchment that possess unique land/soil/slope characteristics (see Figure 2.6). Given these unique particularities, the spatial variability of sub-catchments is more clearly defined. The HRU level of analysis increases the accuracy of calculating sediment loads from the sub-catchment.

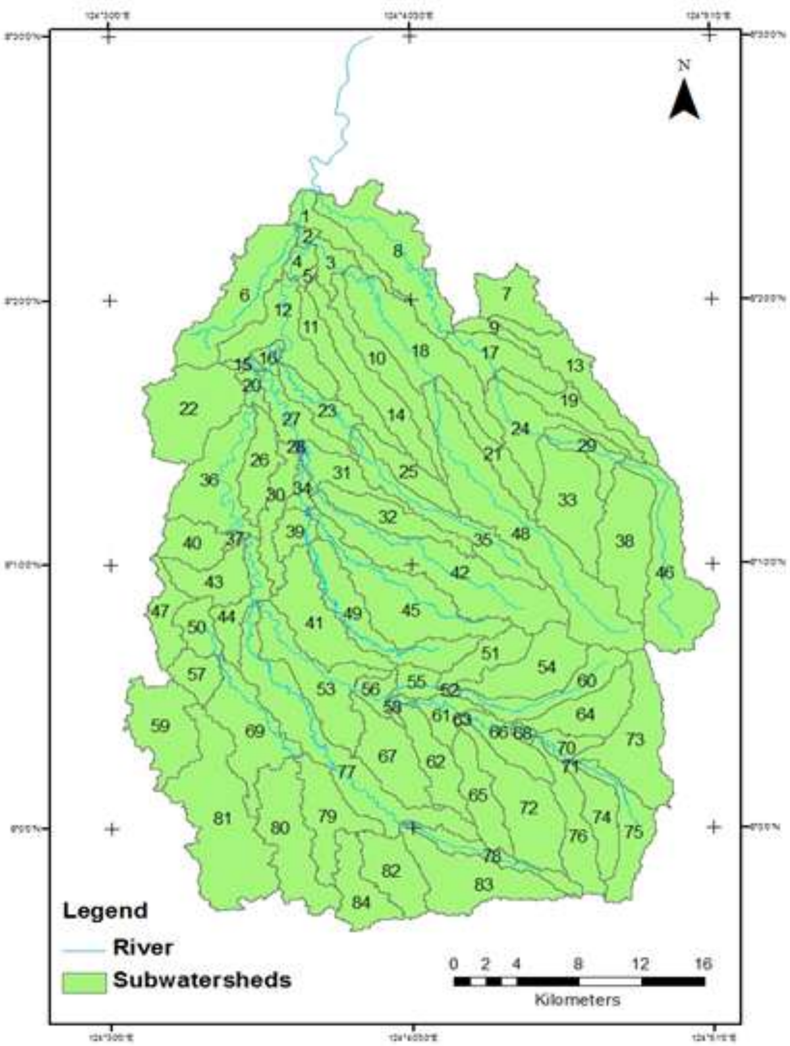


Figure 2.6: Map of the Cagayan de Oro catchment and its 84 SWAT-defined sub-

catchments and outlets and the river/stream networks. Each sub-catchment as a single component contains climate conditions, groundwater and the channel draining it.

2.3.2.2. Land use/cover map.

Figure 2.7 shows the entire Cagayan de Oro River catchment's LUC, generated by the SWAT from the prescribed data input into the model.

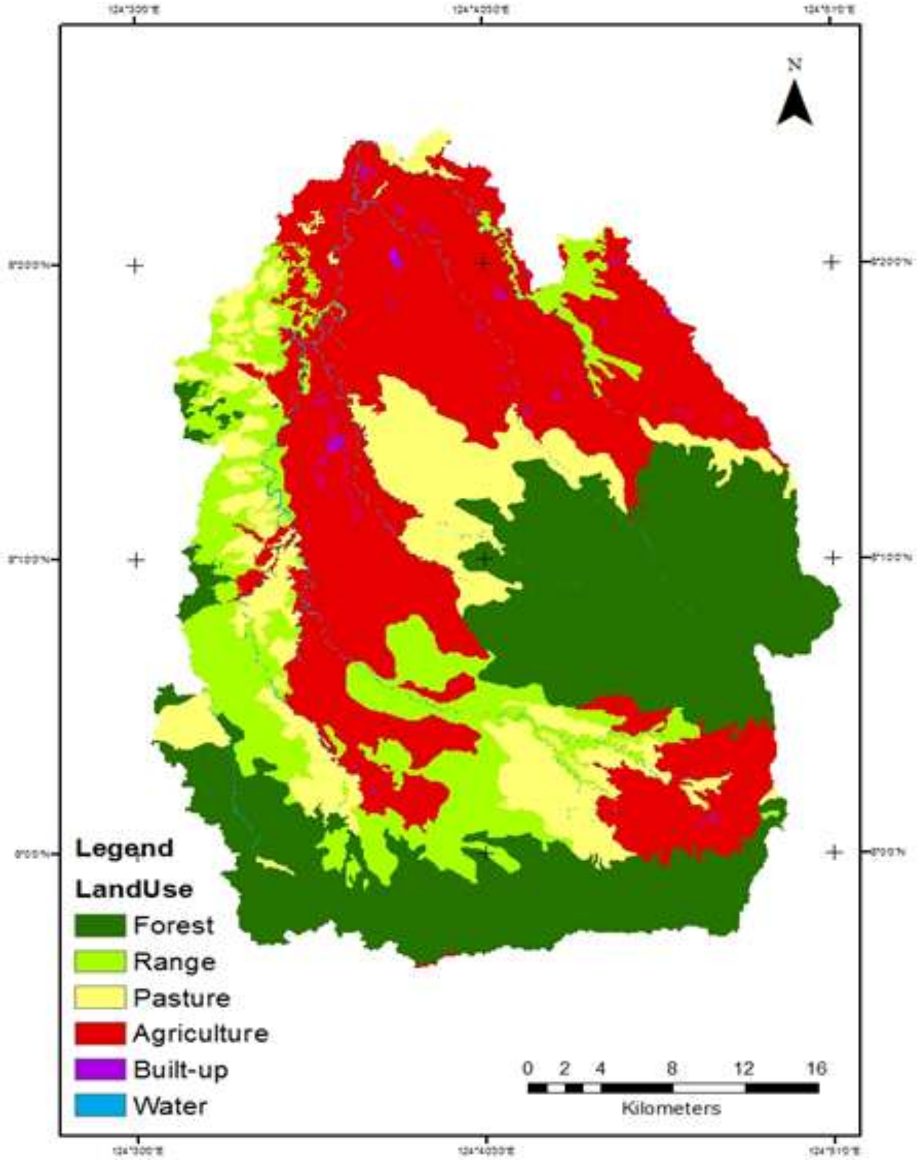


Figure 2.7: SWAT-reclassified land use map of Cagayan de Oro River catchment, showing the dominance of agricultural land and pasture/brush land over the lowlands.

The two highest peaks are located on the catchment's south eastern portions, characterised by dense and mossy forests. Secondary forests are located around the mountains' base areas. The agricultural class, consisting mainly of cultivated land, is generally located in the lowlands near human settlements. Only a small portion of the catchment comprises built-up areas—mostly residential houses, buildings and infrastructure—which are found in relatively populated places like the towns of Talakag, Baungon and Libona (but not in the highly populated city of Cagayan). Inland waters comprise a bigger portion than the built-up areas. The inland water areas consist of the river's main channel, its tributaries and other smaller branching stream networks.

2.3.2.3. Soil data.

Based on the BSWM soil data, the Cagayan de Oro River catchment has two major soil types: *Kidapawan* clay loam and *Adtuyon* clay (see Figure 2.8).

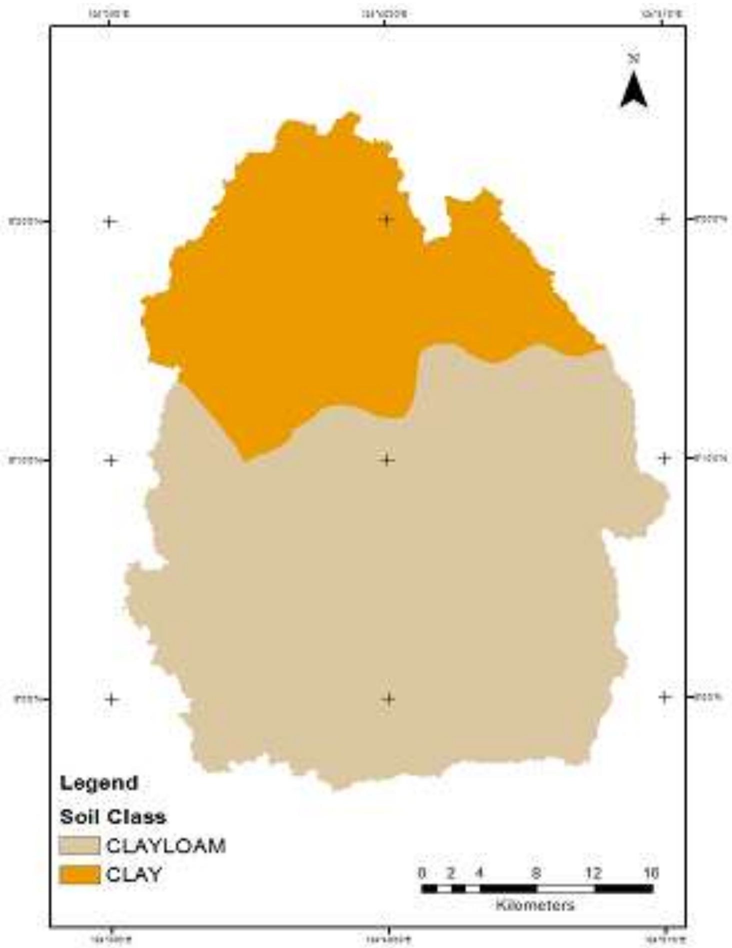


Figure 2.8: Soil map of Cagayan de Oro River catchment showing only

two textural classes: *Adtuyon* clay (north) and *Kidapawan* clay loam (south) (source of datasets: BSWM).

Both soil types are considered best for agricultural crops; they are mostly well drained (Catacutan & Cramb, 2004) and absorb enough water for plant root systems, but not so much that plants are ‘drowned’. A third type of soil in the catchment is *Bolinao* clay, albeit existing in a small percentage (10%). This soil is suitable for crop cultivation, especially corn, coconut and mango (it is not represented on the map as it covers land beyond the river-sampling site, removed from the existing map). *Bolinao* clay is found predominantly in the lowland parts of Cagayan de Oro City (<100 m), where Taguanao lies (Pasco & Picut, 2011). The soil’s clayey surface (Catacutan & Cramb, 2004) attracts water molecules easily but absorbs water slowly. Due to suitable soil types, large cultivated areas abound within the catchment area. All three clay soils have infiltration rates within a moderate range of 1.0 to 5.0 mm h^{-1} (United States Department of Agriculture, 1999).

2.3.2.4. Slope.

Slope is a fundamental property of an environmental landscape. It gives the landscape its primary characteristic relating to control or influencing run-off and sediment flow overland. It directly affects the rate of water flow and the transport of various dissolved and particulate substances from the catchment source to the stream. An increase in slope steepness contributes to the catchment’s instability. This also enhances run-off, posing a greater flooding risk to the lowland areas during storms and strong rainfall events.

The Cagayan de Oro River catchment’s high steep slopes (≥30%) are mostly concentrated in the mountainous areas, and along the river and stream banks, while gentler slopes (≤20%) are found in all parts of the catchment (see Figure 2.9).

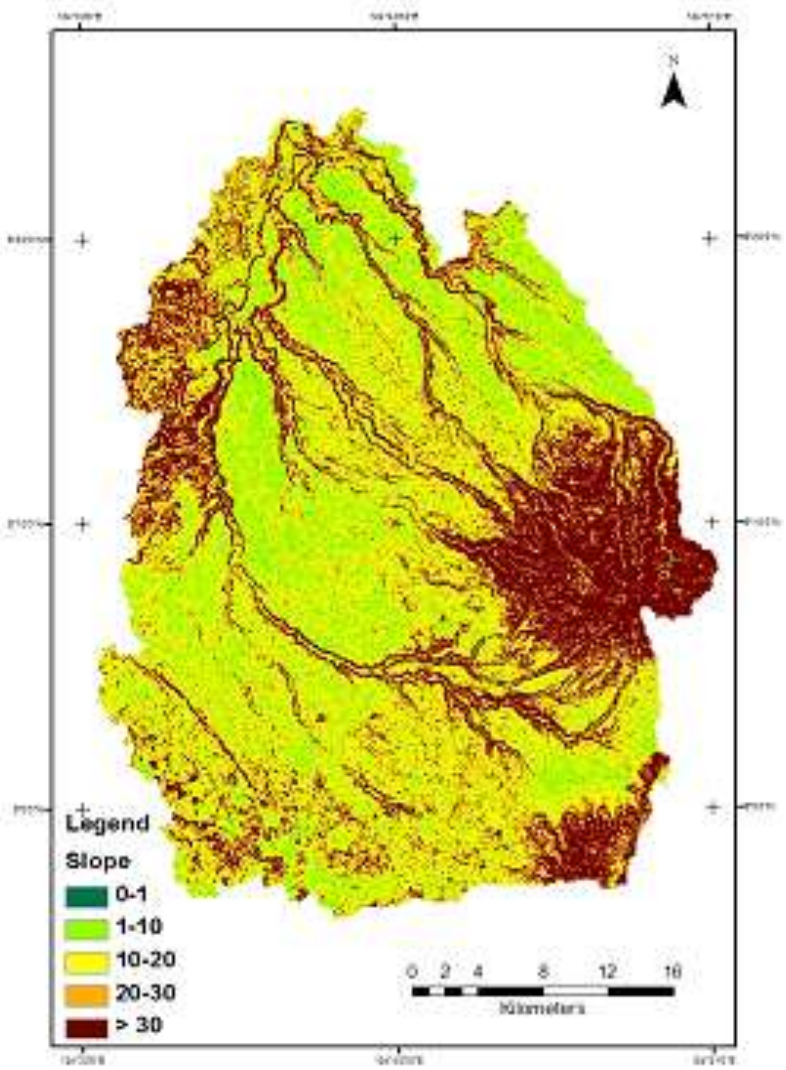


Figure 2.9: SWAT-defined slope map of the Cagayan de Oro River catchment showing steep mountain slopes and riverbanks; gentle slopes are dominant on the lowlands. Slope angle in percentages. (Source of datasets: NAMRIA).

2.3.3. Calibration of the Cagayan de Oro River Catchment Water Balance Equation

Figure 2.10 details a hydrological balance equation for the Cagayan de Oro River catchment, with an average total rainfall input of 3,330.50 mm/yr. An evapotranspiration value of 37% was appropriated for a typical tropical catchment area that experienced several warm months from December to April (PAGASA 2014). During the warm months, forested and other vegetated areas enhanced the interception of rainwater and caused faster evaporation into the atmosphere. Further, during the summer months, warm weather increased the evaporation of surface soil water, more so during harvest season when bare grounds were more exposed to the effects of weather.

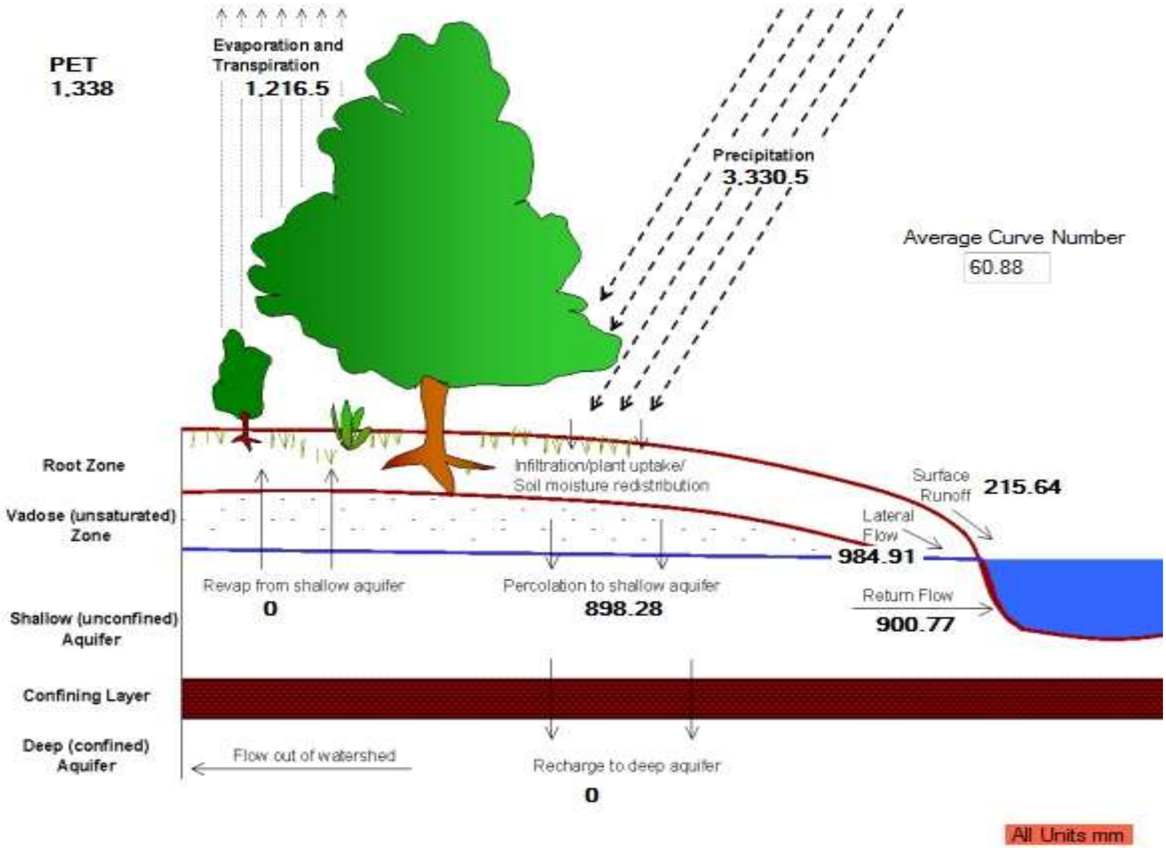


Figure 2.10: Hydrological balance equation exhibited in the Cagayan de Oro River catchment (Data source: actual sampling; illustration from ArcSWAT2012). To balance the input and output of water supply in the catchment, values assigned to each hydrological component were calibrated based on the site's actual conditions.

Table 2.8 shows the rainfall volume's two major allocations to the catchment's water balance: stream flow and the evapotranspiration. A bigger portion (63.5% or 2,115 mm) of catchment water comprised the stream flow (the water that became part of the stream or the river), while a smaller portion (36.5% or 1,216.5 mm) transpired back to the atmosphere. From the total rainfall application on the ground, some reached the channel as surface run-off, while other portions infiltrated the ground and eventually formed part of the base flow.

Thus, stream flow is made up of the surface flow (215.64 mm) and the base flow (2,101.3 mm), comprising 10% and 90% (respectively) of the total stream flow.

Table 2.8: Various water allocations of the water balance in the Cagayan de Oro River catchment.

Water Balance Ratio	
Evapotranspiration/precipitation	0.365 (1,216.5 mm)
Deep recharge/precipitation	0
Stream flow/precipitation	0.635 (2,115 mm)
Total precipitation	100 (%)
Surface flow/stream flow	0.10 (~215 mm)
Baseflow/stream flow	0.90 (~1,899 mm)
Total stream flow	100 (%)
Sub-surface flow/baseflow	0.47 (~985 mm)
Return flow/baseflow	0.43 (~900 mm)
Total base flow	90 (%)

Surface flow is the water from rain that remains on the surface and flows overland to a stream (Neitsch et al., 2011). In Cagayan de Oro River Catchment, it is much smaller in volume (~10%) compared to base flow (90%), perhaps because it is generated only when soil infiltration ceases (i.e., the soil reaches field capacity). Additionally, it is potentially reduced by evaporation during overland flow. Base flow is the water that accumulates underground which is ultimately discharged to the river. In Cagayan River Catchment, the base flow is very high as it is generated by continuous rains in the mountains. As percolated water in shallow aquifers it goes back to the stream as return flow (43%). Moreover, part of base flow becomes the lateral sub-surface flow (0–2 m) (47%).

Table 2.8 shows that the calibrated water allocations in the hydrological balance approximated that of a typical tropical river catchment. The quite large portion of the base flow contrasted against the much smaller surface flow volume indicates an effective vegetation cover and the low to moderate slope angles of most catchment areas.

2.3.4. Calibration and Validation: Predicted Discharge Volume vs. Actual Values

The model underestimated the river discharge by an average 60%. Figure 2.11 shows several observed high peaks that were underestimated and a few low flows that were overestimated.

Notably, the model could forecast (by as close as 12%) the highest discharge measured at the height of Typhoon *Bopha* on Dec 4, 2012. However, the model significantly underestimated the subsequent observed river discharge values on the days after Typhoon *Bopha* until the end of the month. On three occasions: Oct 17 (2012), Nov 20 (2012) and Jan 25 (2013), the model slightly overestimated the river discharge.

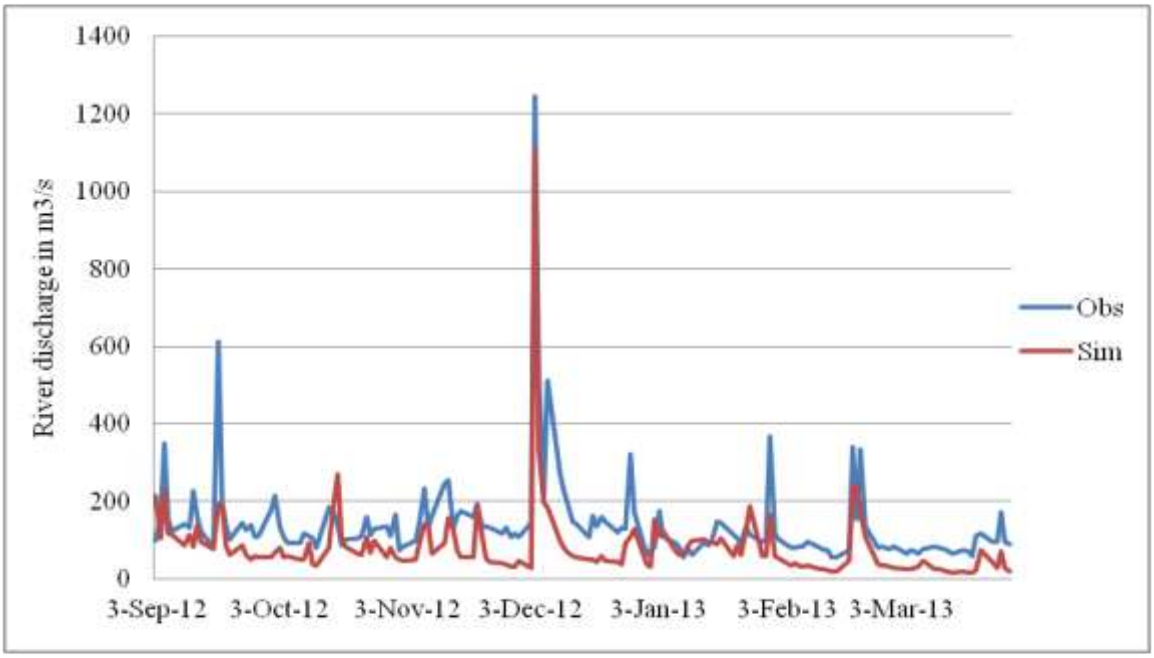


Figure 2.11: Graph shows the model's underestimation of river discharge in most low flows but has closely predicted high peaks pattern during simulation period from Sept 2012 to Mar 2013.

For the validation phase, Figure 2.12 shows the model's underestimation of flow data for both low flows and high peaks. The model overestimated the river discharge (10 and 13 May) only twice. Wide discrepancies between the observed and simulated data for discharge were evident all throughout the validation period (see Figure 2.11). Despite this, the general patterns of simulated flow followed the track of the measured flow, particularly for peak flows. This indicates the model's positive responses, albeit at smaller scales compared to high river discharges generated by strong rainfall events in the catchment.

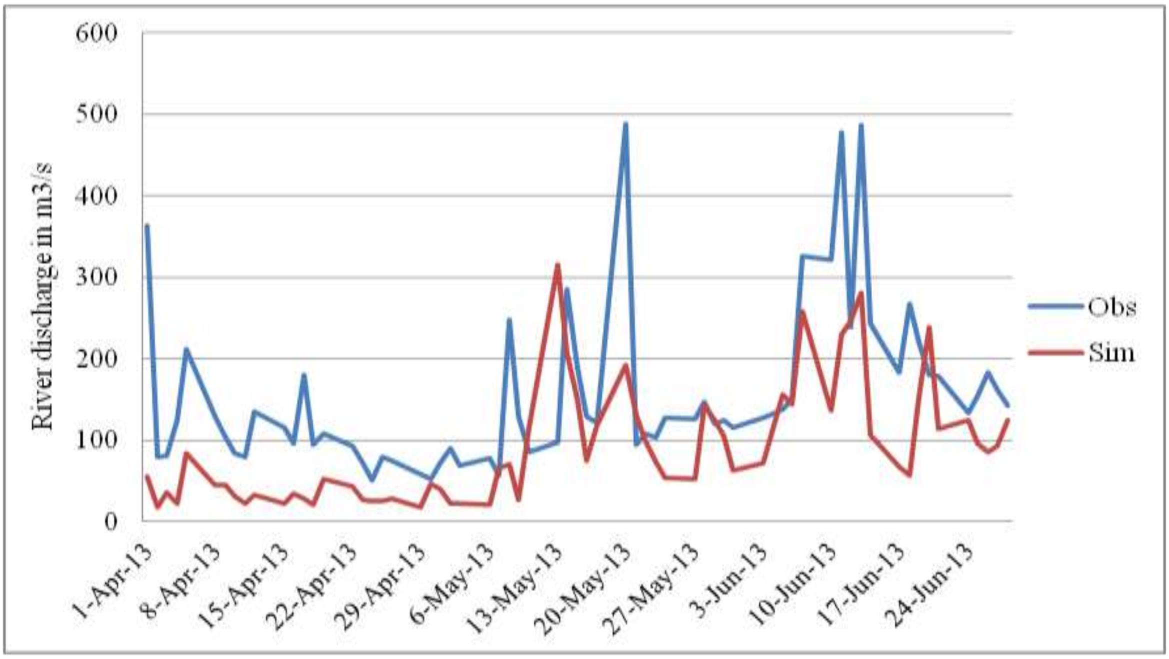


Figure 2.12: Graph shows the model's overestimation of observed daily discharge for both high peaks and low flows during the validation phase from April to June 2013.

2.3.5. Conversion from Sediment Concentration (SSC) to Total Sediment Load

In the present study, sediment samples collected daily in the Cagayan de Oro River were SSC in mg/L. Figure 2.13 shows the daily amount of SSC collected from September 2012 to June 2013 in time-series.

To calculate the sediment load volume of the river outlet as the prescribed unit of SWAT model measurement, measured data in SSC in mg/L were converted to total sediment load in t/ha. The computation was undertaken using the formula below:

Sediment load = SSC in mg/L x Discharge in m^3/s *(Eq. 2.6)*

Total sediment load in mg/s then divided by area in ha *(Eq. 2.7)*

Conversions of the following:

- SSC in mg/L to $tons/m^3$
- Discharge in m^3/s to m^3/day

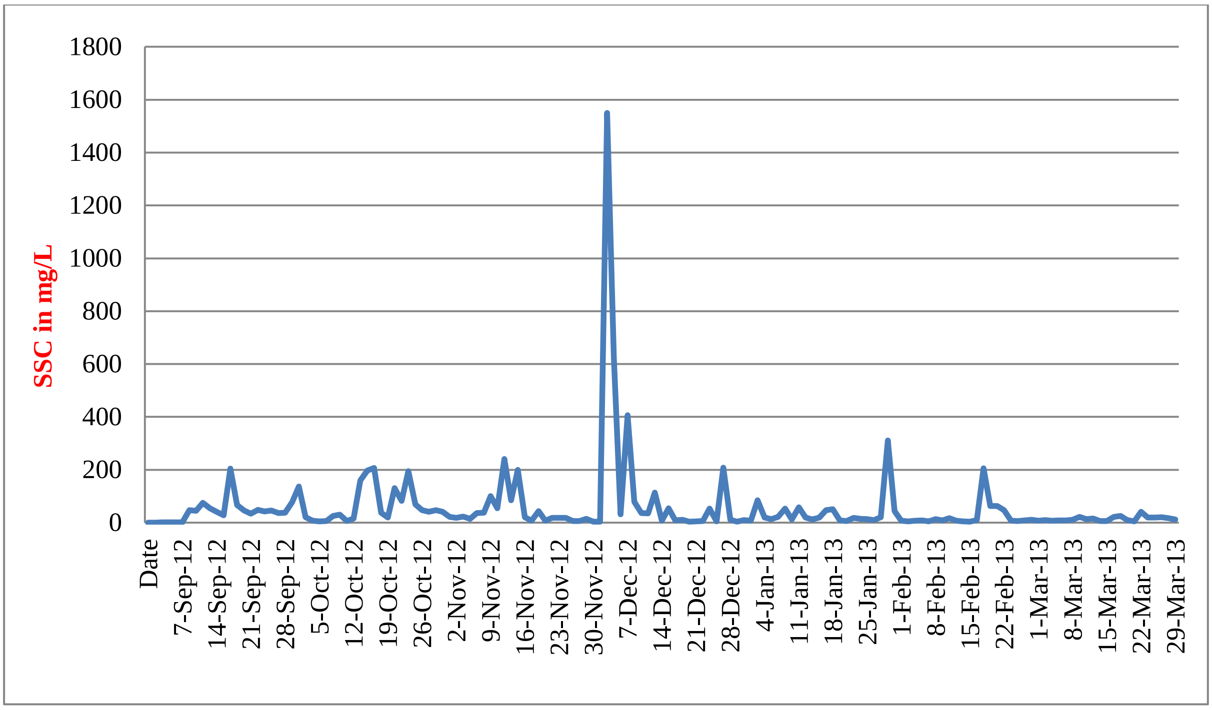


Figure 2.13: Observed SSC, Cagayan de Oro River, Philippines; September 2012–March 2013. Highest peak was during Typhoon *Bopha*.

2.3.6. Calibration and Validation: Predicted Sediment Yields vs. Actual Values

Figures 2.14a and b show the daily observed and simulated sediment yield from September 2012 to March 2013. The model overestimated the sediment yield at an average 28%. From September to December 2013, the model captured—with relative accuracy—both the peaks and low yields of the observed results (see Figure 2.14b). In fact, at the highest peak of sediment yield during Typhoon *Bopha*, the observed value was only 7.5% lower than the simulated one. However, the model overestimated several instances of low-sediment concentration after Typhoon *Bopha* until the end of sampling period in March by as much as 70% (see Figure 2.14a). Relatively low-sediment concentrations were recorded in the river site during the sampling dates of Dec 6, 26 and 28 (2012); Jan 2, 4, 11, 24, 25 and 30 (2013); Feb 19, 20, 21 (2013); February; and Mar 22 (2013).

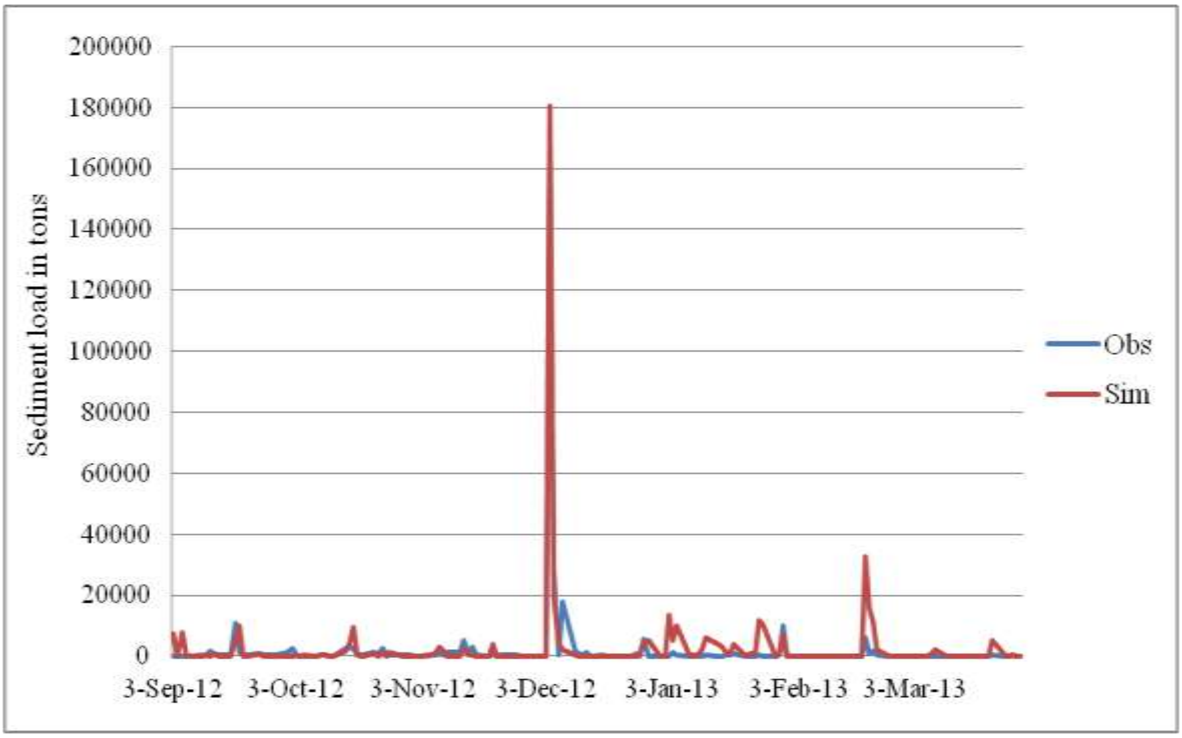


Figure 2.14a: Graph showing the model's overestimation of sediment yield for both high peaks and low flows during the simulation period from September 2012 to March 2013.

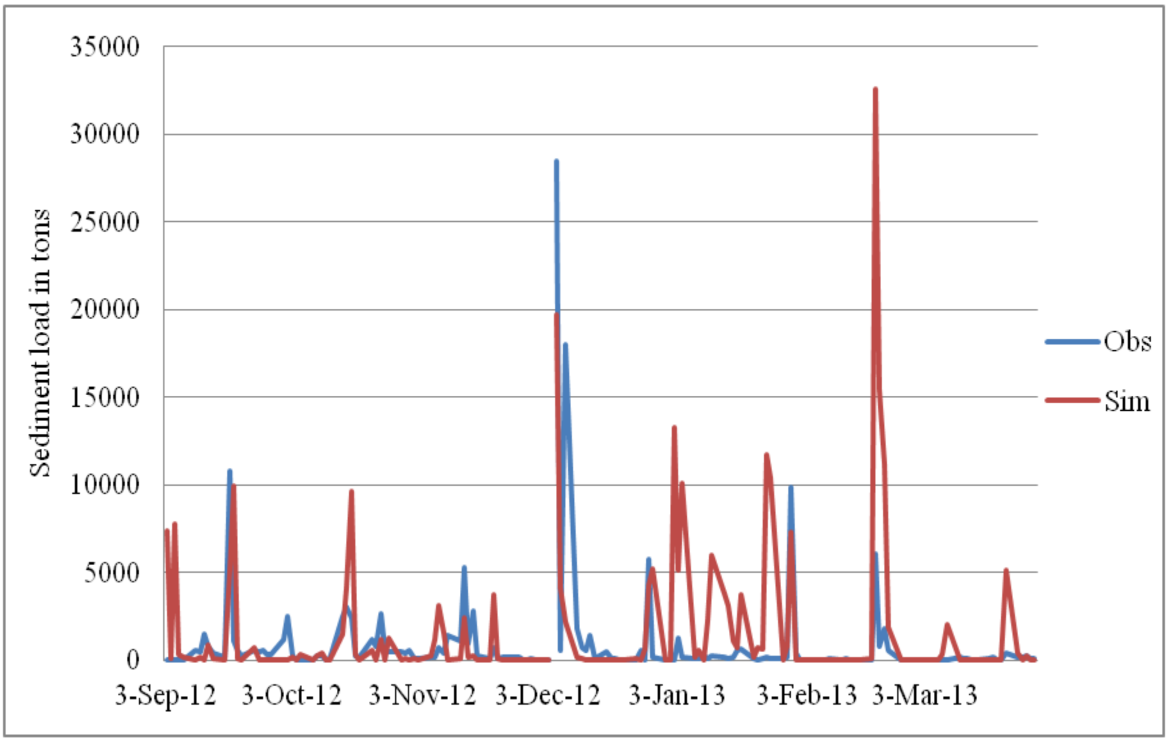


Figure 2.14b: With the highest sediment yield in December 2012 removed, the graph shows more clearly the model's overestimation of sediment yield, particularly from Jan to Mar 2013 for both high peaks and low flows.

Regarding validation, Figure 2.15 shows the model's overestimation and underestimation of the simulated results in different events. The model could simulate, with a relative degree of accuracy, the low-sediment amounts from April to mid-May 2013 and from the last week of May to the first week of June 2013. In contrast, on several occasions of high peaks, Apr 1 (2013); May 8, 20 (2013); June 7, 11, 13 (2013), the model overestimated the sediment yield by 124% to 1,737 %. For three incidents (April 5, May 13 and June 20 in 2013), the model significantly underestimated the sediment yield by 922% to 1,446%.

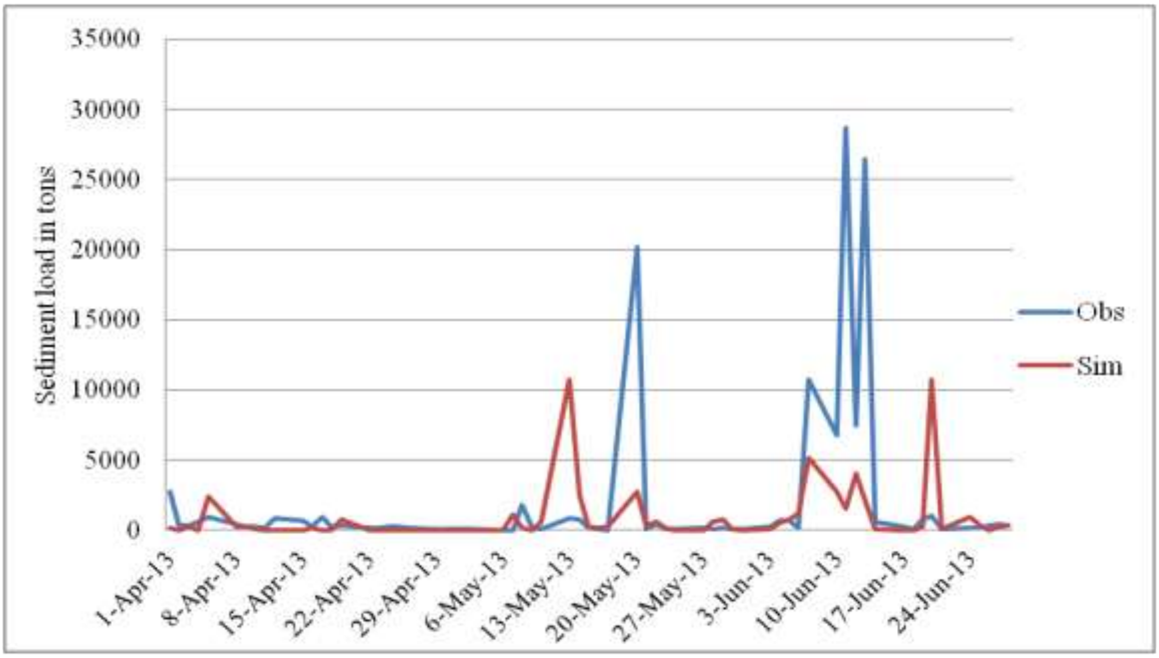


Figure 2.15: Graph shows the model's severe underestimation of simulated sediment yield in certain events, but also the high overestimation of data at other times during the validation phase from April 2013 to June 2013.

2.3.7. Predicted Sediment Yields in the Cagayan de Oro River Sub-Catchments

Table 2.13 presents the summary of sediment yield categories, which includes six sub-catchments severely prone to erosion. These sites comprise only a small portion (2.96%) of the catchment area, while the largest part (76%) was assessed as relatively stable under normal rain conditions. Notably, apart from the very high-sediment yield category, the curve number (CN) and length and steep (LS) values for the other three categories did not exhibit significant differences. In addition, the rainfall inputs for very high and high-sediment yield categories were much higher than for the other three lower sediment yield categories.

Table 2.9: Summary table of sediment yield categories and common key catchment attributes and rain factor. The common key attributes' average values among high, moderate and slight sediment-yielding sub-catchments do not vary a great deal. Significant differences in values are more evident among individual sub-catchments.

Sediment yield (t/ha)	No. of sub-catchments	Total area (ha)	Common key attributes (Mean & standard deviation)		
			CN	LS	Rain (mm/10 mos)
Very high (>50)	3 (2.40%)	1,215 (0.86%)	69.72 2.1	5.12 3.89	>3,787.91
High (>15 to 50)	3 (3.60%)	3,061 (2.10%)	64.89 4.22	3.65 0.28	>3,787.91
Moderate (>5 to 15)	17 (21%)	28,798 (20.50%)	64.42 8.3	3.82 2.8	2,872.24 561.59
Slight (0-5)	61 (72%)	107,014 (76%)	62.40 8.48	3.56 2.88	2,844.59 570.06
Total	84 (100%)	140,088 (100%)			

It is significant that the moderately prone erosion sites or sub-catchments are spread over the entire catchment area (see Figure 2.16). However, a concentration of high-sediment yielding sub-catchments exists at the base between Mt Kitanlad and Mt Kalatungan, where most slopes are steep and a network of interconnected streams and small rivers characterises the area and its surroundings.

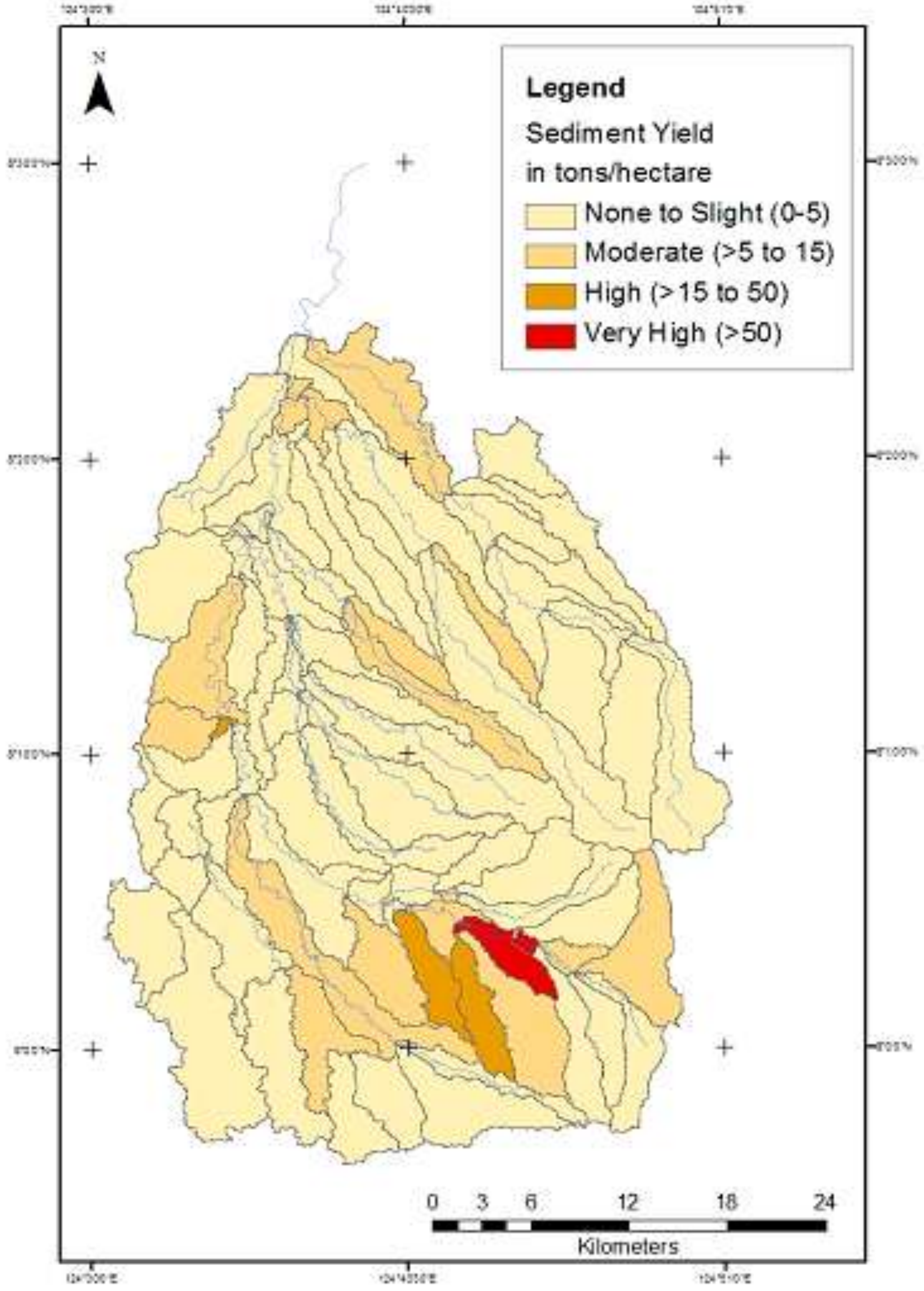


Figure 2.16: The 84 sub-catchments of the Cagayan de Oro River catchment generated by the SWAT model with their corresponding sediment yield values in tonnes per year. Large sediment yield indicates the site's high erosion potential.

2.4. Discussion

2.4.1. Rainfall Effects on River Dynamics

2.4.1.1. Seasonal rainfall effect on river discharge.

Based on the adjusted R^2, total rainfall inputs from the four rain gauge sites—Talakag, Nangka, Tikalaan and Miarayon—explained 71% of the river discharge variation during the dry season. However, during the wet season, only 21% of the variations can be attributed to rainfall inputs from the four gauged sites (see Table 2.9). A higher level of rain influence on total discharge variation during the dry season than in the wet season may indicate that the rainfall's impact originated mainly from gauged stations. In contrast, in the wet season, the gauged rain factor had a low effect on river discharge changes, suggesting the increased influence of non-gauged rain. Normally, during the wet season a rainfall event can be distributed widely in many parts of the catchment including the river system. Thus, river discharge volume largely increases from direct rainfall input and not from the gauged sources.

2.4.1.2. Seasonal rainfall effect on SSC.

The overall results during the wet season show that rainfall totals from Talakag and Tikalaan explained significantly at 22% the changes in the amount of river's sediment load; and in the dry season rainfall amounts from Nangka and Miarayon explained 51% of the SSC variations. The higher rainfall effect on total sediment values during the dry season compared to the wet season may relate to the impact of gauged rainfall. This is low in volume, but is mostly included in the rainfall-river correlation measured input. With the wet season, the rainfall input is much higher than in dry season, but a large portion of it comes from non-gauged sources. Similarly, during the dry season, the gauged rainfall effect may generate low SSC amounts, but these are mostly accounted for in the correlation. During the dry season, rainfall contributions from non-gauged sources are low due to low rainfall in the catchment. In the wet season, heavy rains also generate high SSC amounts, but this is largely due to non-gauged rains.

2.4.2. SWAT Model Performance

2.4.2.1. Water balance equation.

After appropriate adjustments of certain hydrologic allocations, the Cagayan de Oro River catchment's run-off CN was computed at 60.88 (see Figure 2.10). The run-off CN is a function of the catchment's land use, land moisture and hydrologic soil groups. Comparing the CN of 60.88 with the CNs of various land types, soil types and moisture conditions (Cronshey & Division, 1986), the former is classified (roughly) under a wood-grass combination with fair hydrologic conditions. The wood-grass classification is the author's approximation of the catchment's land use characteristics, a combination of forest-grasslands-shrubs-agricultural. The soil's fair hydrologic condition is due to seasonal shifts in rainfall patterns that affect the entire catchment. Soil permeability is classified as the 'B soil group', which is moderately well-drained to well-drained soil (Catacutan & Cramb, 2004). The given CN of 65 from the 'Table of land cover descriptions and hydrologic soil group' (SCS, 1986) is relatively close to the model's simulated CN (60.88) for the Cagayan de Oro River catchment. However, the model's CN for the catchment could not capture accurately the complexity of the whole catchment's physical characteristic and various land use complexity.

2.4.2.2. Calibration and validation for river discharge volume.

The hydrograph in Figure 2.11 indicates general positive association patterns between the observed and simulated values. However, value correlations between the two sets of data were relatively uneven, particularly during events of high peaks from Sept 2012 to March

2013. The model's competence at simulating the run-off volumes is indicated by the NSE value of 0.51 (51%); this is considered satisfactory, based on a widely used guideline in Moriosi et al. (2007). The calibration results demonstrate the sufficient consistency of the model's data on river discharge with the dataset of similar river parameters. This means that the model and its adjusted parameters and constants are satisfactorily capable of estimating actual river discharge performance in the Cagayan de Oro River.

However, based on the statistical indicator results, the validation phase has an NSE value of -0.12, which means the modelling application was unsatisfactory (see Figure 2.12). The underestimation of observed river discharges during the validation phase could be due to the limited range of conditions present in Apr to June 2013. The three-month validation period included both the dry and the wet season, but data were insufficient. During calibration, the SWAT model became adapted to the wetter months and during the very short validation period the simulation did not have sufficient time to adjust accordingly.

2.4.2.3. Calibration and validation for predicted sediment yield.

The overestimation of simulated sediment load values by the model (see Figures 2.14 a & b) could be partly explained by a high rainfall input in particular sub-catchments or HRUs. Due to site-specific rain applications, the discharge volume was not reflected in peak flows at the river outlet. However, the model was sensitive enough to interpret it correctly due to strong rainfall events in particular sites. Other conditions may have facilitated the increased simulated sediment yield. These include the land features of these specific sites affected by rain. Heavy rains aggravate the erosion-prone conditions of these sites as they are largely cultivated, sparsely vegetated and annually cropped. Given the combination of localised heavy rains, steep slopes and highly erosion-prone terrain, the model predicted correctly that these specific HRUs (or sub-catchments) would generate increased sediment load in the stream. However, in the actual sample field collection, sediment amounts were low, most likely due high soil deposition during transport processes. Low-sediment delivery overland and along channels could be attributed to low river discharge from low rain input in most of the catchment area during the summer months. Thus, a discrepancy exists between sediment yield in erosion sites and sediment load reaching the river-sampling site.

Finally, the close match between simulated and observed sediment yield values has an NSE value of 0.91 (91%), which is highly acceptable statistically (Moriasi et al., 2007). With the necessary calibrations performed accurately, the SWAT model could simulate at 91% accuracy the actual pattern of sediment amounts collected in the river during the given sampling period. Further, the PBIAS (%) value was -40.65, which is close to the prescribed satisfactory value of ± 55% for sediment (Moriasi et al. 2007). As with river discharge, a high level of confidence exists here that the modelling is sufficiently capable of estimating SSC values in the actual conditions.

However, based on the NSE value of 0.02, validation of the model's performance for sediment yield during the last three months of sampling was poor (Moriasi et al., 2007). The poor validation performance of the model could be due to the very short validation period (see Figure 2.15), which did not allow enough time for the model to readjust according to the behaviour patterns of the sediment yield.

As proven by two statistical indicators—NSE and PBIAS (%)—the SWAT model, if given proper and correct calibrations and adjustments to its parameters, could have high consistency levels with the river discharge and sediment concentration values. Therefore, it has the internal capability and potential to simulate a real system with relative accuracy, even with a 10-month sampling period. In this sense, the model itself is valid and is acceptable for community use for planning and management purposes.

2.4.3. Common Key Factors and Catchment Attributes Potentially Affecting Predicted Sediment Yield Variations

Four important factors or variables—rainfall, LUC and soil conditions (CN) and slope class (LS)—were considered largely influential on the sediment yield capacity of sub-catchments. These factors were identified based on their recurring close correlation with the high-sediment yield values of the sub-catchments. Several previous studies have also confirmed the major influences of these key variables on erosion and sediment transport processes in many catchments around the world (Douglas-Mankin et al., 2010; Tuppad et al., 2011 as cited by Arnold, et al., 2012).

The SWAT model is based on the assumptions of the MUSLE, which uses run-off variables as the driving force to estimate sediment yield for individual storm event (J. Williams, 1975). The MUSLE was successfully developed in practice to estimate sediment yield by J. Williams and Berndt (1977) with a correlation coefficient of 92%. It observes the equation below:

$$Y = X \times K \times C \times P \times LS \times CFRG \qquad (Eq.\ 2.7)$$

Where Y = sediment yield in ton per hectare

X = erosive energy factor

K = soil erodibility factor

C = crop cover and management factor that captures the relative effectiveness of soil and crop management systems in preventing soil loss

P = erosion control practice factor (including management practices such as terraces, contour farming, and strip cropping)

LS = slope length and steepness factor

CFRG = coarse fragment factor.

An increase or decrease in the value of any MUSLE variable may also affect the sediment yield value in a sub-catchment. For the present study, the model assigned default values to the soil erosion control and coarse fragment factors. LUC characteristics were used for crop cover and management factors. The soil erosion-prone factor was limited to only two soil textural conditions.

2.4.3.1. Rainfall.

Rain is one of the main factors responsible for erosion and deposition of upland sediments downstream and eventually, in the bay (Thrush et al., 2004; Choi & Wilkin, 2007). First, rain is a main driver of soil detachment in soil erosion. Second, rain also causes an increase of surface run-off (Balek, 1977). Rain's capability to erode soil from the land is called 'rain erosivity'. This is a function of rainfall amount and intensity (rain amount/rain duration) as raindrops are poured onto the ground. Rainfall amount influences run-off potential with a given specific set of land cover features, soil type conditions and terrain topography characteristics.

Thus, the MUSLE uses run-off volumes and peak flows to estimate run-off and sediment yield, instead of taking rain strictly as the sole source of erosive energy. For energy, Williams (1975) used the formula below (as cited by Cardei [2010]).

$$X = 11.8\,(Qqp)^{0.56} \qquad \textit{(Eq. 2.8)}$$

Where Q = run-off volume (m^3)
q_p = peak run-off rate (m^3/s)

Run-off is calculated using the SCS CN method and peak flows with the equation below:

$$q = C \times i \times A \qquad \textit{(Eq. 2.9)}$$

Where q = peak flow rate (m^3/s);
C = run-off coefficient representing river basin characteristics
i = rainfall intensity (mm/hr) for the river basin's time of concentration; and
A = river basin area (sq. m).

2.4.3.2. Run-off curve number.

The run-off CN is based on the following: land use, hydrologic soil group and hydrologic condition of the HRU or the sub-catchment. A lower CN value means run-off potential is predicted as low, while a higher CN value indicates high run-off potential. Average to high CN values (60 to 76) of the Cagayan de Oro River sub-catchments indicate average to relatively high run-off potentials, mainly due to land cover variability (see Figure 2.7) instead of soil conditions (see Figure 2.8)

The basic assumption of the CN method is that in every single storm, the ratio of actual soil retention to the potential maximum retention is equal to the ratio of run-off to available rainfall. This relationship is represented by the following equation (NEH-4) (USDA-SCS, 1986), where the CN is the potential maximum soil retention (Ponce & Hawkins, 1996):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \textit{(Eq. 2.10)}$$

Where Q = run-off (m^3/s)

P = rainfall (mm/hr)

S = potential maximum soil moisture retention (mm) after run-off begins

Ia = initial abstraction or the amount of water (mm) before run-off, such as infiltration, or rainfall interception by vegetation; Ia = 0.2S.

CN is then related to:

$$S = \frac{1000}{CN} - 10 \qquad \textit{(Eq. 2.11)}$$

2.4.3.3. Length and steepness of slope.

With the LS factor, the slope length computes the effect of the slope's length on erosion. The slope steepness computes the effect of that steepness on erosion.

The Cagayan de Oro River catchment has a wide range of LS values—from 0.78 to 16.62—indicative of its mountainous southeast side and gently sloping lowlands (see Figure 2.9).

In the USLE, the LS factor is calculated in each grid cell to predict the effect of slope on soil loss (Wischmeier & Smith, 1978). The LS factor is estimated using the following equation (Wischmeier & Smith, 1978):

$$LS = (\lambda /72.6)^{m} (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.65) \qquad \textit{(Eq. 2.12)}$$

λ = slope length in feet

θ = angle of slope

m = 0.5 of the per cent of slope is 5 or more; 0.4 on slope of 3.5 to 4.5%

0.3 on slope of 1 to per cent, 0.2 on uniform gradients of <1%.

The relationship of soil loss to slope percentage is influenced by the type and density of vegetation cover and the site's soil condition.

2.4.4. Predicted Sediment Yield Variations in Cagayan de Oro Sub-catchments

2.4.4.1. Very high-sediment yield: the sub-catchments' attributes and other key factors.

The three sub-catchments (SCs 63, 66 and 68) exhibited very high-sediment yield potential (see Table 2.13). The highest averaged CN value can be attributed to the land uses; predominantly brush, pasture and agricultural lands (Allan et al., 1997; Dedkov, 2004) (see Appendix B). The overall effects of these three land use types increased the potential of soil erosion in the sites. Both sub-catchments SCs 66 and 68 comprise ~50% pasture. In addition, the other half of these sub-catchments are made up of agricultural land (SC 66) and brush land (SC 68). From the SWAT modelling results (see Table 2.13), a considerable increase in the percentage cover of any of these three land types (CN constituent) would also have a positive effect on the sub-catchment's erosion potential. This is logical, as these land use types have a relatively lower mass density of vegetation cover compared to forested areas. Under threat from heavy rains and strong winds, upland vegetation does not have sufficiently dense foliage to cover and protect the ground from the erosive force of large rain drops (Mohammad & Adam, 2010). Given similar pressure from rainfall events, neither are these plants' roots extensive and strong enough to keep soil intact and stable (Ziemer, 1981).

Imposed external disturbances on the land aggravate the sub-catchments' instability. According to a report from the DENR (as cited in Paragas et al., 1999), 75% of the Philippines' cropland is vulnerable to erosion. In this study, the SWAT model has classified 'agricultural land' as a general land use class with annual cropping. Thus, agricultural lands have high erosion potential for two reasons. First, the practice of soil tillage in cultivated fields intensifies soil erodibility, resulting in soil detachment and run-off during rainfall events (Poulenard et al., 2001; Takken et al., 2001). Second, annual cropping follows the seasonal harvest of crops once or twice a year. After harvest, cultivated fields are cleared and left open for the next planting (Neushul & Badash, 1998). In warm weather, reduced vegetation cover due to the desiccated and exposed soil surface causes soil to become loose and highly erodible (Cerdà, 1998). Limited vegetation cover may also result in soil crusting that weakens soil's capacity to absorb water (Nunes et al., 2010). Continuous surface flow can effectively erode top soil and disperse it to adjacent sites. That is why, generally, a much-reduced forest or vegetation cover (or the absence of it) (see Appendix B) is common among these high-sediment yielding sub-catchments.

In relation to soil conditions, clay loam belongs to Group D soils that have very low infiltration rates and a very high run-off potential when thoroughly wetted (USDA-SCS, 1986). With sub-catchments (SCs) 63, 66 and 68, where rain volume and impacts were very high, the consequent run-off and sediment transport rates could have also dramatically increased.

As to the slope conditions of both sub-catchments, 23% to 79% of each area is in the >30% slope class. Of SC 63's land area, 79% has a slope of >30%. All three sub-catchments lie adjacent to one another within the high upstream zone, where a network of head streams, (Baylanan, Banongcol, Sangaya and Sagayan) drain into the bigger Batang River. The riverbanks in these sites are relatively steep, exacerbating the local terrain's instability. The instability of river banks and levees is further aggravated by seepage, erosion and undercutting caused by surface water (Vandamme & Zou, 2013).

The combined effects of reduced vegetation cover, steep slopes and very high rainfall input worsens a catchment area's unstable conditions. An increase in slope angle is correlated with a rise in sediment yield from the site, although this is not as significant as the effect of vegetation cover on sediment loss (Brock & DeBano, 1982). However, with sufficiently dense forest vegetation, sediment erosion can be regulated, as with thickly forested mountain slopes. In contrast, steep slopes of >10% in cultivated and less-vegetated areas generate a considerable rise in sediment run-off volume (Pimentel et al., 1995; Presbitero et al., 1995). Sediment run-off in limited vegetated slopes increases further as the site's rainfall input also site increases (Freebairn & Wockner, 1986)

With these given existing conditions, the triggering effect of extremely high rainfall input explains the very high-sediment yields (Wilson, 1972; Lamoureux, 2000;) of SCs 63, 66 and 68.

2.4.4.2. High-sediment yield: sub-catchment's attributes and other key factors.

A high CN value is mainly due to the existing land cover and uses (García-Ruiz et al., 1995; Dunjó et al., 2004) in all three sub-catchments: SCs 62 and 65 have large tracts of pasture lands, with 52% and 75% coverage respectively (see Appendix B). The rest of SC 62's land cover is mostly agricultural, with 98% of its total land area being combined pasture and agricultural lands. SC 37's total land area includes 63% of agricultural land, with no forest cover. SCs 62 and 65 have much-reduced forest areas, with 0.8 and 21% respectively. Examining SC 65, its forest cover of 21% is easily offset by a much larger area of pasture; this has a much-reduced regulating effect on sediment run-off.

The relatively high LS value is mainly contributed by SC 37, with 58% of its total land area being within a ≥20% slope class (see Appendix B). The dominant steep slopes in the site can be explained by the sub-catchment's location. A closer examination of the DEM map shows that SC 37 is located at the converging point of the main channel and a major tributary, the Pigcutin River and another stream originating from the cluster site. The convergence of these rivers and a stream renders the site's topography as less stable, due to the bank slopes and levees (Vandamme & Zou, 2013). In fact, based on the catchment slope map, this location is characterised by very steep slopes. From ground validation observation, the site has deep ravines running parallel to the main river channel and the main highway. With the other two sub-catchments, the most slope classes are below 20%, comprising 65% of SC 62 and 62% of SC 65 (see Appendix B).

Compared to the moderate sediment-yielding sub-catchments, the high-sediment yielding clusters generally exhibit lower averaged CN and slope values. However, its rainfall input is very high. A positive correlation relationship between rainfall values and SSC measurements clearly demonstrate the significance of seasonal rainfall amounts on the river's sediment load (Wilson, 1972; K. Sharma & Chatterji, 1982). The rainy season and storm events produced a high rainfall amount and a longer rain duration that exacerbated site erosion and accelerated soil transport to the closest streams. With soil erosion, the high rainfall input naturally produced rain drops with strong erosive power able to detach soil particles from the land mass (P. Sharma et al., 1995; I. Pal & Al-Tabbaa, 2009). With sediment delivery, accumulated rain water on the ground generated an increased energy of water flow to carry more sediments overland to the river (Beuselinck et al., 2002; Wang et al., 2007). This exceedingly high localised rainfall input could be attributed to the sub-catchments' location within the catchment's highly elevated mountainous parts, and their proximity to the headwater's base.

2.4.4.3. Moderate sediment yield: sub-catchment attributes and other key factors.

Nineteen sub-catchments exhibited moderate sediment yield results (see Table 2.13). In general, the LUC characteristics between these moderate sediment yielding sub-catchments and the high yielding ones did not show considerable differences. Similar to the latter, most sub-catchments under the moderate category had existing LUC, consisting of 30% to 90% of either agriculture, pasture or brush land (or combinations of the two or three LUC types) (see Appendix B). As an example, SC 4 is 95% agricultural land and SC 8 has 96% of agricultural, pasture and brush land combined. Moreover, these sub-catchments share the common characteristic of sparse or no forest cover.

Despite a huge area covered by land use types with relatively low regulating effects, these sub-catchments maintain a more moderate sediment-yielding capacity, partly due to their low rainfall averages (see Appendix B) (Mathys et al., 2005). In fact, for the sub-catchments mentioned above, the average annual rainfall amounts recorded were between 2,134 and 2,844 mm (213 to 284 mm/month). Further, in certain sub-catchments, the moderate sediment yield is mainly due to low-slope angles, and exists despite a high rainfall input and significant low to densely vegetated areas (e.g., SC 67). Gently sloping landscapes mitigate rainfall impacts on soil and enhance vegetation's regulating effect on sediment overland transport.

Forest cover did not have a clearly effective regulating effect on sediment yields in the sub-catchments. This is due to one reason: forest cover values are very low compared to the percentage cover of land use types such as agriculture, pasture and brush land. The amount and physical distribution of forest cover in relation to other low to dense vegetation cover affected the rate of sediment losses (Bartley et al., 2006). Land uses without sufficient vegetation cover are unstable; this is more apparent on the steep sloping parts of the sub-catchment (Brock & DeBano, 1982). Naturally, agricultural, pasture and brush land have a diminished capacity to prevent soil erosion and transport. This is due to the absence of large woody plants that provide strong roots preventing soil disintegration, and sufficient canopy cover protecting soil from weathering effects (Costa et al., 2003; Hurni et al., 2005). Additionally, only a few HRUs and sub-catchments have remaining forest areas, and these are relatively small in their percentage cover (see Appendix B). Further, forests' regulating effect on erosion and sediment transport depends on the geographical location of vegetation cover within a HRU or sub-catchment. For example, good forest cover occupying steep slopes has a limited regulating effect on the run-off rate potential, while forest areas located on flat lowland surfaces may have enhanced regulating effects, due to favourable plain topography (Harden & Scruggs, 2003).

In general, the driving factor in most sub-catchments' sediment loss is the rainfall volume at each HRU or sub-catchment (Zabaleta et al., 2007). A slight decrease in rainfall input resulted in a corresponding decline of sediment yield values at many sites. Ultimately, rainfall's effect on the soil and its transport is largely determined by the sub-catchments' land cover and topography.

2.4.4.4. Slight sediment yield: sub-catchment's attributes and other key factors.

The remaining sixty-one (61) sub-catchments in the Cagayan de Oro catchment produced the smallest amounts of sediment (see Figure 2.16). The capacity of a sub-catchment to regulate the amount of sediment generated per HRU is determined by the dominance of any of these three factors—rainfall amount, LUC and slope—or any combination of these factors in relation to the others.

For LUC, the presence of a sizeable forest cover equalised the enhancing effect of other land uses on sediment yield or prevented the increase of sediment yield directly. Large forest areas and dense vegetative cover have an increased capacity to regulate erosion and sediment transport rates (Stocking, 1994). First, forest trees provide strong, deep and extensive root systems that hold soil in place so it is not washed away during heavy rains (Ziemer, 1981; Abe & Ziemer, 1991). Second, thick forest tree cover diminishes the hard impact of raindrops on soil, preventing the erosion and disintegration of soil aggregates that could lead to further erosion (Eldridge & Rothon, 1992; Greene et al., 1994).

Several sub-catchments possess very high forest cover due to their locations near the base of Mt Kitanglad. Some sub-catchments lie on the sloping side of the mountain, giving them steep slopes, but with a high forest cover area (see Appendix B). Other sub-catchments near the foot of Mt Kalatungan have very high rainfall input, but the forest cover area is also significant. The presence of thick forest cover limits the erosion and sediment transport processes (Brock & DeBano, 1982), despite the presence of erosional factors such as high rainfall and steep slopes.

It is important to note that a low-sediment yield could be attributed to relatively low rainfall amounts in the sub-catchments (see Appendix B) (Römkens et al., 2002).

2.4.5. Massive Erosion and Flooding During Typhoons *Washi* and *Bopha*

The Cagayan de Oro River catchment's high vulnerability to erosion was clear during Typhoons *Washi* and *Bopha*, when very strong rains in the uplands resulted in massive mud floods in the lowlands and heavy losses of lives and properties. Severe impact of heavy rains on specific sub-catchments was noted in the previous studies of (Pimentel & Kounang, 1998).

The very high variability of rainfall patterns over both area and time exacerbates the risk of erosion in the catchment (Seeger, 2007). A strong and widespread storm can trigger a considerable loss of sediment in at least half of the total number of sub-catchments. This is due to the presence of large areas of catchment attributes, as identified by the SWAT model, which are vulnerable to erosion, such as cultivated land, less-vegetated/forested areas, high elevation and very steep slopes.

2.4.6. Model Limitations and Other Sources of Discrepancies in the Simulated Results

Discrepancies between simulated and measured data for both river discharge and sediment yield were examined in light of the model's limitations, the inadequacy of some dataset inputs, and the limited sampling period. Possible reasons for the discrepancy have been identified accordingly.

2.4.6.1. On the underestimation of simulated river discharge volumes.

The model assumes that water infiltrating the deep aquifer is not part of the future water budget calculations (Nietsch et al., 2005). With this assumption, a consequential loss of some amount of water (as predicted by the model) was evident (Luo et al., 2012).

Other sources for underestimating the simulated discharge data were directly related to the inadequate discharge dataset input into the model (Arnold et al., 2012). One was the inadequate rainfall amount sourced from only eight stations to represent the rainfall pattern of the entire catchment (Conan et al., 2003; Bouraoui et al., 2005; Cao et al., 2006). Compared with the observed discharge, the simulated discharge was only half of the observed amount (Tables 2.9 & 2.10). In fact, the World Meteorological Organization (WMO) requires one (1) rain gauge per 100 sq. km of spatial separation between gauged sites (Lanza et al., 2006).

2.4.6.2. On the overestimation or underestimation of actual sediment yield.

Consolidating agricultural sub-classes into one class under one common parameter when each differs in various parameters may have caused simulation errors. The SWAT model used sorghum as the agricultural plant for the entire catchment. However, the actual agricultural plants used may represent more than ten different plants over the catchment. Sorghum, which belongs to the grass family and has a leaf index area of 3.0 m^2/m^2 and a canopy height of 1.0 m (Kiniry & Bockholt, 1998 as cited in Arnold et al., 2012), may not adequately represent certain larger agricultural crops—such as coconut, coffee, olive palm and banana—that make up a sizeable group in the agricultural area. Moreover, the model placed sorghum as an annual crop subject to seasonal cropping (Kiniry & Bockholt, 1998 as cited in Arnold et al., 2012). A smaller sized seasonal crop has less regulating capability to keep soil intact and prevent it from being eroded and dispersed downwards.

Soil data are divided into two textural classes, which discounted variations in the proportion of clay, silt and sand. Due to the limited soil classes, soil characteristics such as soil hydraulic conductivity, which affects soil hydrology, were considered as one class only for half of the total catchment area. Consequently, other areas in the catchment having clay variations with higher and better water-absorbing capacities were not reflected correctly in the simulation.

Categorising slope into five classes oversimplified the catchment's actual topographical characteristics. It reduced the gradient variability in different areas of the catchment. In the actual situation of some sub-catchments, more steep slopes and shorter slope lengths were usually found near a branching network of streams and rivers. Complex slopes and depths have high regulating effects on overland flow, and therefore are likely sites for sediment deposition.

The SWAT model used MUSLE's structure and assumptions to calculate sediment output per day with a number of run-off variables. However, based on the erosional and run-off factors included in the equation, MUSLE did not consider the deposition of sediment portions at several points along the slope from the detachment site to the river site (J. R. Williams & Singh, 1995). Without the deposition of materials, the amount of sediment yield (t/ha) at the site of erosion was assumed to be the same as the amount of sediment (t/m^3) deposited in the river.

It could be that some parts of the river during the dry months have dried out or become shallow, resulting in a diminished flow of discharge and sediments. It is possible that sediment deposition occurred in slow flowing parts of the river, as sediments travelled along the channel (Alibuyog et al., 2009a). In the Bubunawan sub-watershed, higher sediment deposition could have occurred within the existing dam site and along the channel, due to low water velocity or morphological factors that resulted in underestimating the observed data for sediment yield.

2.4.6.3. The inadequate validation of water discharge and sediment yield.

Finally, the short length of the discharge record time-series may have caused the resulting poor performance of hydrologic simulations (Muleta & Nicklow, 2005). The charateristics of both wet and dry seasons in the calibration phase were not reflected in the limited range of conditions performed during the validation period (Gan et al., 1997). To assess the model's performance correctly, calibration and validation processes need sufficiently long rainfall and water discharge records to capture the hydrologic persistence behaviour of river discharge (Muleta & Nicklow, 2005).

2.5. Summary and Conclusions

The MLRA results showed the significant effects of spatial and temporal rainfall variations in the Cagayan de Oro River catchment area on river discharge and SSC in the Cagayan de Oro River. To account for the influence of existing catchment land features and management practices on the rainfall-run-off relationship, the SWAT model was employed to predict the run-off volume and sediment yield of every sub-catchment. Based on the NSE and PBIAS (%), the SWAT model in itself was amply equipped and sufficiently capable of simulating actual river discharge and sediment yield values. However, at the validation phase (which was too brief for the model parameters to make the necessary adjustments), the results were inadequate. The very short data collection period was the main reason behind the model's insufficient validation performance (Muleta & Nicklow, 2005).

Given the weak validation performance of the model, the following findings enumerated below should be taken as indicative only of the actual sub-catchment conditions specifically of their sediment yield capabilities, and therefore not conclusive enough for use in making critical decisions for the watershed management.

The SWAT model's results suggest that most sub-catchments of the Cagayan de Oro River catchment have generally low-sediment yields (72% of all sub-catchments). However, the model also approximated three sub-catchments (land area: 1,214.75 ha) with very high volumes of sediment yield; three sub-catchments (land area: 3,061 ha) with high-sediment yields; and 17 sub-catchments (land area: 28,798.25 ha) with moderate yields. Analysis of each 'priority sub-catchment' (within moderate to very high range) identified the dominant driving force (e.g., high rainfall) and a combination of key contributory factors (e.g. very steep slopes, large cultivated lands) to have most likely caused the increased sediment yields at the sites. Common risk factors (or catchment attributes) were identified in "hotspot" sites.

One factor is the dominant agricultural (Alibuyog et al., 2009), pasture (Weaver & Noll, 1935) and brush land areas (>50% coverage of the total land area) considered as an individual sub-class (or a combination of two or three sub-classes). Another risk factor is the large area of steep slopes in the sub-catchment (>25% of land area has ≥20% slope) coupled with reduced forest or vegetation cover—or a total absence of it. Steep slopes are mainly due to the sub-catchment's location near a mountain base (e.g., SCs 35, 61, 62, 65, 66, 72 and 73) (see Figure 2.16), and/or within a confluence zone of two or more rivers and streams (e.g., SCs 2, 3, 4, 21, 37, 52, 63 and 68) (see Figure 2.16). The interrelationship of these factors—such as steep slopes with low vegetation cover (e.g., rolling slopes grown with low-dense crops, mountain slopes covered with brush land, river confluence zones mostly comprising pasture lands) and a concentration of steep bank slopes within a minimally vegetated and protected area—have rendered the sub-catchment highly vulnerable to erosion (Abernethy & Rutherfurd, 1998). This unstable sub-catchment is put at even greater risk during storms and prolonged heavy rain in the area.

Other important findings are notable. These include:

1) Sub-catchments with very good forest cover, preferably ≥70% of the total area, and is widely distributed, can regulate erosion and sediment generation, even on very steep slopes (>30%).
2) Sub-catchments with good forest cover (≥50%), few cultivated areas (<50% of the total land area) and low-slope angles (≤20%) do not increase sediment yields even with storms and heavy rains
3) Sub-catchments with reduced vegetative cover (e.g., dominantly-agricultural lands) but with dominant low-slope classes (<20%) may not produce high-sediment yields.

Chapter 3:

Sediment plume behaviour and coastal current circulation patterns in the coastal marine environments of the Cagayan de Oro River catchment

3.1. Introduction

3.1.1. Catchment—Coastal Connectivity and the Key Factors Affecting its Sedimentation Dynamics

Upland erosion and the subsequent sedimentation are not limited to the catchment areas and affect more than the freshwater ecosystem and habitats. A continuum from the ridges to the lowlands also naturally transports water, sediments and other eroded upland materials downstream through the catchment's river systems and finally into the bay or ocean (McKergow et al., 2005; Saxton et al., 2012). Within the river channel, as flowing sediments approach the bay zone, various factors and conditions (e.g., sediment size and weight, river flow velocity channel morphology, coastal bathymetry) act on it and influence the plume's structure and trajectory (Ashworth & Ferguson, 1986; Milliman & Syvitski, 1992). As the plume leaves the river mouth and navigates offshore, various bay forces (e.g.. waves, tides, wind, Coriolis force) continue to affect the plume's (and therefore the sediment's) movement and direction until the deposition phase (Geyer et al., 2000; Dong et al., 2004).

3.1.2. The Cagayan de Oro River Catchment and Macajalar Bay

The present study identifies Macajalar Bay as the place of confluence for river discharge and other upland materials from the Cagayan de Oro River catchment via the Cagayan de Oro River (see Figure 3.1). Two other major river systems, the Iponan and the Tagoloan, drain into the same bay. The Cagayan de Oro catchment was chosen over these specifically, due to its increased vulnerability to degradation. This degradation results from a) the presence of large-scale land-based activities in the uplands (e.g., crop plantations, agricultural farm expansion) (Ecosystem Alliance, 2015); b) a rapid increase in urban population and infrastructural development (Philippine Statistics Authority, 2013); and c) the proliferation of manufacturing plants along Macajalar's coastal areas (Quizon, 2005).

Figure 3.1: The Cagayan de Oro River catchment and Macajalar Bay connected by the Cagayan de Oro River that transports sediments and other materials to coastal areas and offshore (base map from Google, 2015).

A close connection between the Cagayan de Oro River catchment and Macajalar Bay, in particular, the river plume and the coastal marine environs, was suspected due to actual observations and previous studies of coastal habitats in the bay. Increased river sediment plumes were observed during strong rain events in the uplands. Siltation at the river mouth was also observed to worsen after heavy rains and typhoons. Further, previous ecological surveys (Quiaoit et al. 2010) have reported the threatened status of marine ecosystems and fishery resources in the bay (to be discussed in the next sub-section). In the present study, the river sediment source is located proximate to existing seagrass and coral habitats in the bay.

However, no scientific study has yet been undertaken to demonstrate a relationship between the present conditions of marine resources in the bay and river-borne sediments. Two main sets of information are needed in this study: a) the potential location(s) of sediment deposition in the bay, and b) the weather- and bay-forcing factors that determine the SSC level at the affected site.

Demonstrating sedimentation-coastal habitat connectivity is challenging. In fact, the extent and direction of river plume trajectory could continually vary, depending on the influences of various factors and conditions, such as the river run-off, wind force and direction, tidal action, coastal bathymetry, re-circulating currents and boundary forces (Walker et al., 2005; Warrick et al., 2007; Hu et al., 2009). Due to the number of factors and conditions that could potentially influence the plume and the complexity of interactions over time, a modelling tool is needed to quantify the effect of each and all factors on sediment transport and persistence in the bay.

The resulting interplay of these factors and conditions within the bay has had a direct bearing on the affected site and the marine resources within it. River sediment plume threatens coastal marine habitats such as seagrass and corals, as determined by the prevailing weather conditions and the site's bay-forcing factors (Storlazzi et al., 2004; Carballo, 2006; Devlin & Schaffelke, 2009;).

3.1.3. The Study's Objectives

This present study aims to predict the extent of area encroached upon by river sediment plumes on the sampling sites of seagrass and corals, as influenced by key forcing factors during different events. The selection of potential influential factors was based on the datasets required by the Delft3D model and on Hurlburt et al.'s (2011) studies.

Using the Delft3D model, this study had four specific research objectives:

1) To demonstrate the general coastal current circulation flow in the bay near the river mouth.

2) To determine the suspended sediment dispersal behaviour under three different river discharge conditions.

3) To identify the bay-forcing factors that determine river sediment dispersal pattern.

4) To identify the potential areas of highest sediment concentration and deposition within the coastal marine environs.

The Delft3D, as a modelling tool, simulated actual coastal current circulation near the river mouth and predicted the fate of river-suspended sediment within the river-coastal continuum, as influenced by the interplay of various bay-forcing factors and conditions (Flemming, 1981; Schoellhamer, 1996).

Both coral and seagrass habitats are important biological indicators of sediment presence, both suspended and settled (Rogers, 1990; Neil et al., 2002; Erftemeijer & Lewis, 2006). Sedimentation effects on these habitats could be seen in increased water turbidity reducing sunlight penetration to the bay floor, or by the physical burial and smothering of organisms. Knowledge of sediment plume movement patterns in the bay is vital for drafting appropriate intervention measures for effective integrated coastal and catchment management programs (Xue et al., 2004; Bunn etal., 2007;).

3.1.4. The Study's Significance

Continuous sedimentation in the bay has had adverse effects on its three coastal habitats and fish populations within the vicinity (Newcombe & MacDonald, 1991; Wilber & Clarke, 2001). Previous studies of Macajalar Bay have reported the declining conditions of ecological and fishery resources in certain parts of the bay. Atrigenio et al. (1998) and Quiaoit et al. (2008) have reported a decline of fishery and marine resources in Macajalar Bay. Live coral cover also declined from good at 59% (Atrigenio et al., 1998) to fair at 38% (Quiaoit et al., 2008) between these two studies. Seagrass cover has increased in some areas and declined in other parts of the bay (Atrigenio et al., 1998 and Quiaoit et al., 2008).

Suspected sedimentation draining from the Cagayan de Oro River has most likely influenced reef and other marine habitat deterioration in certain parts of the bay. What is not clear is the extent in distance and plume concentration by which sediments have affected the marine and fishery resources. Previous studies of the bay's resources were limited to assessments of the bay's ecological and fishery resources.

The present study was confined to coastal habitat sites near the Cagayan de Oro River mouth. However, the study's results and findings can assist in understanding the dispersal patterns of sediments in other parts of the bay, affording a larger picture of plume influence here. Overall, knowledge of river plume characteristics, the extent of coverage, and its relation to coastal marine habitat conditions are useful for effective coastal and bay management planning. It is hoped that the study will also increase awareness among government authorities and local communities (both uplands and lowlands) regarding the vulnerability of marine environments to catchment impacts and exacerbating factors.

3.1.5. The Study's Scope and Limitations

Given the limited time and resources, this study has focused on and limited its scope to the following research concepts and related methods:

1) The study focuses on the coastal surface current circulation net effect on the distribution of river-borne suspended sediments in the coastal waters, as determined by the bay-forcing factors. No analysis was presented of other water movements, such as deep currents and vertical mixing.
2) Sediment plumes from the Iponan River were not considered in the study. The next chapter focuses on the reefs near the Cagayan de Oro River mouth, and the Iponan River is located further west of the Cagayan River mouth.

3) Salinity and TSS sampling sites in the east and the west were contained within the imaginary river plume-covered areas, which were as close as possible to the locations of coral reefs and seagrass meadows.
4) Bay-forcing factors and other variables were measured within a 10-month period between November 2012 and June 2013. The southwest monsoon months were not included.

3.2. Materials and Methodologies

3.2.1. Site Description—Macajalar Bay

Macajalar Bay borders the north of Misamis Oriental on Mindanao Island, Philippines (see Figure 3.2). It is part of the Bohol Sea that receives water from the Pacific Ocean through the Surigao Strait, and passes through the Dipolog Strait to the Sulu Sea (Hurlburt et al., 2011).

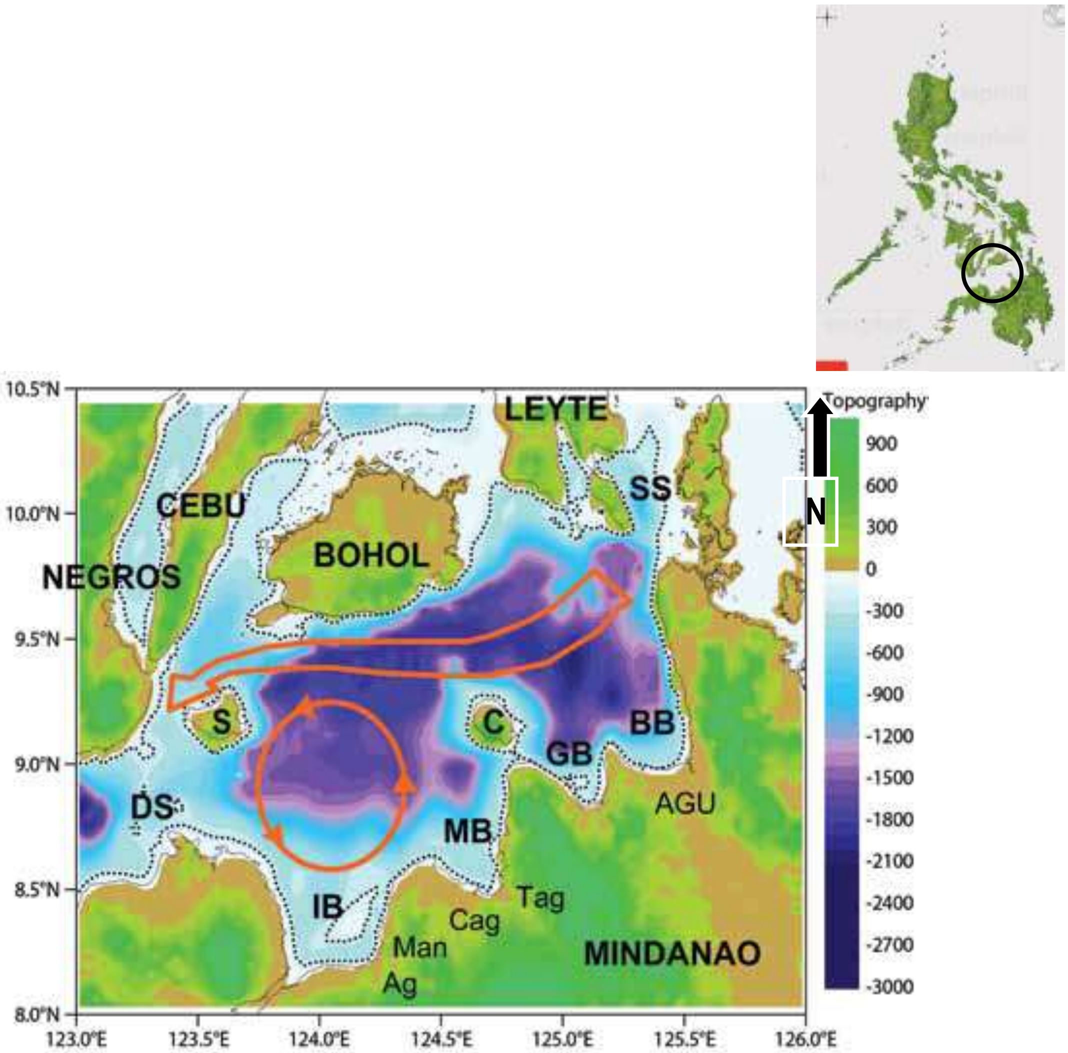


Figure 3.2: Maps showing a southwest surface current (orange arrow) called the Bohol Jet and a cyclonic eddy called the Iligan Eddy (Gordon et al., 2011; Hurlburt et al., 2011) north of Macajalar Bay. The eddy facilitates the dispersal of plume from the Cagayan de Oro River (Cabrera et al., 2011) through a southwest - northwest circulation at the outer part of the bay (source: Cabrera et al., 2011)

The bay mouth is 50 km wide and encompasses a 30 km coastline covering an area of approximately 1000 sq km (see Figure 3.3). The river mouth and its vicinity is shallow due to the intertidal flat on the western side of the river opening; the water depth changes from the coastline at 0..4 m to 100 m (eastern side) within a few hundred metres seaward.

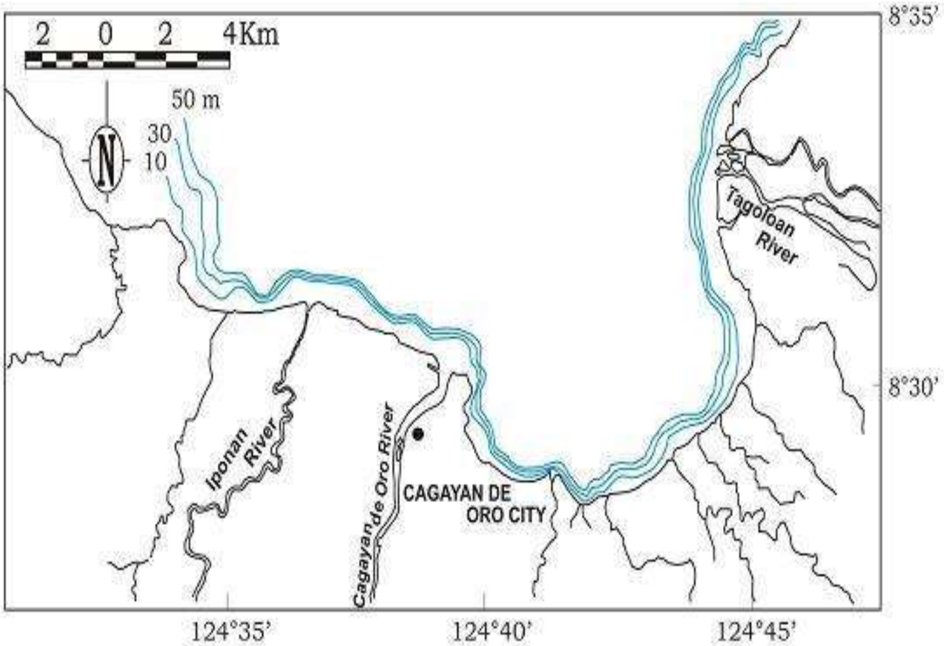


Figure 3.3: Macajalar Bay and the Cagayan de Oro River. Two major rivers, the Tagoloan and the Iponan, drain into the bay but are not included in the present study and modelling work. The bay is characteristically wide at its mouth and has a depressed curve on the southeast portion (source: NAMRIA map)

Under normal conditions, the bay experiences light to moderate winds from the northeast, with moderate effects on coastal water waves. The local wind force has varying intensities throughout the year, with corresponding effects on the sea current. The current flow in the bay becomes strongest from December to March, when it coincides with the prevalent northeast monsoon wind (PAGASA, 2010). During the southwest monsoon months, the dominant wind from the southwest is relatively weakened by the year-round northeast winds. The southwest monsoon wind is generally strong and brings significant rain.

Annual rainfall rates average around 2500 mm/yr and rain falls mainly from June to September, when the rate ranges from 280 mm to 400 mm/mo (PAGASA, n.d.). The rainfall rate is lowest from February to April, with a range from 30 mm to 100 mm/yr (weatherbase.com). The average number of rain days during the wet months range from 13 to 15 days, while in dry months the average is from 6 to 8 days; the average number of days with thunderstorms in Cagayan de Oro City is 129 d/yr. The bay experiences the highest number of sunny hours, with around 340 hrs/mos in April and May and less in June at 117 hrs/mos. Evening and day bay sea surface temperatures range from 27° C to 32° C.

3.2.2. Methodology Framework

The framework demonstrated two main sets of methodologies, the actual and the simulated measurements of TSS and salinity concentrations at the two sampling sites (see Figure 3.4).

3.2.3. Field Survey and Laboratory Work

The study consisted of two main phases: a) actual TSS and salinity measurements along the inshore waters on both sides of the river mouth, and laboratory work for TSS measurement; and b) Delft3D model simulation of coastal current circulation and river plume dispersal patterns within the river mouth area and inshore waters (Flemming, 1981; Schoellhamer, 1996) (see Figure 3.4). Results from both studies were compared and examined to validate the model's simulated results.

In the bay, each study plot was established within the plume trajectory route on both sides of the river mouth. A visual assessment of sediment flow considered the plume's potential cover to encompass the seagrass or coral community sites.

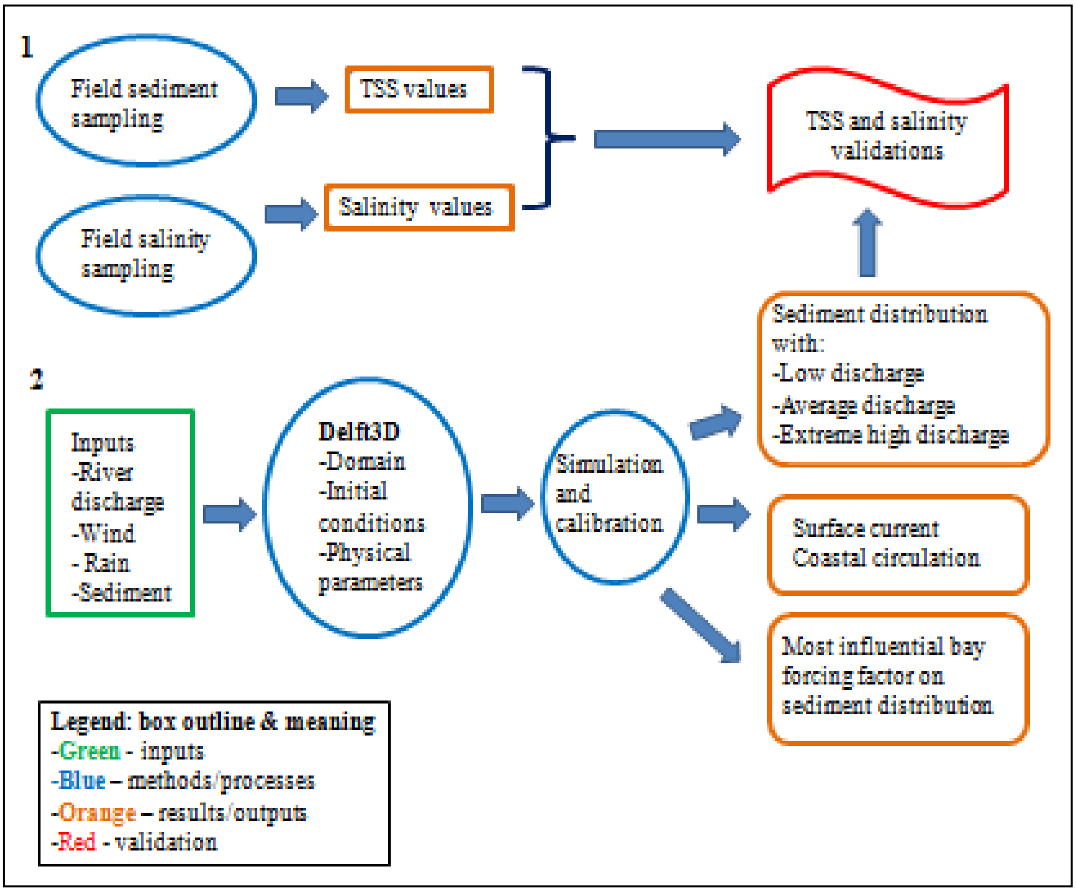


Figure 3.4: The framework consists of two main parts: field sampling to measure TSS and salinity values in designated sampling sites near the river mouth, and the modelling of sediment transport and coastal current flow using the Delft3D FLOW. The model's simulated results were validated using actual field data.

3.2.3.1. Delineation of sampling site and collection of water and sediment samples.

To determine the TSS and salinity levels in the study plots of both corals and seagrasses, sampling activities were conducted at designated points roughly representing the entire plot. After this, the actual values of both TSS and salinity variables were plotted using ODV (Ocean Data View) software (Schlitzer, 2002) on the corresponding locations of each study plot within the bay.

Sampling activity occurred once a month (sampling days were randomly chosen), from November 2012 until June 2013. Sampling activity started at 7:00 am and continued until 12 noon; from observed experience, rains in the uplands usually occur in the late evening and by the early morning after rains, run-off will have reached the river mouth.

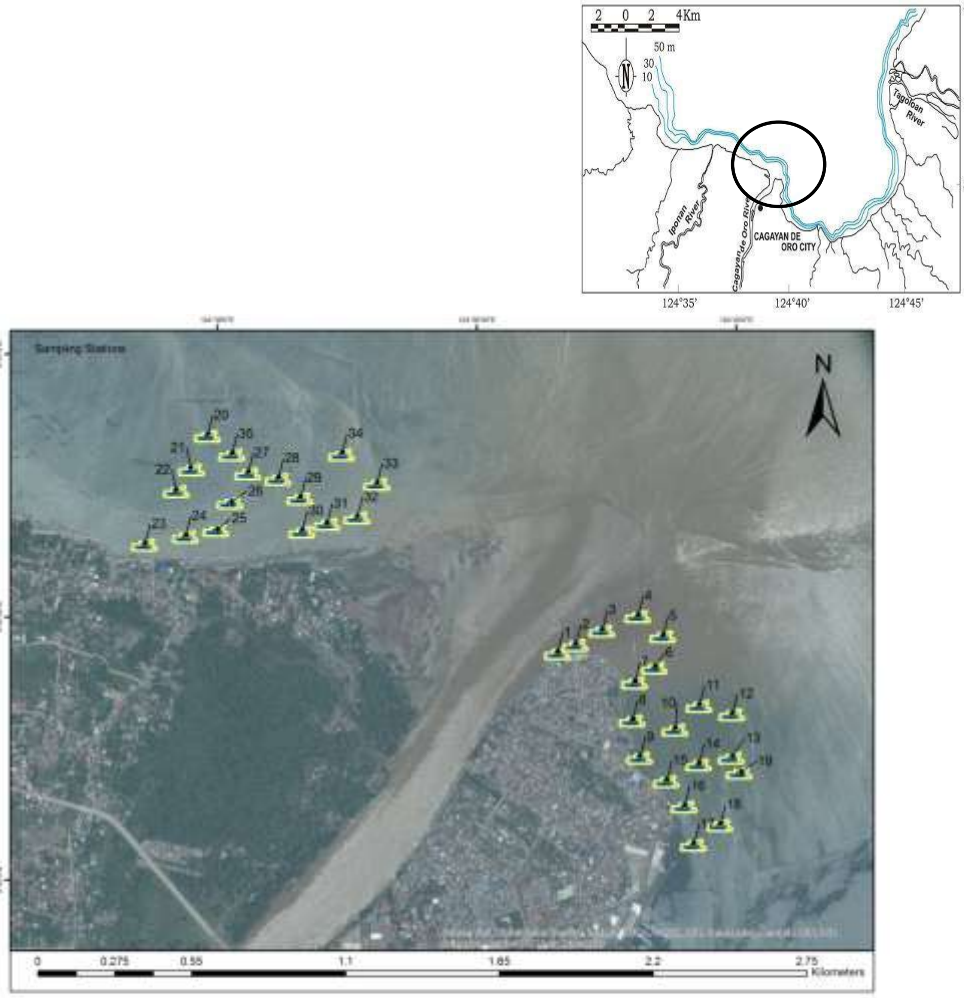


Figure 3.5: Sampling points (yellow icons) where water samples for TSS and salinity values where collected at both sites Macabalan (east) and Bonbon (west) Between the two sites is the river mouth where plume is formed and comes out to extend alongshore and offshore. Macajalar Bay (inset); (base map from Google Earth, 2015).

Sampling points were established within each plotted study site: 19 points along five layers on the eastern side and 16 points along three layers on the western side, following a spiral route pattern to cover most parts of the plot (see Figure 3.5). Water samples were collected at each sampling point within the plot area. For salinity, a handheld refractometer was used to measure the salinity level of seawater samples at each station. For TSS, a one-litre plastic bottle was used to scoop seawater half a metre deep (approximated surface layer depth, or depending on water depth) from the sea surface.

3.2.3.2. Laboratory work.

Sediment samples collected in bottles were allowed to settle for five days. Clear water was decanted and the remaining water passed through 1 µm filter paper to collect solids (including clay) with the help of a vacuum pump. Sediments were then oven dried at 105˚ C for 24 hours. The dried sediments were then weighed after 30 minutes of cooling.

3.2.4. Study Sites' Bathymetry

In shallow continental sea shelves, the bottom topography exerts a strong influence on surface water, forcing currents to turn around banks (Loeng, 1991). Intertidal mudflats and silted river beds near the river mouth have affected current movement patterns within the estuary (Wells & Kemp, 1981). To account for the new changes of bottom topography in the study sites, a bathymetric survey was conducted in Macabalan and in the Bonbon coastal sites, encompassing the two study plots located on both sides of the Cagayan de Oro River mouth. The survey measured the depths and contours of the seafloor, covering 300 km^2 of the eastern side and 390 km^2 of the western side of the river mouth. A map was plotted using map source software to delineate the area for bathymetry and to serve as guide for the actual measurements (see Figure 3.6).

For the eastern side, the survey lines parallel to the coastline were segregated into three sets following the main contours of the Macabalan coast. The ten parallel lines extend 1km seaward from the coastline. On the western portion, the imaginary lines run parallel to the Bonbon coast 2km west. The parallel lines extended 1.5 km seaward from the coastline.

Figure 3.6: East (Macabalan) and west (Bonbon) plots near the Cagayan de Oro River mouth. Guide points were established using GPS to determine the site parameters and the desired exact locations for inclusion in the bathymetric survey of both coastal sites (base map from Google Earth, 2015).

An echosounder unit was attached to a slow-moving boat that followed the route established by the imaginary lines. A GPS unit was used to read and record the latitude and longitude coordinates of important coastal site point locations. Corrections were made in the depth readings, based on the water fluctuations while the survey was being conducted.

3.2.5. Description of the Delft3D Model

The Delft3D is a software package primarily designed for applications relating to water flow and quality in any open water conditions such as rivers, oceans, lakes and coastal shelves (oss.deltares.nl). The package consists of several modules built around a mutual hydrodynamic core to provide a complete picture of three-dimensional (3D) flow, surface waves, water quality, ecology, sediment transport and bottom morphology in complicated, coastal areas. Each module comes with its own set of menus to run the configuration. The

Delft3D can work with different modules and each module can interact fully with the others. Some of the modules are for (FLOW), morphology (MOR), and waves (WAVES).

3.2.6. Delft3D FLOW Model

For this study, the Delft3D FLOW module was employed to simulate river flow and sediment dispersal patterns off the river mouth. TheDelft3D FLOW is a multi-dimensional (2D and 3D) hydrodynamic and transport simulation program (Deltares, 2001). It can simulate non-steady flows in shallow water and transport phenomena that result from tidal and meteorological forcing on a rectilinear or curvilinear boundary fitted grid. The model also considers the water density gradients, wave action and tidal movements. The module can be used for various applications, such as storm surges (with tide- and wind-driven flows), stratified and density-driven flows, river flows, deep lakes and reservoirs, freshwater discharge in the bay, dissolved pollutant transport, sediment transport and salt intrusion.

3.2.7. Delft3D Model Set Up

3.2.7.1. Domain.

A nesting scheme was used to model the hydrodynamic flow patterns for the inner part of the Macajalar Bay near the Cagayan de Oro River mouth (see Figure 3.7). The computational domain includes an irregular-shaped bay area that extends ~7 km seaward from the southernmost tip to the northern boundary. Horizontally, the distance along the northern edge runs at approximately 11 km from one end to the other. The model bay area includes a smaller river outlet, the Iponan River, located on the southern part of the bay and east of the Cagayan de Oro River. The coordinate system was spherical and so the Coriolis force was calculated from the latitude coordinates in the grid file. The horizontal plane consisted of 224 grid square points for M-direction and 95 grid points for N-direction.

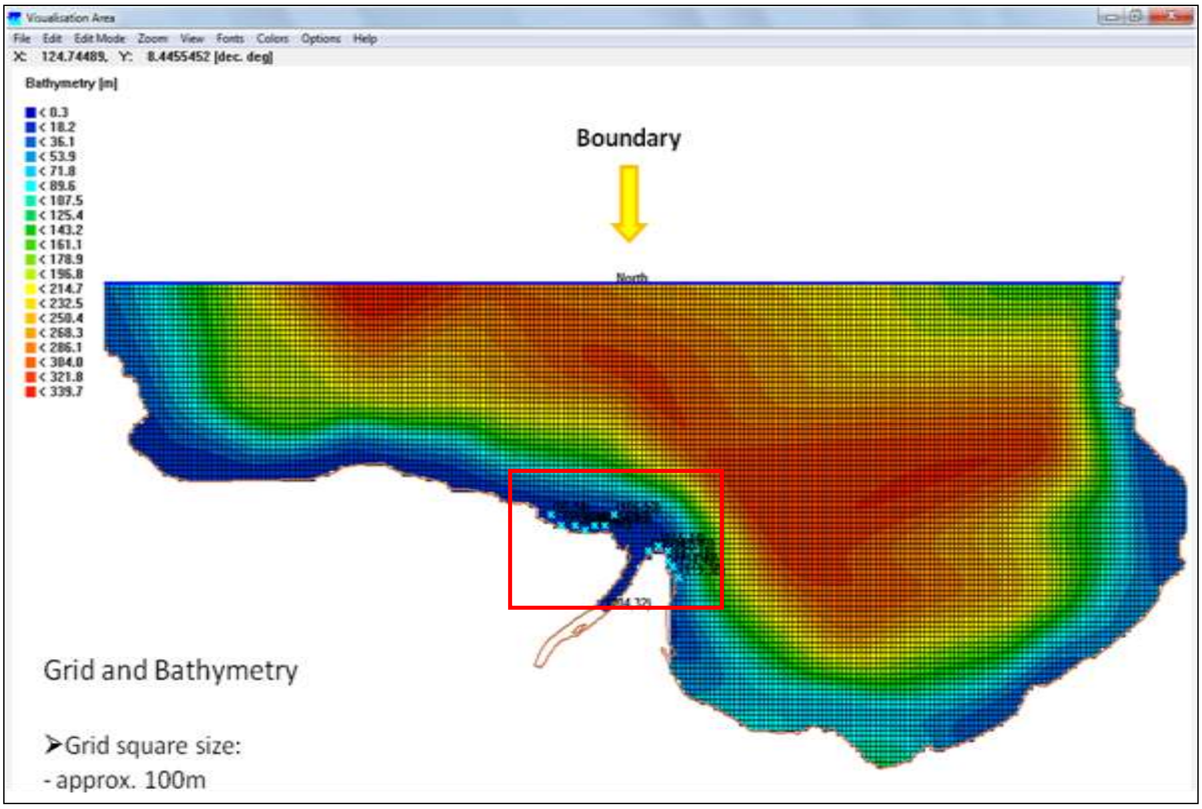


Figure 3.7: Domain of the Model study within Macajalar Bay, Philippines, generated by the Delft3D showing inland boundaries and deepest parts of the bay. Inset: sampling sites.

The model created each grid square with a size at approximately 100 m x 100 m. In the vertical direction, five layers were assigned with different thicknesses: (from the surface going to the bottom): 10%, 20%, 10%, 30% and 30%. Nobeltec, a marine navigation software (Wilson, 2006), was employed to generate a non-uniform depth bathymetric map of the model area, with a depth range of >0.3 m along the silted coastal shore and >339.7 m on the northern portion.

The open boundary condition selected was 'water level', due to the basin's large size and the relative accuracy of the quantity. Along the open northern boundary, the forcing type was astronomic flow conditions, which used 13 tidal constituents, amplitudes and phases. The key players determining the diurnal type of tide (one high and one low) of the bay are M2, S2, N2, K1 and O1. The general formula for astronomical tide, based on the Delft3D FLOW is:

$$H(t) = A_0 + \sum_{i=1}^{k} AiFi \cos\ (\omega it + (Vo + u)i - Gi \quad (Eq.\ 3.1)$$

Where:

$H(t)$ = Water level at time t

A_0 = mean water level over certain period of time

k = number of relevant constituents

i = index of constituents

Ai = local tidal amplitude of a constituent

Fi = local nodal amplitude factor

ωi = angular velocity

(Vo + u) i = astronomical argument

Gi = improved kappa number (= local phase lag)

3.2.7.2. Tidal data from selected sampling dates.

Regarding the tide data for both April to May 2013 and December 2012, seawater level changes extracted using the Delft3D Dashboard from the TOPEX 7.2 tidal model (Bosnic et al. 2014) were used and then compared with tidal data from the nearest tide station in Bohol (north of Macajalar Bay) (see Figure 3.8). The regression analysis showed a very close fit, with R^2 of 0.99. This means that the hydrodynamic flow in the model closely approximates the actual flow in the bay.

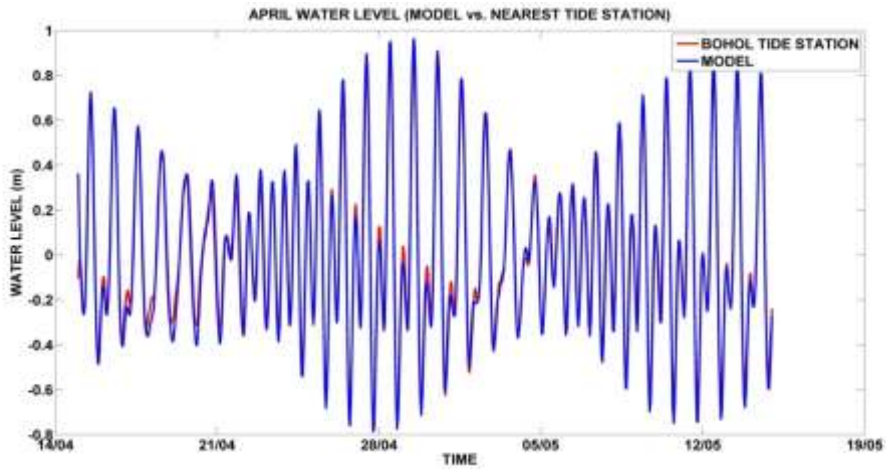


Figure 3.8: A comparison of the daily water level in the Macajalar Bay from April to May 2013, taken from the Delft3D Dashboard and the nearest station, showing that both sets of water level values are compatible.

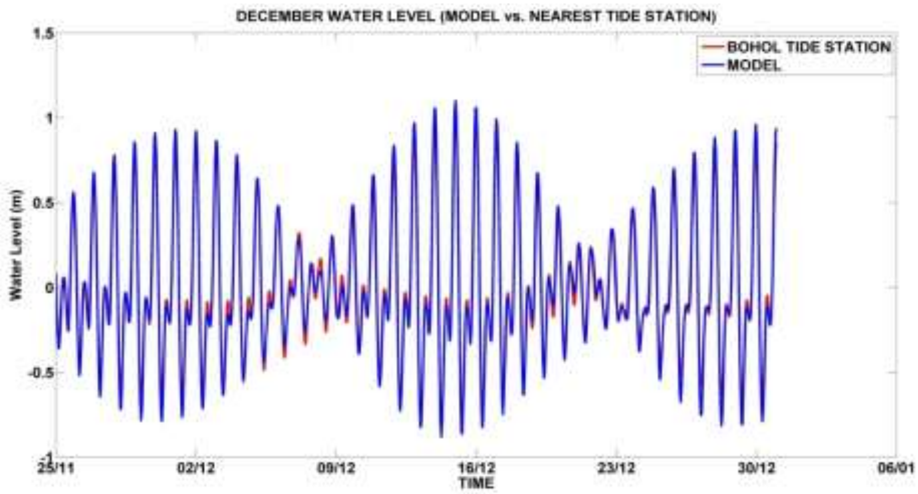


Figure 3.9: A comparison of the daily water level in Macajalar Bay in December 2013 taken from the Delft3D Dashboard and the nearest station, showing that both sets of water level values are compatible.

3.2.7.3. Initial conditions of the model bay area.

For the initial conditions, salinity and temperature (as seawater constituents) were specified uniformly in the whole study site at 33 ppt. and 28° C respectively. Water level and flow velocity were set at the default values of zero. Constituent concentration (sediment) was also set at a default value of zero.

3.2.7.4. Physical parameters.

The constants had the following given values: gravitational acceleration was 9.81 m/s^2, water density was 1024 kg/m^3, air density in wind stress formulation was 1 kg/m^3.

Wind speed was 0 at first breakpoint and 100 m/s at second breakpoint. The bottom roughness was computed according to the Manning formula at a constant value of 0.25 $s/m^{1/3}$ in both *u* and *v* horizontal velocities in the x and y direction. For side wall roughness, free or zero tangential shear stress was selected, due to the large-scale hydrodynamic simulations that normally negate roughness effects from the wall. In the horizontal plane, eddy viscosity and diffusivity of 1 and 10 m^2/s respectively were applied over the whole area. In the vertical direction, eddy viscosity and diffusivity were both set at a uniform value of zero. The turbulence model of k-epsilon was selected, where the coefficients were determined by transport equations for both the turbulent kinetic energy and the turbulent kinetic energy dissipation (Deltares, 2011). For the heat flux model, the background temperature was imposed throughout the whole area.

3.2.7.5. Initial sediment input.

Sediment data in the model were mud (cohesive) and sand (non-cohesive). Cohesive sediment mud data were as follows: specific density was 2,650 kg/m^3, dry bed density, 500 kg/m^3, and settling velocity, 0.15 m/s. For other data, default values were used. The critical shear stress for sedimentation was 1,000 N/m^2 and critical shear stress for erosion was 0.5 N/m^2. The erosion parameter was 0.0001 $kg/m^2/s$. The initial thickness of sediment on the bed was 0.05 m. Non-cohesive sediment sand data were as follows: specific density was 1905 kg/m^3, dry bed density 1600 kg/m^3, and median sediment diameter 200 µm. For overall sediment data, the reference density for hindered settling used for formulation was 1,600 kg/m3. Richardson and Zaki's (1954) formulation was followed to account for the reduced settling velocity of a single particle in high concentration mixtures, due to the presence of other particles (Deltares, 2011).

The morphological scale factor was assigned a value of 1. The spin-up interval before morphological bottom updating began was 720 minutes. The threshold depth for calculating sediment was 0.1 m. Sediment transport parameters were applicable only to non-cohesive sediments. For reference height formulation, Van Rijn's reference height method was followed; this was 1. At each step, sediment thickness was calculated and threshold value was placed at 0.05000 m.

3.2.8. Preparation of Bay-Forcing Datasets as Model Inputs

The following datasets of bay factors were input in the Delft3D model: river discharge, wind speed and direction, rain and sediment (mud and sand) loads. The included datasets were based on the model's requirements and on Hurlburt et al.'s (2011) proposed inputs as the key forcing factors within Macajalar Bay's inner portion.

3.2.8.1. River discharge.

River discharge volume depends mainly on the amount of rain supplied to the catchment areas and the river channel (Arnell & Reynard, 1996; Arora & Boer, 2001). To determine the discharge volume in the present study, the river velocity rate and river channel cross section area were measured at Taguanao Bridge along the Cagayan de Oro River and were then used for the discharge calculation (see Section 2.2.3.4). The model considered two river discharge conditions from actual daily measurements: average and extremely high. These simulated the observed river discharge amounts as influenced by catchment rainfall dynamics.

Table 3.1: Discharge volume and TSS values as inputs under three discharge conditions

	Average discharge & zero sediment	**Average discharge & average sediment**	**Extreme high discharge condition**
River discharge (m3/s)	113.49 m3/s	113.49 m3/s	1,245.33 m3/s
TSS concentration mg/L	Zero additional sediment input (	57 mg/L from sampling during Jangmi event	1,550 mg/L

For a zero sediment condition, the model obtained the averaged value (113.49 m3/s) from the daily river discharge inputs during the entire period from 15 April to 15 May 2013. The same averaged value (113.49 m3/s) from same set of daily river discharge measurements was used for the average discharge condition, but sediment values were set at 57 mg/L (see Table 3.1). For extreme discharge conditions, the model made a run of the entire month of December 2012, using the month's daily river discharge measurements, but it took only a snapshot of 4 December (Typhoon *Washi* or *Pablo*) discharge values (1,245.33 m3/s) as the representative condition.

3.2.8.2. Sediment input.

As the study aimed to determine sedimentation dynamics in coastal waters, various sediment concentration values were input to simulate the actual conditions. For the collection and measurement of river-suspended sediments (SSC), see Chapter 2 (Section 2.2.3.4) and for coastal-suspended sediments (TSS) see Chapter 3 (Section 3.2.3). Two sets of observed SSC values were input into the model: river sediment values of 57 mg/L from Typhoon Jangmi and 1,550 mg/L from Typhoon *Washi*. These were used to simulate sediment distribution patterns along the river-coastal continuum under two discharge conditions, average and extremely high. In addition, coastal sediment values of 59 mg/L from 26 December 2012 and 60 mg/L from 22 April 2013 were used to validate model results from the same two dates. A uniform and constant sediment value of 350 mg/L was also used in the model simulation to identify the bay-forcing factor with the most influence on sediment distribution patterns.

3.2.8.3. Wind data.

Local wind data were obtained from a weather station managed by the Xavier University Engineering Research Centre (ERC). The datasets included wind speed and direction, which were measured beginning at 12 am of the sampling day until 9 pm of the same day, with a 15-minute interval. From the same wind datasets, two general local wind directions were identified: The land breeze, which is generally from the southeast (SE) and is prevalent beginning early evening (~5 pm) until early morning (~9 am); and the stronger north (N) or northwest (NW) winds, which originate from the sea and persist mostly during the daytime (~9 am to ~5 pm). Overall, wind speed and direction in April did not exhibit significant changes from the diurnal fluctuations (see Figure 3.10). Only Typhoon *Washi* on 4 December registered a very strong NW wind, at ~45 m/s (see Figure 3.11).

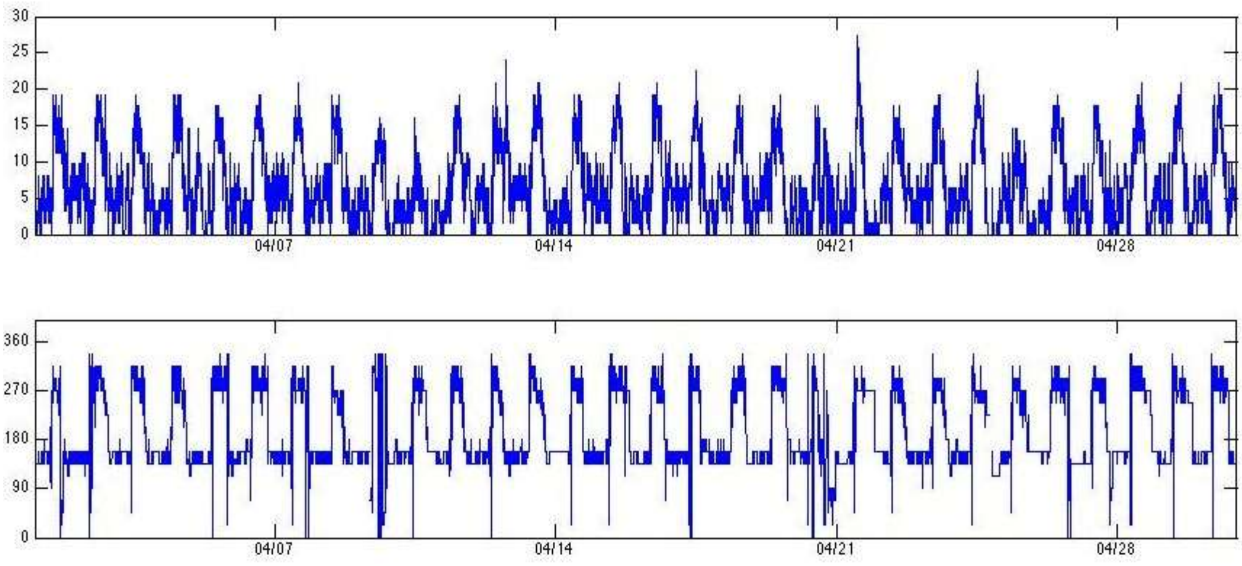


Figure 3.10: Wind speed in m/s (top graph) and wind direction (bottom graph) in April 2013, showing the absence of very low or very high peaks during the entire run (source: ERC-XU).

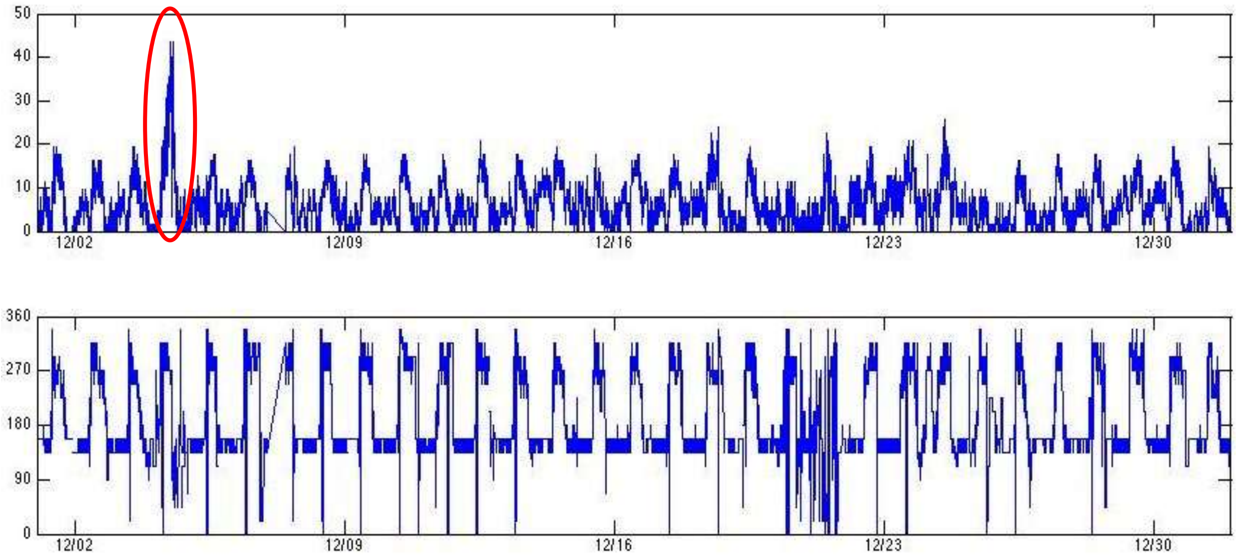


Figure 3.11: Wind speed in m/s (top graph) and wind direction (bottom graph) in December 2012. Wind speed on 4 Dec shows the highest peak (encircled in red) in the entire run (source: ERC-XU).

3.2.9. Actual Simulation and Calibration

During the model's actual run, seven (7) days were used as spin-up time before the start of the modelled month. A longer spin-up time was preferred to achieve a steady grid calculation before the desired sampling date. In the April run, errors were raised as 'vertical wiggles' and 'velocity changes became too high', which could be attributed to steep slopes in the bathymetry. Given the problem of steep slopes in the bathymetry, a possible solution might involve a flooding scheme. This scheme was cited by Stelling and Duinmeijer (2003) as applicable for problems involving rapidly varying flows, for instance in hydraulic jumps and bores. This was developed for two-dimensional (2D) simulations as a rectilinear grid of dry land inundation with obstacles such as road banks and dikes.

At times, 'vertical wiggles' indicating warnings and errors reappeared. The morphological scale factor (MORFAC) of 1 was used as default value, supposedly for all months. To remedy the errors, the MORFAC value was reduced from 1.0 to 0.25. The reduction prevented the very high bed-load transport rate from developing bottom wiggles, in contrast to the smooth behaviour of the suspended load. For the advection transport scheme, the Van Leer-2 Method (Van Leer, 1974) was used instead of the default cyclic method. This is slightly less accurate, but can give more positive definite results for monotonous solutions (no over-and undershoots) in the horizontal diffusion.

3.3. Results

3.3.1. Field Survey and Data Collection

3.3.1.1. Actual TSS and salinity values off the river mouth.

Monthly TSS and salinity values from each coastal sampling site were averaged and plotted on a graph against the station point's distance from the river mouth. Each graph shows the distribution of TSS and salinity values vis-à-vis their respective sampling plots with varying distances from the river opening (see Figures 3.12 to 3.15). It was hypothesised that high-TSS and low-saline concentration values near the river mouth may have been influenced by river plume encroachment on the eastern and western sampling sites.

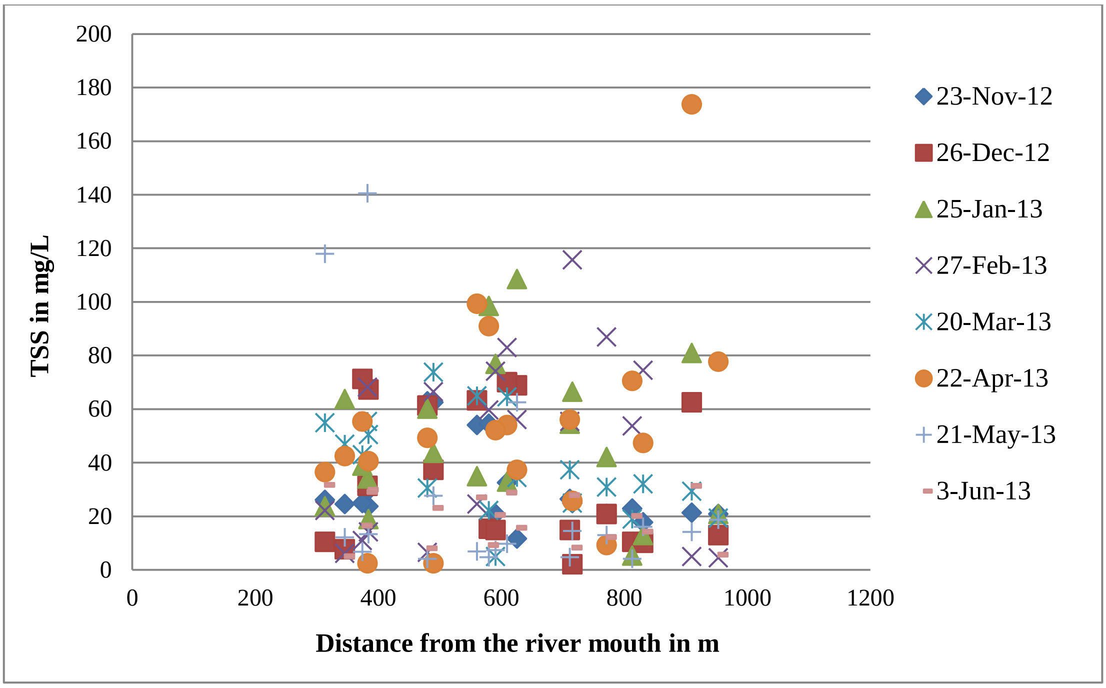


Figure 3.12: In Macabalan, no clear correlation between TSS values and distance from the river mouth was exhibited in any site. High-TSS concentration values (>20 mg/L) were distributed in all stations across the plot and so were low TSS values (<20 mg/L). Very high-TSS occurred as randomly distributed in several stations.

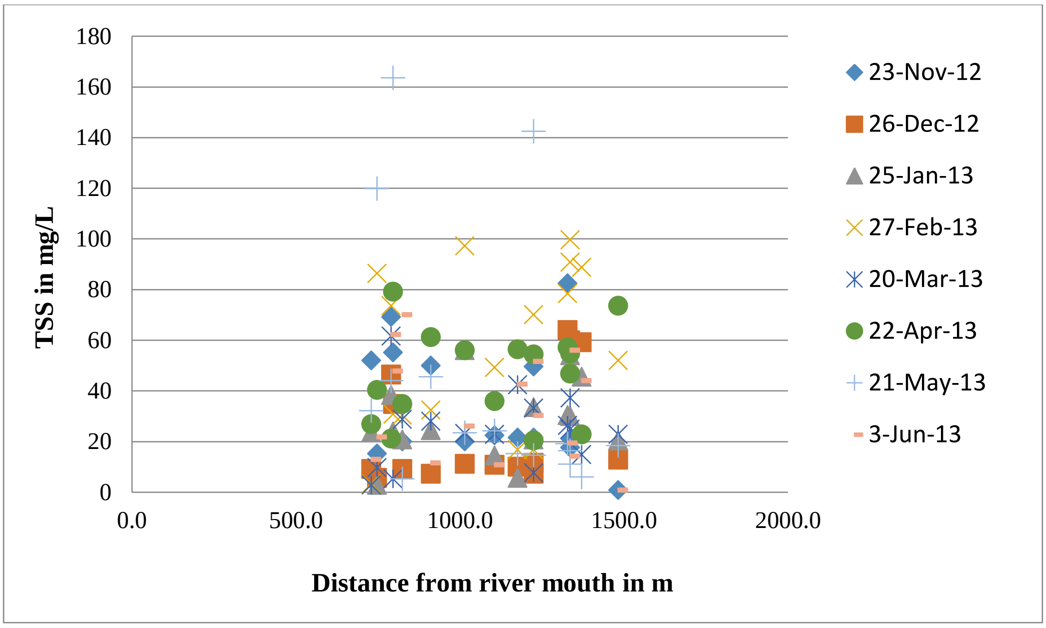


Figure 3.13: In Bonbon, there was no clear correlation between TSS values and plot distance from the river mouth. High-TSS values (>20 mg/L) were found in stations across the plot, and so were low TSS values (<20 mg/L). Extremely high-TSS levels occurred in May. Most low values were from December.

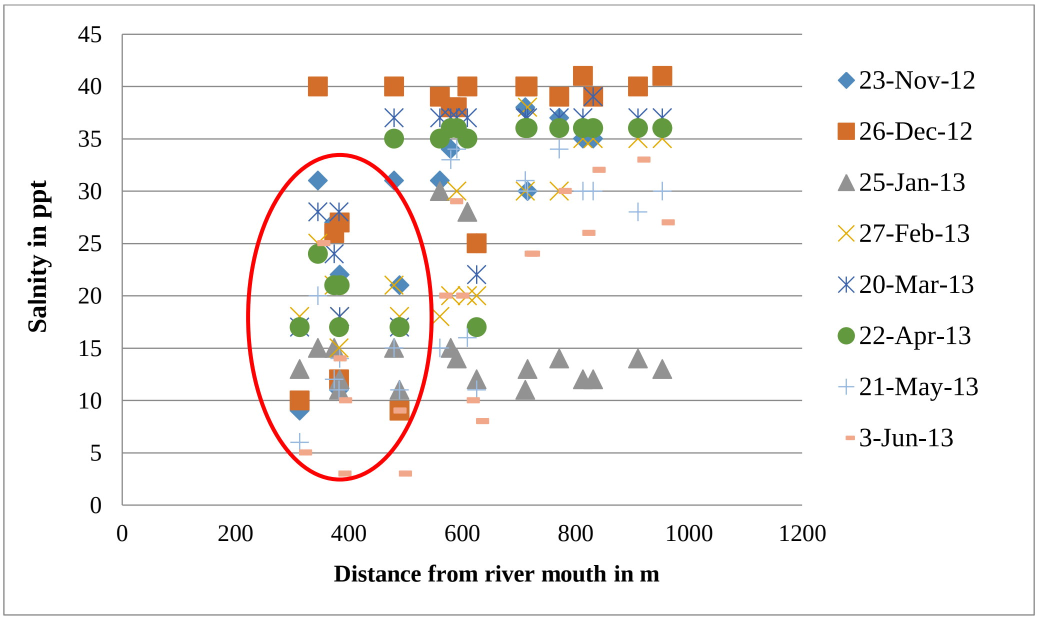


Figure 3.14: In Macabalan, many stations close to the river mouth from several months showed low-salinity values, indicative of river water intrusion in the sampling plots. Noteworthy are the months of December 2012, with normal salinity in most stations and January, with low salinity values in most stations. Correlation between salinity and distance is exhibited to some extent.

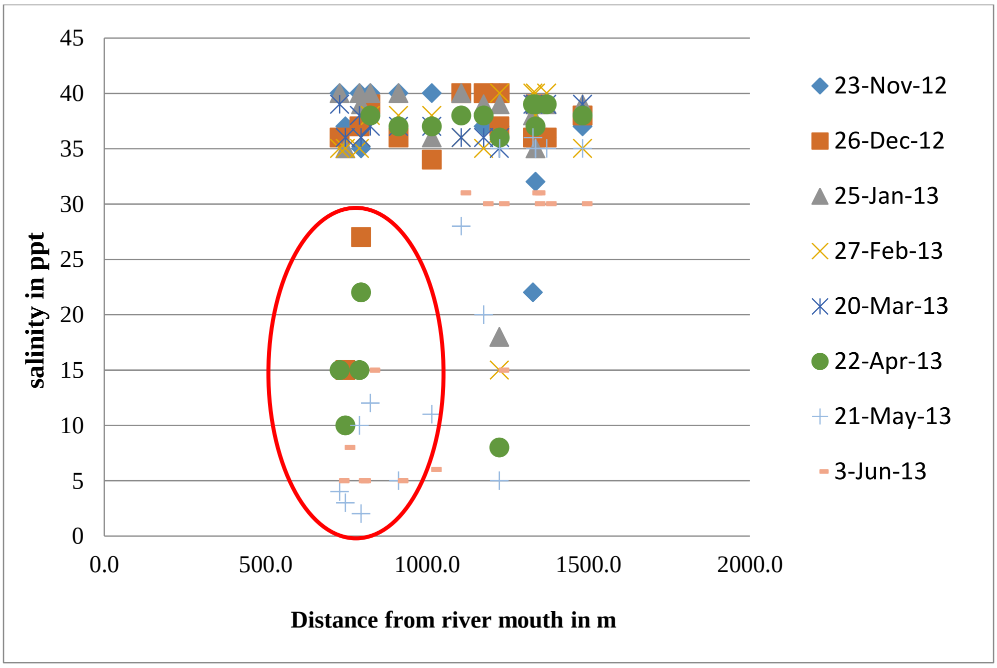


Figure 3.15: In Bonbon, low salinity values from some months are shown in several stations close to the river mouth (encircled in red). Large normal salinity values from most months were distributed beyond the ~700 m distance from the river opening.

3.3.2. Validation of Model-Simulated TSS and Salinity Values

The sampling days 22 April and 26 December were chosen to correlate simulated and observed TSS and salinity results. For both the simulated and the observed TSS data, the total sediment loads consisted of mud and sand.

For TSS on 22 April in Macabalan (see Figure 3.16), five sampling points near the river mouth had sediment values close to the simulated TSS values (0.03-0.05 kg/m3). However, two stations closest to the opening showed very low-sediment values (~0.01 kg/m3). Bonbon, revealed three observed sediment values close to the TSS levels of the simulated map (0.02-0.04 kg/m3). Observed TSS values higher than the simulated ones were randomly distributed at both sampling sites. On 26 December in Macabalan (see Figure 3.17) two station points near the river mouth had sediment values close to the simulated TSS value (0.03-0.05 kg/m3). In Bonbon, seven stations exhibited observed TSS values close to the simulated sediment values (0-0.015 kg/m3). Similar to 22 April, observed TSS values higher than the simulated ones were found randomly distributed at both sampling sites.

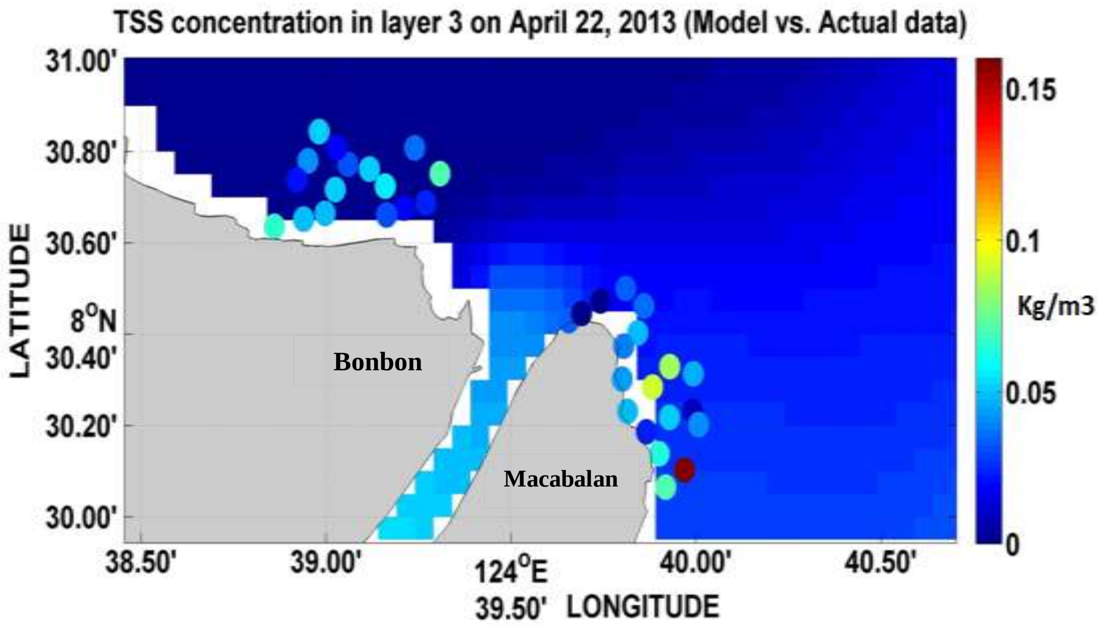


Figure 3.16: The map from Apr 22, 2013 sampling shows the concentration levels for both upland-derived and coastal-based sediments (round icons) on both coastal sites near the river mouth. Overlain maps suggest a weak correlation between two sets of sediment data in both sites (east and west).

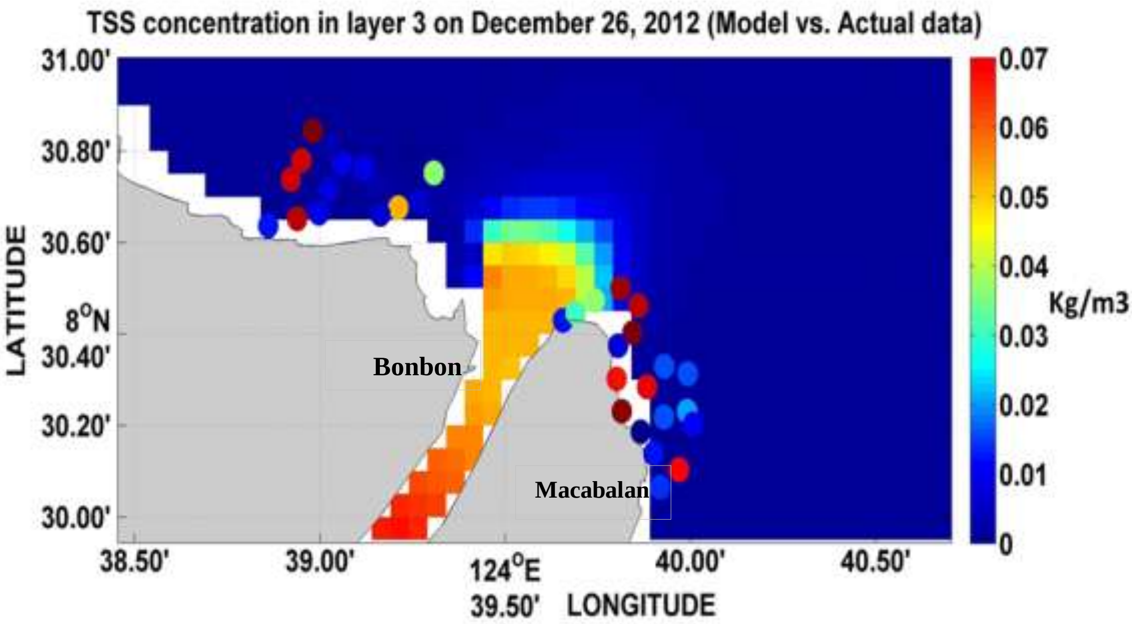


Figure 3.17: The map from Dec 26, 2012 sampling shows the concentration levels for both upland-derived and coastal-based sediments (round icons) on both coastal coastal sites near the river mouth. Overlain maps suggest a weak correlation between two sets of sediment data in both sites.

In relation to salinity, on 22 April in Macabalan (see Figure 3.18), six stations close to the river opening exhibited low-saline concentration values. Similarly, in Bonbon four stations near the river mouth showed low-saline concentration levels, while the rest were close to normal salinity values. On 26 December in Macabalan (see Figure 3.19), six stations indicated the intrusion of freshwater, while in Bonbon only two stations close to the opening showed a considerable decrease in salinity levels.

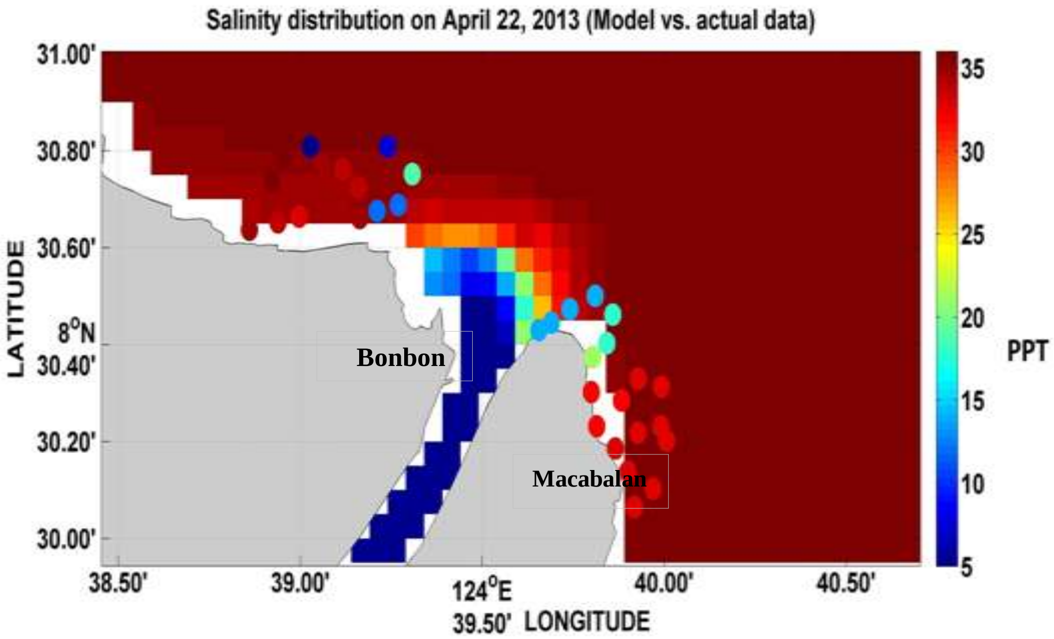


Figure 3.18: The map shows a positive correlation between simulated Salinity values and actual saline concentration values during the 22 April. sampling. Low-saline values near the river mouth indicate river freshwater intrusion on coastal plots. Sampling stations distant from river opening have normal salinity values, except for the five sites to the west.

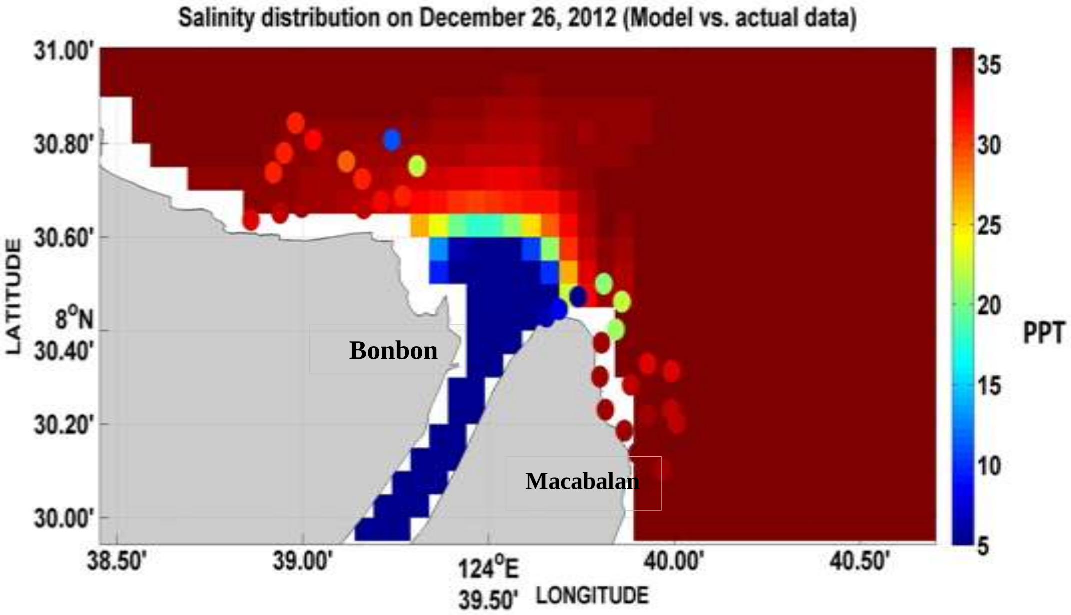


Figure 3.19: The map shows a positive correlation between simulated salinity and actual saline concentration values during the 26 Dec sampling. Low-saline values near the river mouth indicate river freshwater intrusion on coastal plots. Sampling stations distant from the river opening exhibited salinity levels within the normal range (30 to 35 ppt.).

3.3.3. Tidal Data from Selected Sampling Dates

Based on the sampling dates, Macajalar Bay is predominantly a mixed tidal type, with large variances in tidal range between the two tides each day. Based on astronomical data obtained from both boundaries, the amplitude for K1 is larger than the rest of the tidal constituents, while O1 is larger than all constituents, except for K1 and M2. The bay also exhibits a semi-diurnal tidal type with two high tides and two low tides each day. Tidal currents enter the bay through the wide bay opening slightly oriented towards the northwest. After entry, the current generally follows a north-south flow pattern with tidal flooding directed towards the south and the receding tide flowing towards the north. However, the tidal current pattern is either reinforced or weakened by alternating land and sea breezes that affect the bay water. The resulting tidal flow pattern from the non-linear interaction between tidal forces and wind-driven waves is complex. Boundary-forcing factors and water depth configurations exert an additional influence that further modifies the bay's current flow patterns.

3.3.4. Key Forcing Factors in Surface Current Circulation and Sediment Distribution

For all three scenarios, the average condition was run from 15 April to 15 May 2013. The following variables were input into the model: average discharge 113.49 m3/s, rainfall 0.2755 mm/hr, with actual tide and wind values. Sediment input was at 350 mg/L, which was uniform and constant in the whole time-series.

Scenario 1 consists of all three bay-forcing factors—river discharge, wind and tides (flood and ebb)—acting on the suspended sediment distribution within the river channel and off the river opening.

Scenario 2 describes the combined effects of the river push and tidal action on the movement of suspended sediments from the river channel and seaward. Without the wind factor, alternating NW and SE wind effects were reduced.

Scenario 3 presents the combined influence of the river discharge and the wind force on suspended sediment transport along the channel and in inshore waters. The absence of tide factors minimised the landward and seaward tidal effect along the coast.

3.3.4.1. Scenario 1: river discharge + tides + wind.

3.3.4.1.1. During flood tide.

Simulated results with all key forcing factors present during flood tide showed net sediment plume distribution on the southeastern portion of the bay, but the highest sediment concentration along the channel and river mouth (see Figure 3.20). A heavier TSS level was observed on Layer 5 (deepest) compared to Layer 1 (surface).

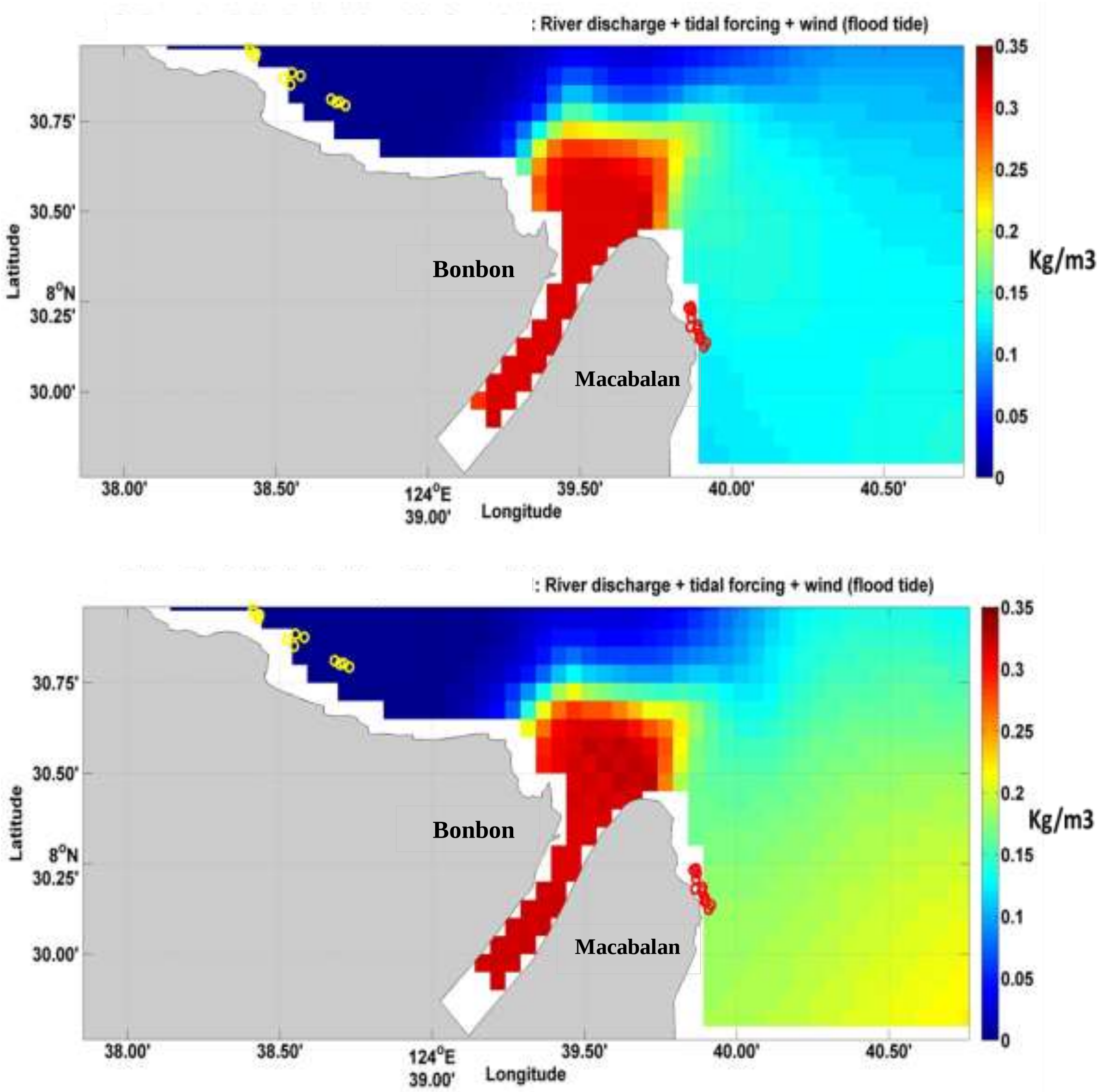


Figure 3.20: Influence of all three forcing factors on river sediment plume at flood tide; Both Layers 1 (top) and 5 (bottom) show heavy suspended sediment distribution on the east and southeast portions (seagrass site in red and corals in yellow circles).

3.3.3.4.2. During ebb tide.

At the ebb tide event, the river sediment plume's net movement is towards the southeast, but some sediment particles are dispersed northward off the river mouth, due to effect of receding tides. The highest sediment concentration is along the channel and at the river mouth (see Figure 3.21). A higher sediment concentration was evident in Layer 5 than in Layer 1. Tidal fluctuation did not significantly influence suspended sediment distribution in the bay.

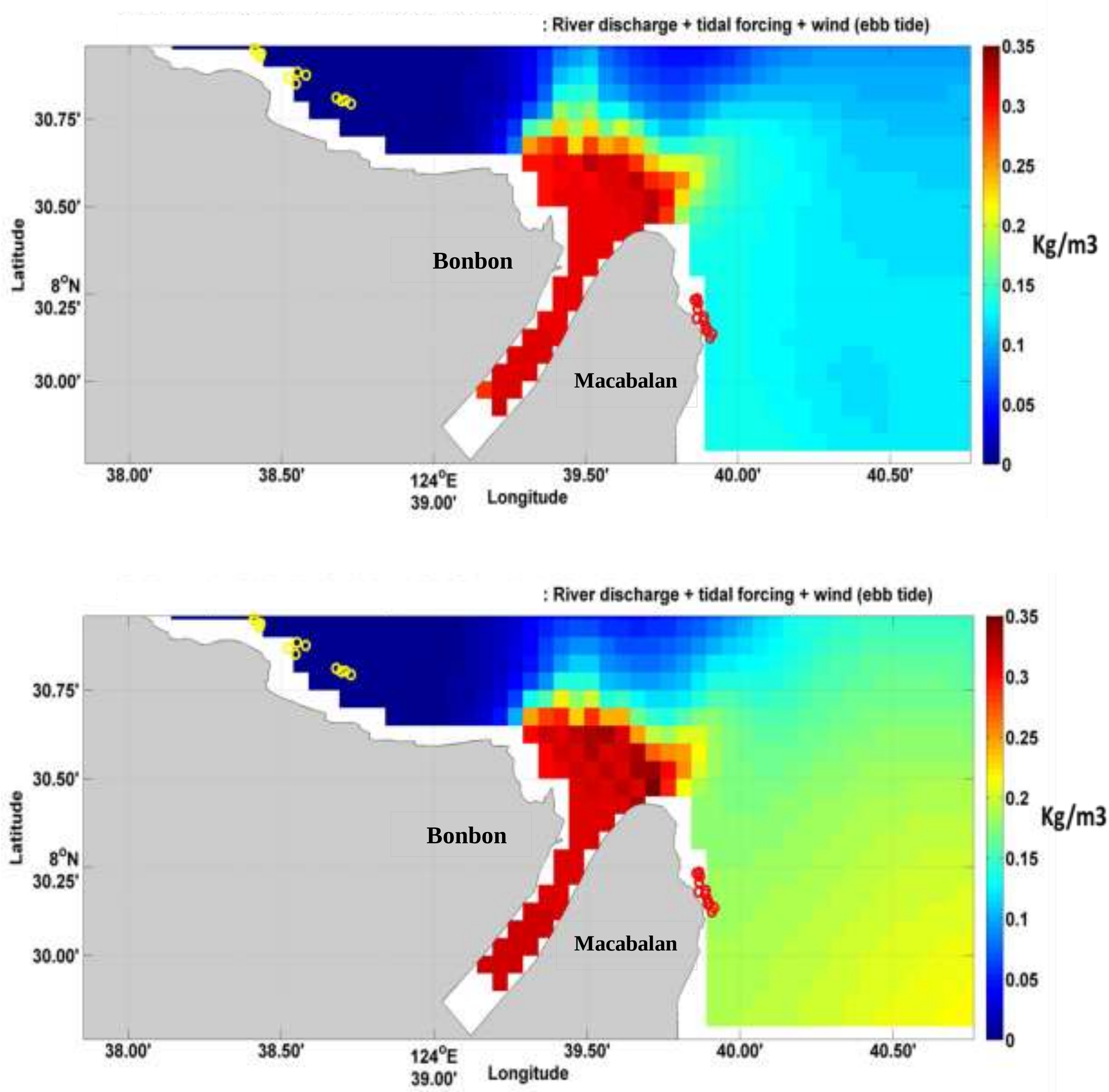
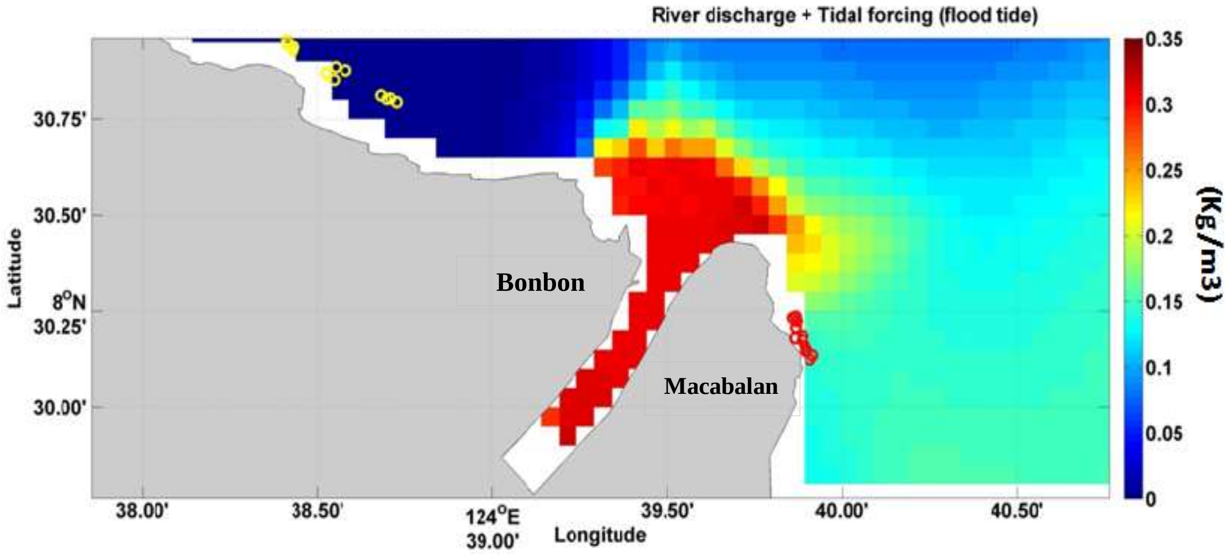


Figure 3.21: Influence of all three forcing factors on river sediment plume at ebb tide; both Layers 1 (top) and 5 (bottom) show heavy suspended sediment distribution on the east and southeast portions (seagrass sites in red and corals in yellow circles).

3.3.4.2. Scenario 2: river discharge + tides – wind.

3.3.4.2.1. During flood tide (no wind).

In the absence of wind, the river sediment plume's net distribution during the flood tide is heavily weighted towards the southeast, with an increasing sediment gradient from the river mouth to the southeastern portion of the bay (see Figure 3.22). It is apparent that sediment concentration is much higher in Layer 5 than Layer 1.



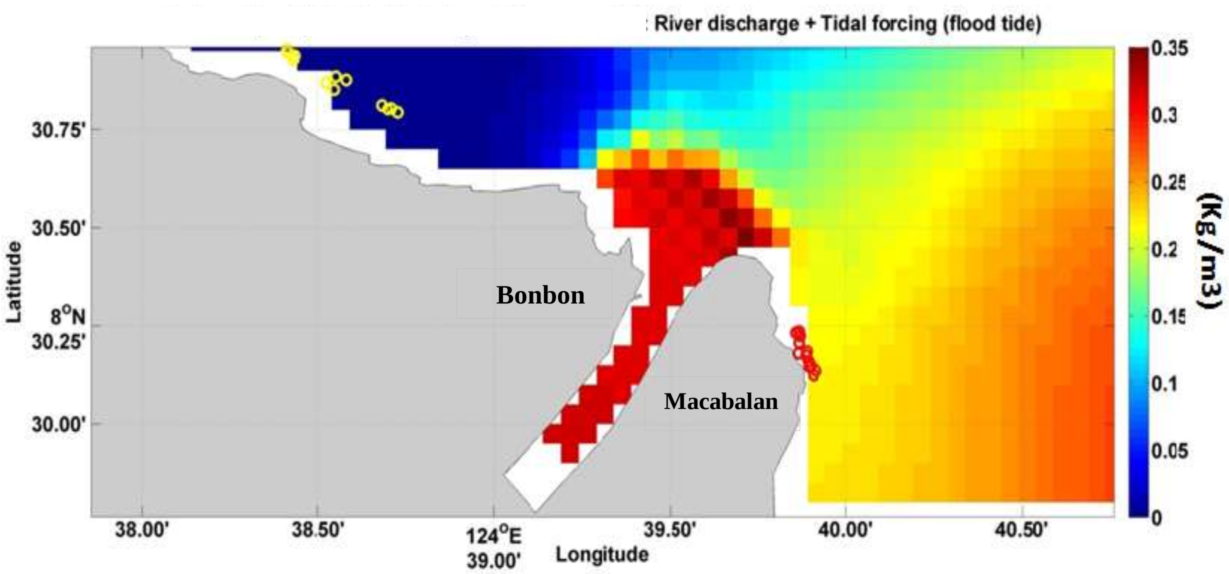


Figure 3.22: Influence of river discharge and tides on sediment plume at flood tide, both Layer 1 (top) and Layer 5 (bottom) resulted in an east and southeast net distribution of suspended sediment. The plume encroached on the seagrass site (red circles).

3.3.4.2.2. During ebb tide (no wind).

During the ebb tide, the model's Scenario 2 exhibited a net distribution of dispersed sediments on the southeastern portion of the bay, with the highest concentration along the channel and river mouth (see Figure 3.23). Additionally, a higher sediment accumulation was observed in Layer 5 than in Layer 1.

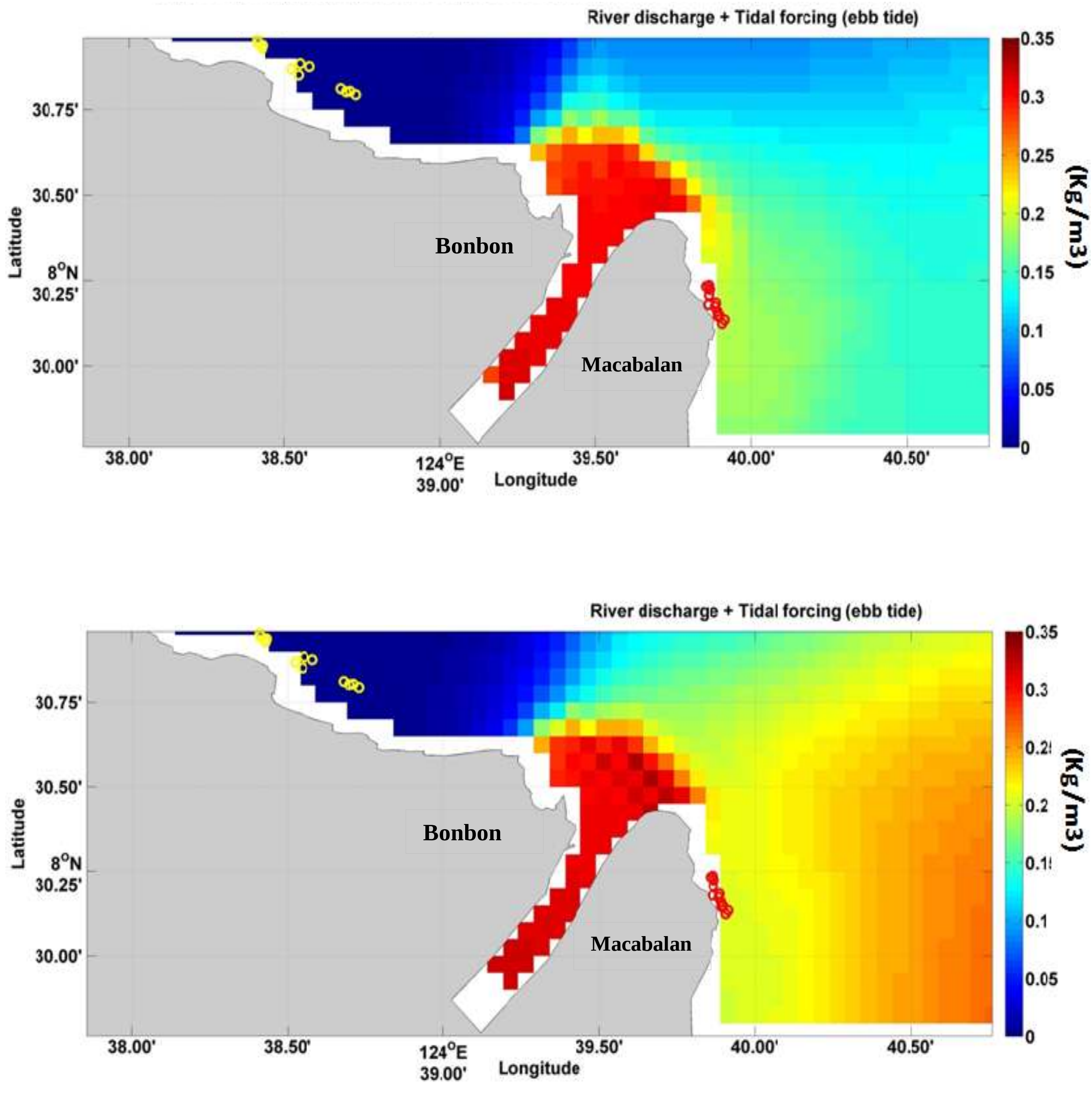
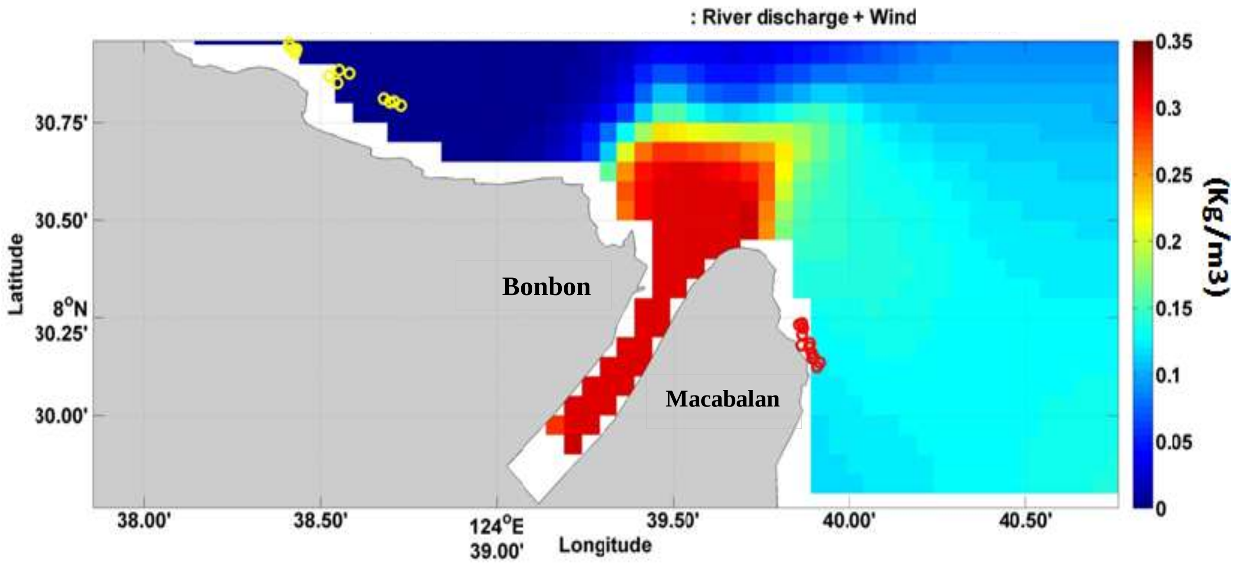


Figure 3.23: Influence of river discharge and tides on sediment plume at ebb tide, both Layer 1(top) and Layer 5 (bottom) resulted in east and southeast net distributions of suspended sediment. The plume encroached on the seagrass site (red circles).

3.3.4.3. Scenario 3: River discharge + wind – tide.

With only the river push and the wind force, the net distribution of sediments was heavily weighted to the east and southeast of the bay (see Figure 3.24). The highest sediment concentration was evidently within the channel and at the river opening. Clearly, Layer 5 has a much higher sediment concentration than Layer 1.



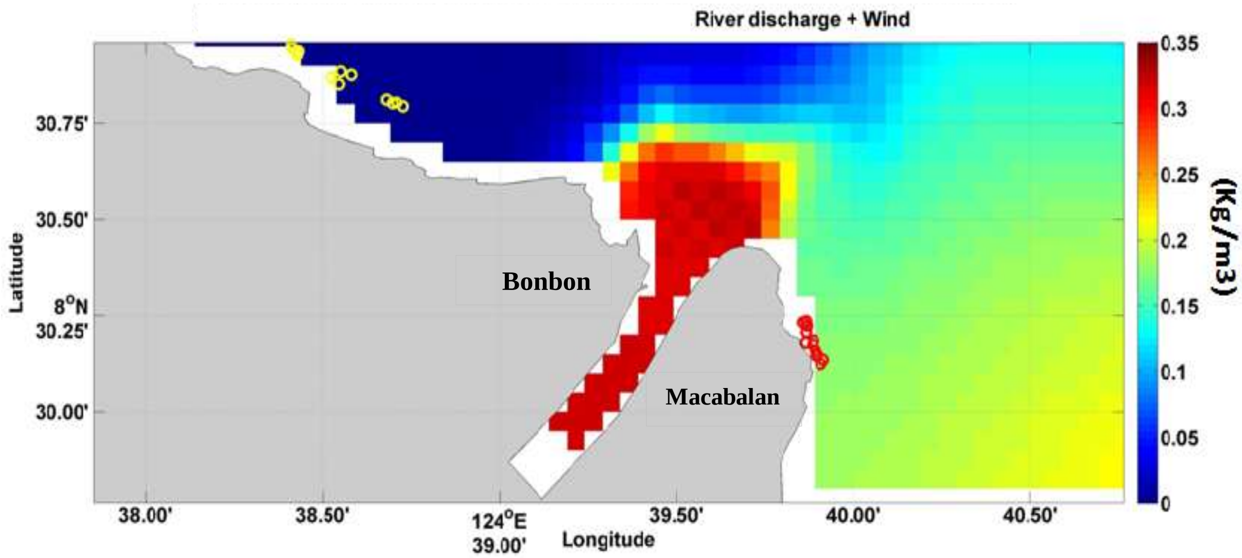


Figure 3.24: Influence of river discharge and wind on sediment plume; both Layer 1 (top) and Layer 5 (bottom) resulted in an east and southeast net distribution of TSS. The plume encroached on the seagrass site (red circles) and not the corals (yellow circles).

3.3.4.4. Tidal vs. wind influence on river-suspended sediment distribution.

Between the two scenarios, Scenario 2 (discharge + tide) demonstrated a higher concentration and wider encroachment area of suspended sediments on the eastern and southeastern portions of the bay than Scenario 3 (discharge + wind). This indicates that tides have a greater influence than wind on the sediment plume movement. Nonetheless, it is apparent from the model scenario results that both wind and tides reinforced each other to affect the eastward and southeastward distribution, and the subsequent deposition of river sediments.

Between the two tidal movements, the ebb tide dispersed more suspended sediment to the seagrass site than the flood tide, as shown by Scenario 2.

Further, Layer 5 transported a much higher sediment concentration than Layer 1. This is due to Layer 5 having a larger allocated portion in percentage terms (30%) than Layer 1 (10%), as well as suspended sediments tending to settle down to the lower layer if the weight increases and the current velocity is reduced (Van Rijn, 1993).

3.3.5. Simulated (Depth-averaged) General Coastal Circulation

The Delft3D model simulated the general circulation pattern in Macajalar Bay near the Cagayan de Oro River mouth during the entire month of December 2012 (see Figure 3.25). The map (inset) shows the northern origins of the coastal current flow heading inland. The key forcing factors, particularly the flood tide and the northwest wind, exert influence on the current southward flow, while the coast blocks and splits the main current into two opposite directional flows. Subsequently, the eastward current (see the main map) forms two gyres: a cyclonic circulation on the north and an anti-cyclonic flow on the south, while its prevalent current proceeds eastward. River outflow direction is heavily influenced by the eastward coastal current.

Parts of the main eastward flow move northward due to the east coast boundary blocking effect. The cyclonic circulation occupies most of the southern inner bay and limits water movement within it. The strongest current velocity is near the centre of the bay, while reduced flow strength was observed on the peripheries closer to the coast. Seagrass communities are located along the southeast coast of the river mouth.

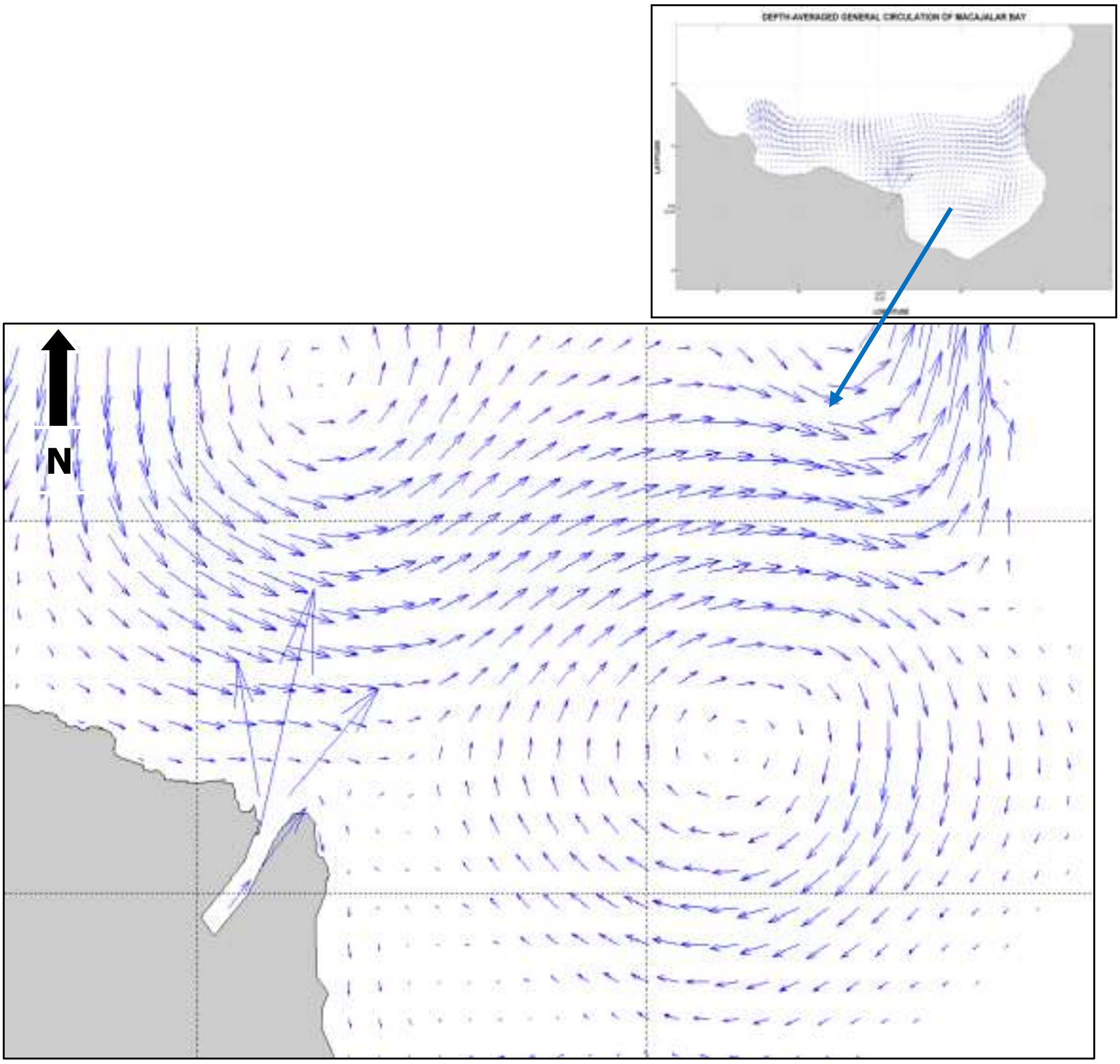


Figure 3.25: Coastal current circulation pattern during Dec 2012, showing the main flow movement towards the east and the formation of two gyres: one on the north with cyclonic circulation and the other on the south with anti-cyclonic movement. The net flow direction is generally east, then south due to the south gyre's effect.

3.3.6. Different River Discharge Conditions and their Effects on Sediment Distribution

The model simulated the different discharge conditions to predict the locations most likely to be affected by sediment accumulation within and outside the river channel during both normal and extreme local weather conditions. Layer 3 is the estimated seawater depth during water sample collection. Layer 1 shows surface layer sediments.

Table 3.2: River discharge conditions and resulting sediment distribution within the river mouth and along the seagrass zone

River discharge conditions	Sediment concentration within river mouth	Sediment dispersed along coastal inshore waters
Average discharge & zero sediment load	n/a (no additional sediment)	n/a (no additional sediment)
Average discharge & average sediment load	Flood = 30~40 mg/L Ebb = 35~40 mg/L	Flood = 10~25 mg/L Ebb = 25~30 mg/L
Extreme high discharge & extreme high-TSS load	Flood = 1,400~1,600 mg/L Ebb = 1,200~1,500 mg/L	Flood = 200~400 mg/L Ebb = 300~500 mg/L

3.3.6.1. Average river discharge & low-sediment load conditions.

River discharge values were taken from April 15 to May 15, 2013 time series. All the other data inputs came from the same actual dates except for the sediment input (see Figure. 3.26).

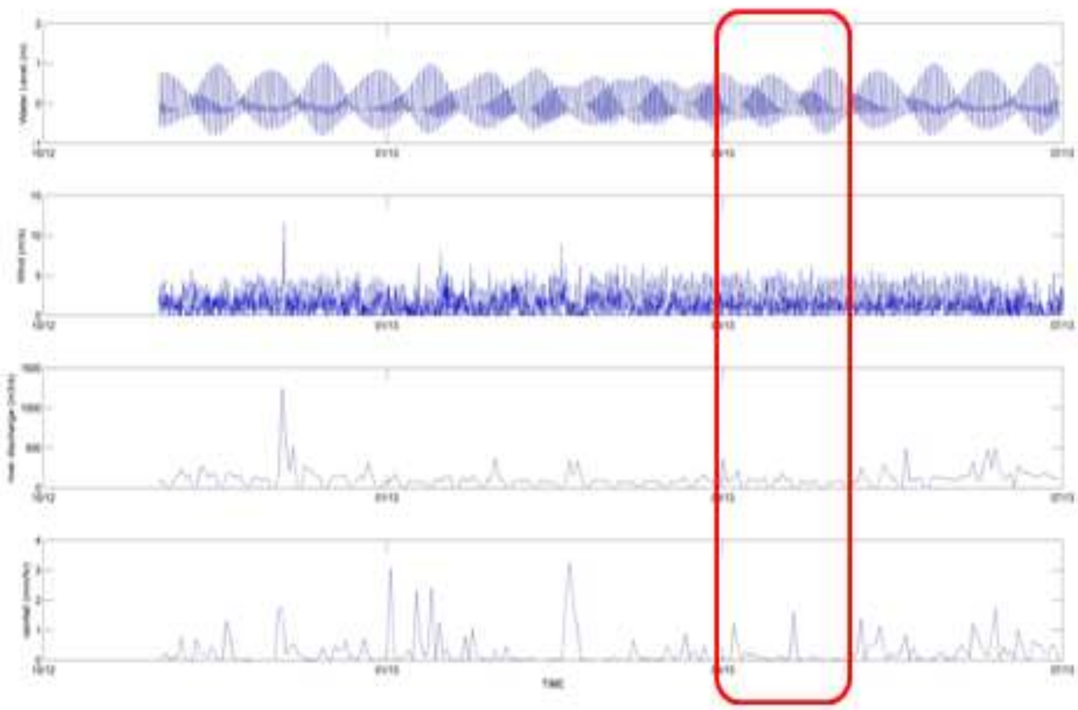


Figure 3.26: Low conditions consist of the following (inside red enclosure): tide data (1st graph) from actual dates; wind data (2nd graph) from actual sampling; discharge flow used the same mdf as average run (3rd graph); rainfall rate is 2.755 mm/hr (4th graph), but sediment concentration for both sand and mud are set to zero for the whole time-series.

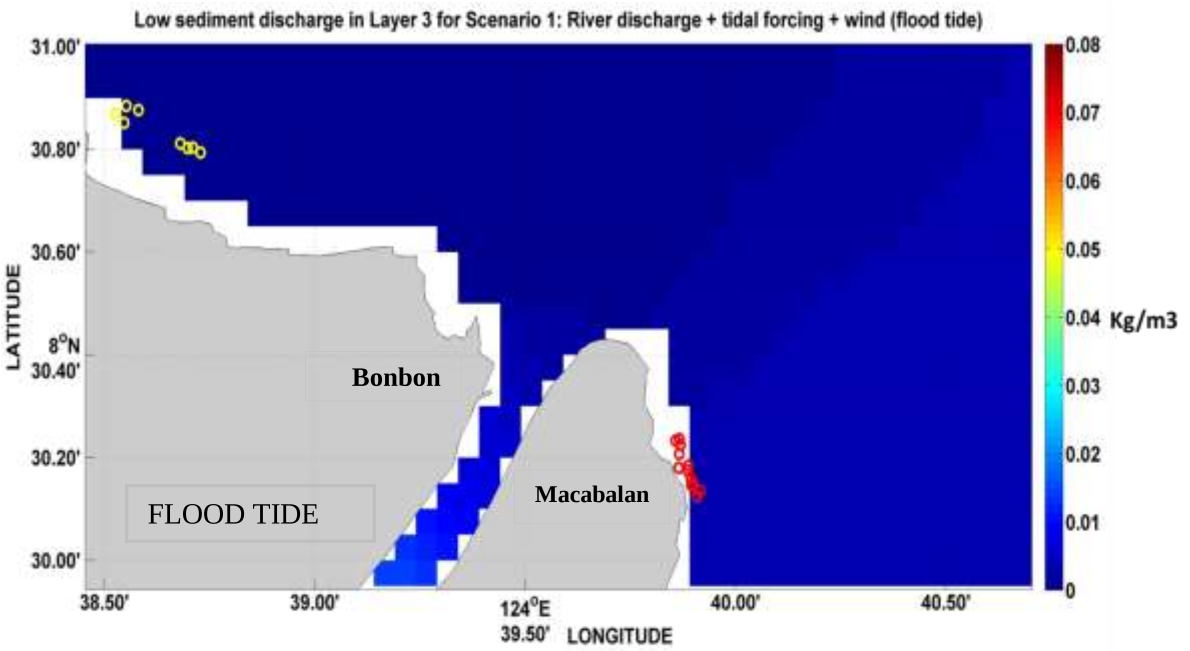


Figure 3.27: Layer 3 at low-sediment load (zero) at flood tide shows dispersed sediment on the east/southeast portion of the bay, with visible layering of increased SSC from river mouth towards southeast. Yellow circles represent the coral reefs, while red ones are seagrass meadows.

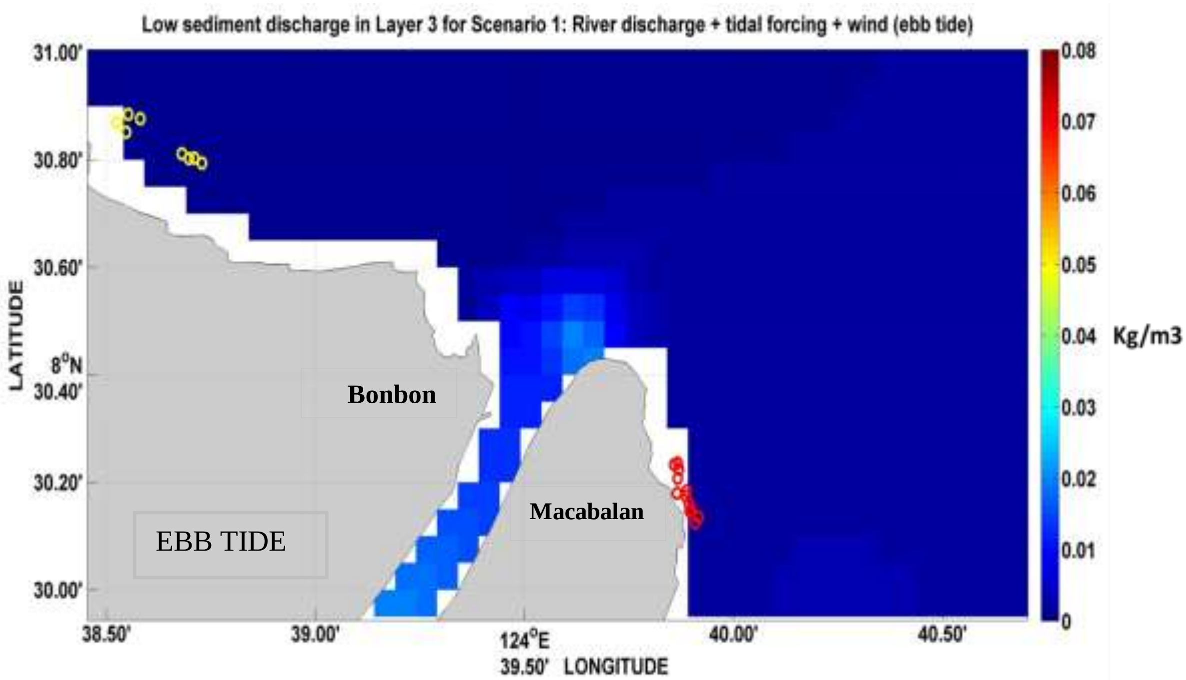


Figure 3.28: Layer 3 of low (zero) sediment load at ebb tide shows higher sediment concentration at the river mouth and within the channel, compared to inshore. No visible layering of sediment concentration was observed on southeast portion of the bay. Yellow circles represent the coral reefs, while red ones are seagrass meadows.

With a low-sediment discharge input, the model's results during both flood and ebb tide events exhibited strong sediment dispersal and subsequent accumulation at the southeastern portion of the bay. However, a lesser sediment amount was retained at the river mouth during the flood tide (see Figure 3.27) than in the ebb tide event (see Figure 3.28). With regard to dispersed sediments, TSS concentration varied slightly between two tidal events: a wider extent of distribution of the highest TSS concentration was evident along southeastern coast during the flood tide than the ebb tide event. With a zero additional sediment input, most remaining sediments were pushed further towards the southeast by rising tides than by receding flows. Quite visible layers of sediments were observed in both tidal events, indicating the southeast directional flow of tidal oscillation in relation to the river outflow. Coral and seagrass sites (yellow and red icons) are located west and east of the river mouth respectively.

3.3.6.2. Average river discharge and sediment load condition.

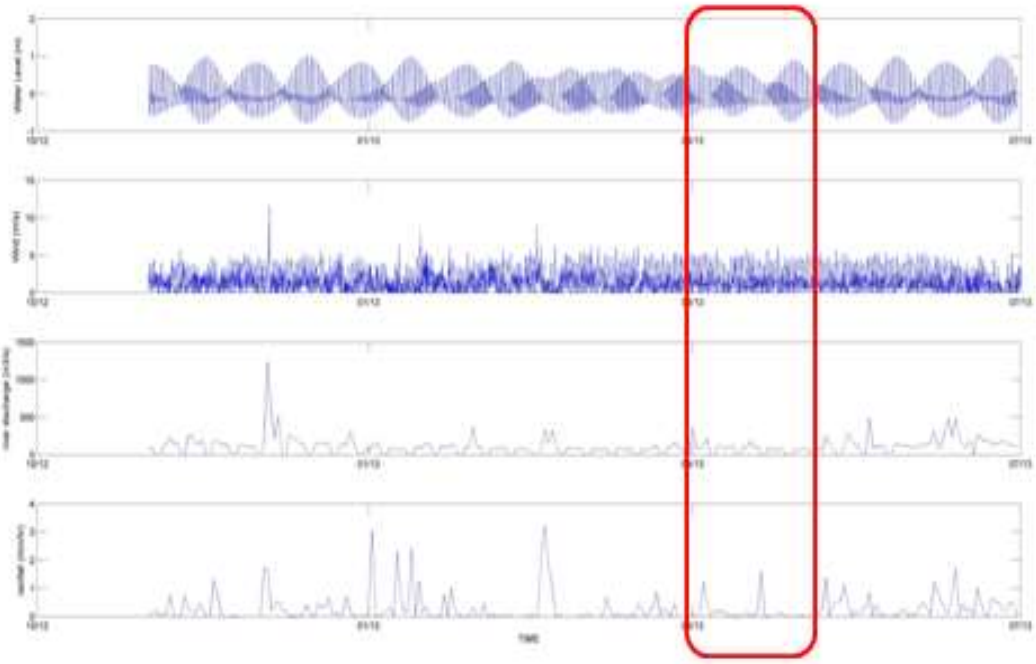


Figure 3.29: Graphs show a red enclosure that delineates the average discharge condition run over whole time-series: 15 April to 15 May 2013: tide data (1st graph) from actual dates: wind (2nd graph) used: same as low (as wind does not have significant changes in the time-series); average discharge rate: 113.49 m3/s (3rd graph); rainfall rate: 0.2755 mm/hr (4th graph); and TSS value of 57 mg/L was uniform and constant during the whole time-series.

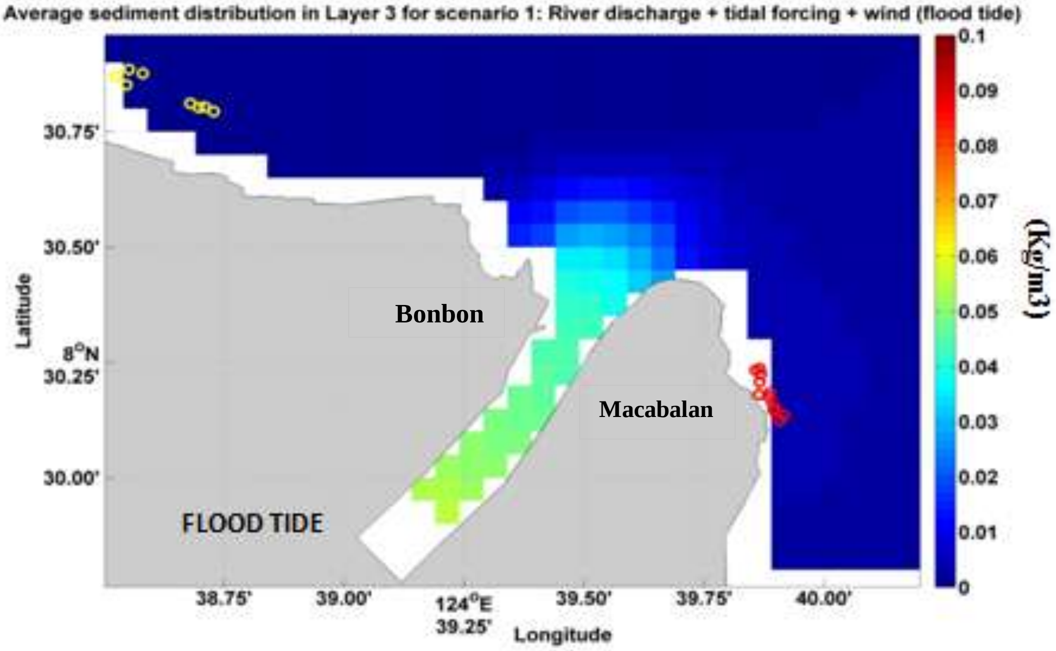


Figure 3.30: Layer 3 of average discharge condition at flood tide event shows suspended sediment dispersal towards the southeastern portion of the bay and high-TSS concentration along the channel. Minimal sedimentation is present on the eastern side. Seagrass sites in red and corals in yellow circles.

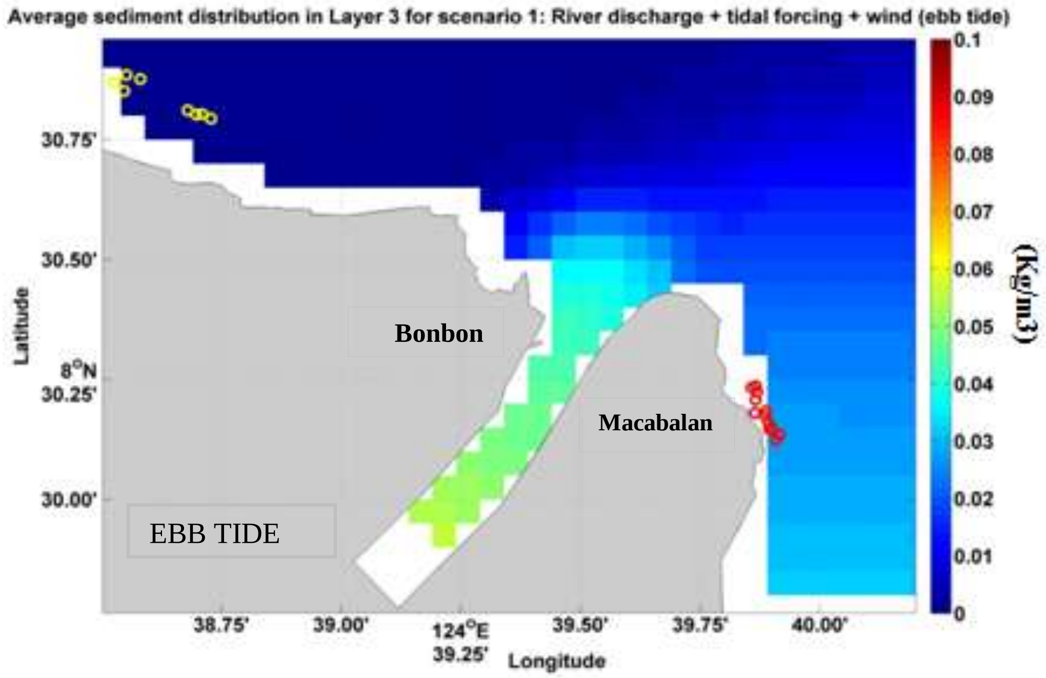


Figure 3.31: Layer 3 of average discharge condition during ebb tide shows suspended sediment dispersed towards the southeastern portion of the bay and high-TSS concentrations along the channel. Sediment encroachment is evident on the eastern side. Seagrass sites in red and corals in yellow circles.

With an input of 57 mg/L (addition), sediment distribution was retained mostly within the channel and at the river mouth area, less sediment was dispersed offshore. With dispersal direction, in both the flood and the ebb tide events, the river plume was dispersed mostly east and southeast of the bay. Comparatively, the model's results exhibited a higher concentration of inshore sediments during ebb tides (30 to 40 mg/L) (see Figure 3.31) than in flood tide events (10 to 20 mg/L) (see Figure 3.30). In fact, the rising tide effects tended to regulate sediment disperal offshore, while receding tides enhanced river outflow. TSS concentration along the channel and at the river mouth must also be higher during flood tide than ebb tide events.

3.3.6.3. Extreme high river discharge and sediment load condition.

The model simulated river discharge conditions with very high river water and TSS discharges from Typhoon *Washi* to predict the distribution of heavy sediment loads through very strong river discharge flow velocities.

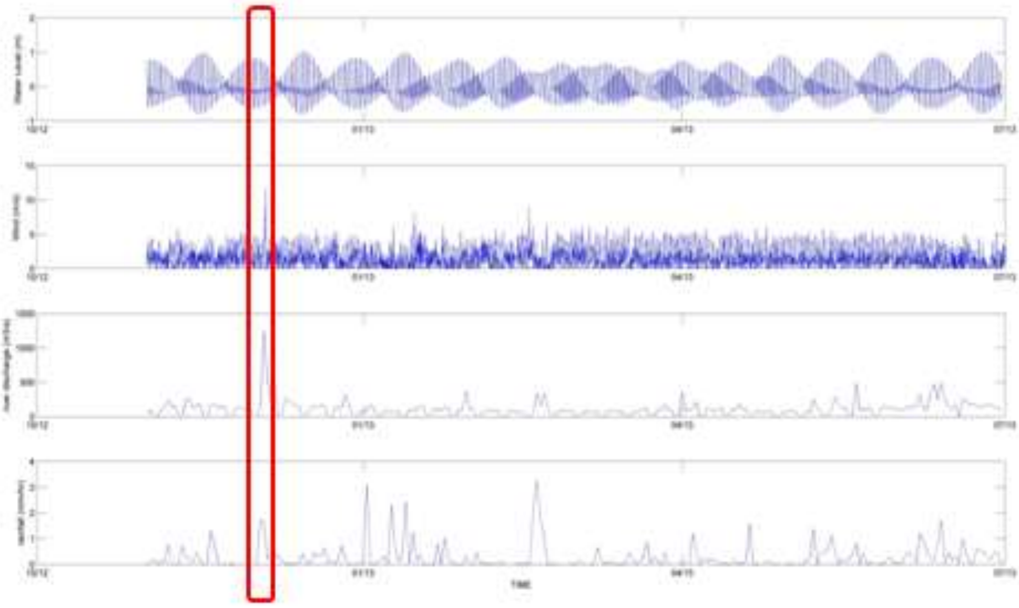


Figure 3.32: Extreme river discharge conditions constitute a run of the entire Dec data, but only a snapshot of 4 Dec (inside red enclosure), as represented on the model map. All the required data inputs were from the actual date of Typhoon *Washi*. Discharge flow and TSS values were the actual measurements at Taguanao Bridge.

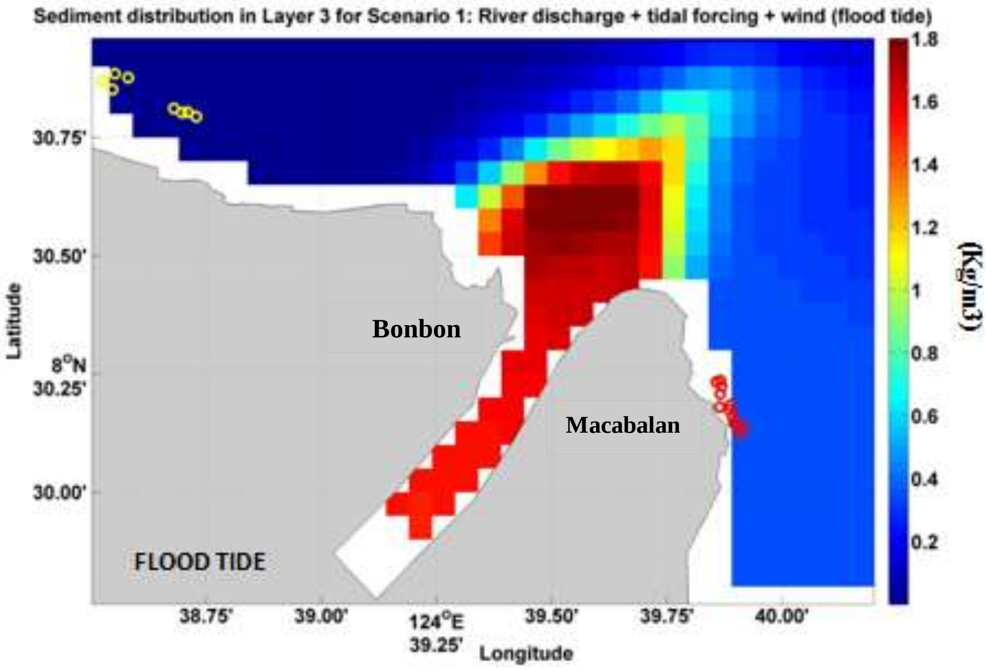


Figure 3.33: Layer 3 of extreme high discharge conditions at flood tide shows the outflow of river plume with high-TSS values on the southeastern portion, but the highest concentration of sediments at the river mouth. Seagrasses in red and corals in yellow circles**.**

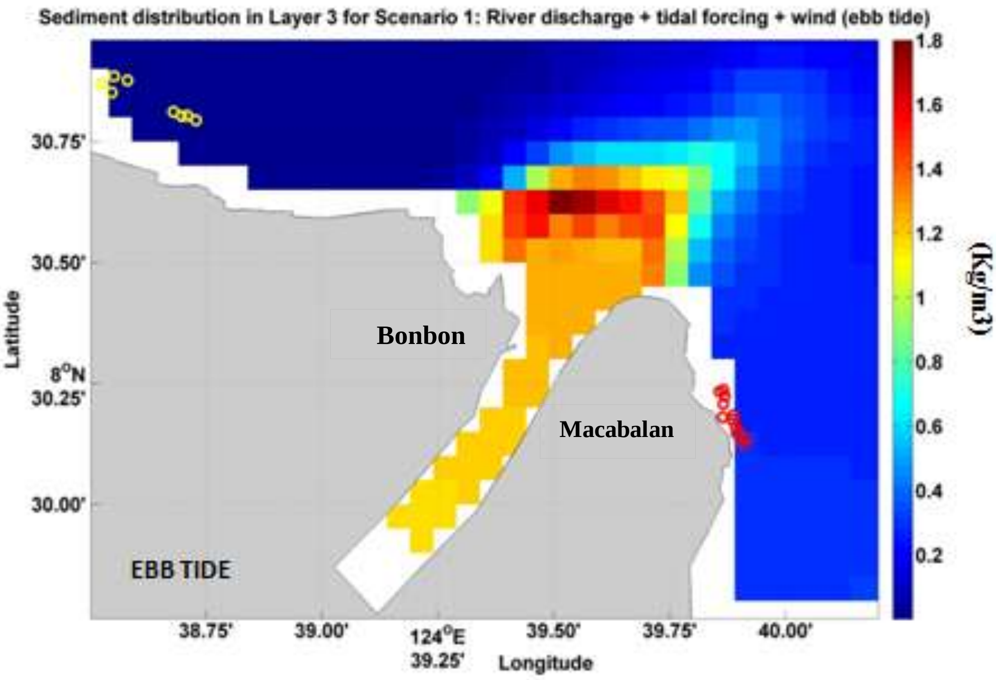


Figure 3.34: Layer 3 of extreme high discharge conditions during ebb tide shows the outflow of river plume with high-TSS values on the eastern and southeastern portion, but with the highest SSC at the river mouth.

Even with an extremely high river discharge volume, the model results exhibited the highest sediment accumulation within the channel and at the river mouth. The amount of dispersed sediments outside the opening also increased. Regarding direction, the river plume was dominantly eastward and southeastward of the river opening, while a minimal amount of river sediment was dispersed westward. Comparatively, the model results show that more TSS was trapped within the channel and the river mouth during flood tides (from 1,400 to ~1,600 mg/L, see Figure 3.32) than ebb tides (from 1,200 to ~1,500 mg/L, see Figure 3.33), due to the stronger riverward push of the former. Therefore, it is also more likely that dispersed sediments east and southeast offshore are higher during ebb tides than in flood tides. Notably, under extreme high discharge conditions, more sediments are trapped within the river mouth and fewer load values are dispersed along inshore waters outside the river mouth.

3.4. Discussion

3.4.1. Validation of Simulated Results (TSS and Salinity) by Actual Measurements

TSS concentration values at many of the Macabalan site stations were observed for eight sampling days over a period of eight months as being above 20 mg/L (see Figure 3.12). This indicates the presence of additional suspended sediments in the plot. The random distribution of high-sediment values was also observed within the sampling plot. Therefore, we can speculate that constant wave action and water disturbances may enhance sediment re-suspension at different plot stations, most particularly in the shallow depth parts. In selected sampling dates, however, the first few stations located closest to the river opening exhibited high-sediment values. This could indicate sedimentation influence, as shown in the simulated results from both the April (see Figure 3.16) and December (see Figure 3.17) samplings.

Similar to Macabalan, TSS concentration values in many Bonbon stations were above 20 mg/L (see Figure 3.13). This could have been caused by bottom sediment re-suspension and enhanced by strong near shore waves (Voulgaris & Collins, 2000). High-sediment concentration values were randomly distributed throughout the sampling plot, while only a few stations close to the river opening indicated the possible intrusion of river sediment plume in the April (see Figure 3.16) and December (see Figure 3.17) samplings.

Therefore, both sets of actual field data provided weak validation of the model-simulated results in April and December. This could be due to constant coastal water mixing and to the presence of other suspended sediment sources in the site (Gordon & Goñi, 2003).

In the Macabalan sampling plot, some stations close to the river mouth exhibited low salinity values compared to those from further stations (see Figure 3.14). A gradual increase in the salinity level with distance from the river opening was observed in both actual and simulated results from April (see Figure 3.18) and December (see Figure 3.19) samplings.

This positive correlation between salinity level and distance from the river mouth was demonstrated at most sampling stations. It indicates the relative influence of river freshwater on the sampling plot's ambient water (Schmidt & Luther 2002).

Similarly, in Bonbon river water was suspected to have influenced the sampling plot's ambient water, as shown by the low salinity values at the station points close to the river mouth (see Figure 3.15). Normal salinity levels were recorded at the reef site, and these levels most likely apply to the rest of the reefs westward. Apparently, river plume influence on the reef waters was minimal.

Actual salinity measurements from both sampling dates supported the model's simulated results in the April and in December samplings.

3.4.2. Validation of Simulated Results (Dispersed Sediments) by Satellite Images

Available Google images from two rain days exhibited a far-westward extent of river plume and a lesser plume with eastward dispersal (see Figure 3.35 a, b). This apparent discrepancy between the model's and the image's plume flow direction may be due to the time difference between the satellite's snapshot of the river plume and the model's spatial representation of the suspended sediments' net distribution in the bay. The satellite image of the river plume was taken at its initial outflow as it bulged out of the river opening, like a fan with all its fronts extending seaward. Due to the river channel morphology, the initial outflow direction was west and northwest and the plume edge did encroach on the reefs. Upon closer examination, the bulging plume revealed its current flow shifting to the east. The later change in the image's dispersal direction conformed to the net effect of coastal current circulation on sediment distribution during a day or month of simulation runs. Thus, both spatial presentations specifically described the same river plume movement offshore as initially swaying slightly to the west and northwest and then eventually shifting to the opposite side, due to the east-southeast current.

Figure 3.35: Satellite images (a & b) show plume flows veering towards the east after an initial westward outflow; in fact, the swath of plume flooding reaches the coral reefs (brown icons) (base maps from Google Earth, 2015).

3.4.3. Validation of Simulated Results (TSS) by Coastal Bathymetry

The mudflat zone, which is almost on the same height level as the coastal shore (from 0.05 to 0.1 m) and the river mouth, with very shallow depths (from 0.1 to 0.4 m), are both noteworthy on the bathymetric map. Both coastal manifestations of accumulated sediment deposits due to weakened westward outflow confirmed the simulated results.

Two very uneven depth profiles between the eastern and the western sites were also noted (see Figure 3.36). The eastern side is characterised by a narrow strip of relatively shallow coastal area (>20 m), but with the depth increasing rapidly to 100 m within 1.5 to 2 km seaward. The western side adjacent to the river mouth is a very shallow area of 0.5 to 6 m from the shoreline, going seaward within a distance from 3 to 4 km. This is a result of the long-term accumulation of river-borne sediments, beginning from the outlet and moving towards the northwest part of the estuary. Diminished wave energy at the river mouth contributes to mudflat formation (Wells & Kemp, 1981).

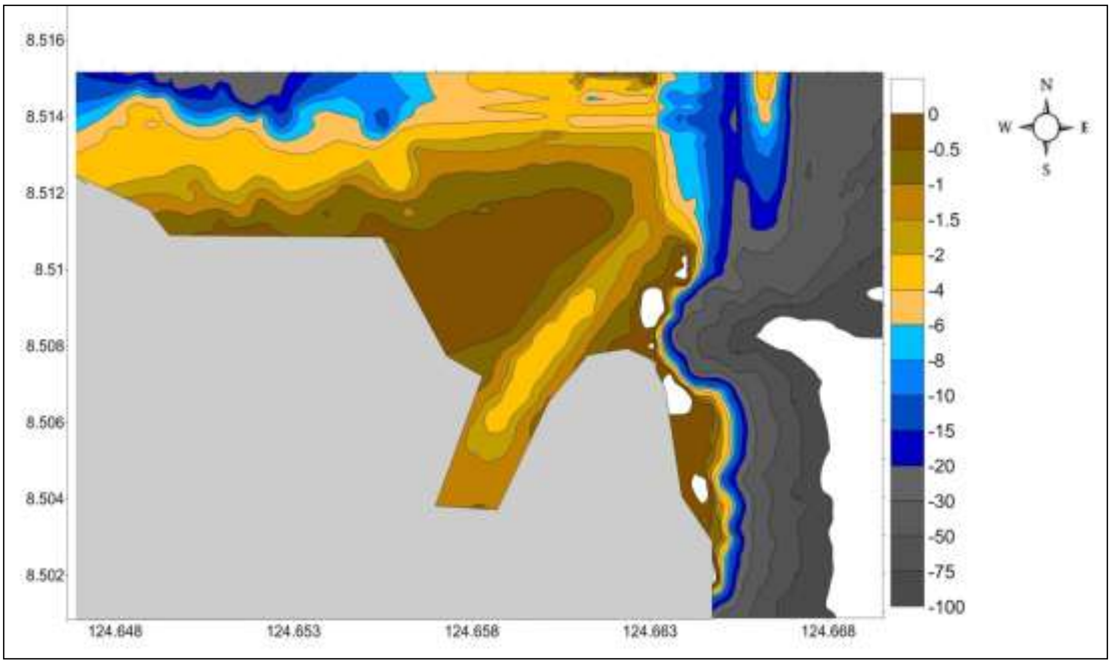


Figure 3.36: Bathymetric map of the coastal marine environments of the Cagayan de Oro River mouth, Macajalar Bay, showing relatively deep waters close to the Macabalan (east) coastlines and shallow waters in Bonbon (west); in particular, the mud accumulation along Bonbon shore. Units are in metres.

3.4.4. Key Factors that Influence Southeast Coastal Current Flow

Geyer et al. (2000) have proposed that within coastal current circulation, bay-forcing factors such as wind and tides do influence the sediment plume structure and movement, particularly outside the river mouth. Incoming waves and rising tides have a high energy level in the more open and deeper parts of the bay (Padman et al., 2009) and are in more direct contact with the river plume as the latter flows out of the confined channel.

The prevailing east-bound coastal current offshore of the river opening (see Figure 3.25) is largely influenced by tidal oscillation (see Figures 3.22 & 3.23) and by a relatively strong north and northwest wind force (see Figure 3.24). The open north boundary of the model provides a strong tidal forcing that fluctuates in a daily two-way northward and southward directional flow. The net effect is a prevalent southward current reinforced by the northwest wind from midday until late afternoon. This southeastward effect on the current is not neutralised by the much weaker southeast wind that prevails in the evening until the following morning.

The tidal-dominated southward current is further influenced by coastal boundary forcing and by the southern coast's morphology, as manifested in gyre formation. The main current heads towards the coast and breaks into two main directions: eastward and westward from the forcing effect of the coastal boundary. Of more interest to the present study is the eastward current, as it drives the coastal current circulation from the reef site to the seagrass meadows, passing through the river opening. As the eastward current pushes forward, the two large masses of water on both sides circulate to opposite directions due to their confined locations. This is caused by the incoming current from the north and the coastal boundary forcing from the south (see Figure 3.37). The northern gyre's effect forces some portion of the eastward current to circulate far offshore of the river mouth. The southern gyre includes some portion of the eastward current in anti-cyclonic circulation within the large body of water, partly enclosed by the long depressed coastline.

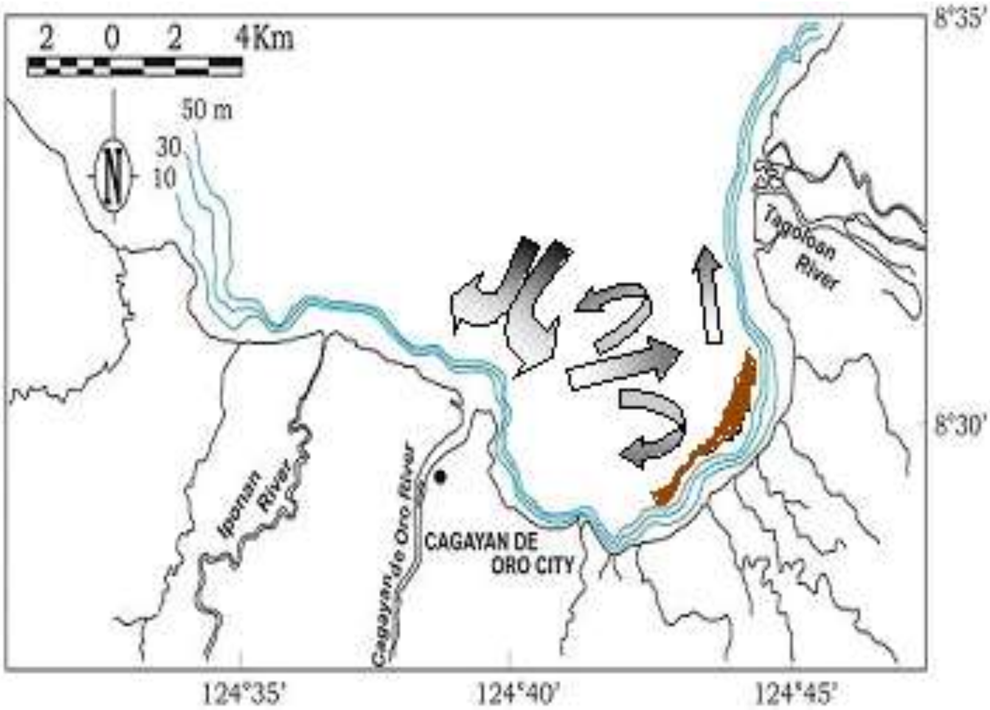


Figure 3.37: Six major coastal flows and sediment dispersal directions (arrows) that distribute most sediments (brown icons) towards the southeastern coast of the bay. Other dispersed sediments may remain circulated along major water current routes and locations (source of base map: NAMRIA map).

Given the prevailing coastal circulation pattern, it is more likely that river plume is swayed mainly farther eastward, but some sediments may persist north of the river mouth due to the gyre's circulating effect. This means that some upland-derived sediments may be dispersed along the eastern coast and carried off again northward by the same current flow. However, a large portion of the plume is transported south by the anti-cyclonic circulation. Dispersed sediments are likely to be confined within this sheltered portion of the bay due to the gyre's strong circulating force and its weak northward flow velocity. This may lead to subsequent sediment deposition within the depressed section of the southeastern coast. Here, the circulation effect furthest from the centre is much reduced and the shallow water energy level near the coastal shore is weakest. It is unfortunate that the present study did not undertake actual sediment sampling along the southern coastal shores after days of extreme rain to validate the model results.

3.4.5. Key Factors that Influence River Sediment Plume Dynamics

3.4.5.1. Catchment rainfall and river discharge correlation.

Rainfall input in the river potentially contributes to the river velocity energy level (Dettinger & Diaz, 2000; Groisman et al., 2001). However, the positive relationship between rainfall and run-off can be complicated due to local weather conditions (e.g., high evaporation), land use types, (Bruinjzeel 1996), land-based activities (e.g., irrigation systems) and water storage capacity (e.g., extensive aquifer use) (Marengo & Tomasella, 1998).

In cases when sampling periods of the same catchment spatial characteristics vary temporally, the weather conditions (particularly the rainfall amount) determine the river discharge volume and velocity variations. Further, given the same physical conditions, the rainfall intensity dictates the amount of sediment yield and consequently the river's SSC (see Chapter 2). In the present study, examples of this are the following: Typhoon *Washi* generated the highest river run-off and sediment discharge values; normal rain days resulted in average river discharge and SSC amounts; and slight rains produced very low run-off and suspended sediment loads downstream. It is expected that given the rainfall patterns in Cagayan de Oro catchment and its vicinity, river discharge conditions would be mostly average throughout the year, but extreme conditions do occur several times and impact heavily upon catchment soil and vegetation.

3.4.5.2. Factors that influence highest sediment concentration at the river mouth.

The force of the river flow, together with the outlet geometry and the strength of tide- and current-push, govern the sediment plume direction and extension off the river mouth

(Geyer & Kineke, 1995). Within the river mouth, river run-off velocity exerts a considerable influence on the discharge (Wright & Nittrouer, 1995). The river flow provides the momentum and buoyancy of the river plume as it enters the bay area. High-velocity outflow can create long extended plumes towards offshore areas (Geyer & Kineke, 1995), while a weak push of outflow may limit plume extension within the river mouth zone. Relatively lower river discharges are further weakened by shallow water depth at the river mouth (Yankovsky & Chapman, 1997) and the opposing tidal or wave action (Wright & Coleman, 1974; Wright, 1977). The combined effects of these factors and conditions mean that most suspended sediments are trapped within the river opening (Mulder et al.,1998). Despite this, presumably some suspended sediments, upon continuous pushing by the river outflow, are advected further out to sea (Villanoy, 2009). Some distance off the river mouth, the existing bay-forcing factor(s), such as wind and tides, determine the discharge fate in the bay (Geyer et al., 2000).

In all the simulated river discharge conditions, TSS concentration levels were evidently highest at the river mouth among all affected areas within the coastal waters. This is partly due to the very gentle slope range of between 0 to 3% (Department of Public Works and Highways (DPWH), 2000) for the river channel within a few kilometres from the bay zone. In fact, the depth range (from -1.5 to -4.0 m) of the immediate receiving coastal water is just a couple of metres deeper than the river mouth and channel depths (from 1.5 to 2.5 m, see Figure 3.37). A relatively weak outflow, coupled with a shallow shelf results in a limited sediment transport distance (e.g., Mississipi River, Coleman et al., 1998), as most sediment is trapped at the river mouth. Even with an extreme discharge volume of more sediment, plume concentration (e.g., Amazon River, Geyer & Kineke, 1995) stays within the river mouth.

3.4.5.3. Mudflat formation and its influence on river plume outflow.

The depth of the receiving water and the strength of the counterforce from tidal- and wind-driven currents can affect the plume's structure and extension in the bay (Beardsley et al.,1985; Geyer & Kineke, 1995; Kineke et al., 2000).

The model-generated maps show a river plume movement that is dominantly eastward and southeastward, following the prevailing coastal current circulation flow in the bay. As a result, the westward extent of sediment dispersal is diminished (see Figure 3.35). With a reduced westward flow velocity, most deflected suspended sediments gradually settle down and are deposited on the west corner outside the river opening (Leopold & Wolman, 1960). Increased sediment accumulation is particularly enhanced during ebb tide, when accumulated sediment materials are almost on the same level as the bay water.

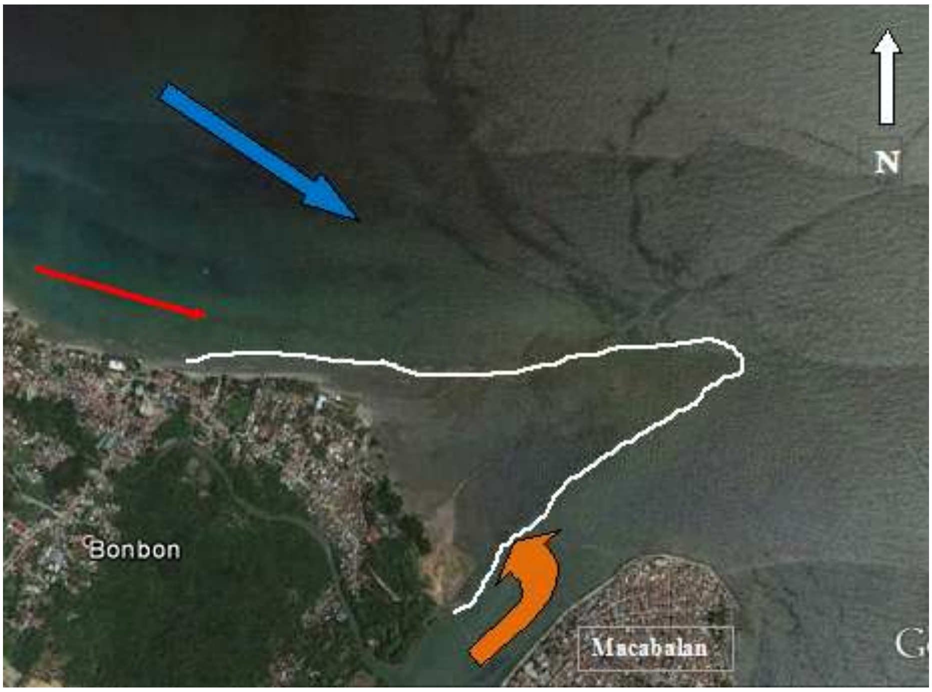


Figure 3.38: The map shows a mudflat expanding structure (white) as influenced by the weakened river outflow (orange arrow), the eastward longshore current (red arrow), and the main southeastward current (blue arrow) mudflat structure manifests its continuous expansion seaward towards northeast and the gradual erosion on its northwest side, probably due to a longshore current-forcing effect (base map from Google Earth 2015).

Over time, the accumulated terrigenous materials have formed a mudflat along the Bonbon coast, which is characteristically muddy due to being submerged most of the time. During low tide, a portion of the elevated mudflat protrudes above the water level surface, and appears like a sandbar extending a kilometre seaward (see Figure 3.39). Consequently, the shallow depth flat zone heightens the bed-friction effect and causes sediment flow velocity to further weaken; with this, the resulting sediment deposition and mudflat lateral expansion increases (Wright, 1977). Existing coastal features, such as a mudflat or a sand bar, support the model's results of a restricted initial sediment dispersal westward.

3.4.5.4. Influences of river discharge and tidal action on sediment dispersal.

Among the key bay-forcing factors, the river discharge velocity is most influential in dictating sediment discharge rates within the channel and outside the river mouth. Both tidal flow events revealed that in extreme disharge conditions (see Figures 3.33 & 3.34) dispersed sediments during flood and ebb tides were only ~25% & ~31% respectively of the total TSS input. These relatively low percentages of dispersed TSS values as compared to flood (~44%) and ebb (~61%) during average discharge conditions (see Figures 3.30 & 3.31) imply a reduced dispersal velocity as river sediment concentration increases. This could mean that a higher sediment amount is dispersed offshore in extreme discharge conditions but at a lower percentage than in average discharge conditions.

Alternating tidal actions exhibit influence on variations in the actual amounts of dispersed sediments. Under average discharge conditions, dispersed sediment concentrations on the eastern side were higher and more widespread during ebb tides (range of 30 and 40 mg/L; 62% of TSS value at the river channel) than in flood tides (range of 10 and 20 mg/L; 50% of TSS value at the river channel). In contrast, a rising tide—due to its landward movement—facilitates more sediment material trapping at the river mouth. Evidently, in extreme discharge conditions the rising tide maintains higher TSS concentration levels along the channel when compared to sediment concentrations within similar sites during ebb tides. Therefore, we can infer that more sediments are carried seaward with the ebbing tide.

3.4.5.5. Coastal formations and their influence on sediment dispersal.

Under all river discharge conditions throughout the year, there is continuous sediment concentration and possible deposition at the river opening and along the banks. The model's results are clearly confirmed by the shallow depth river mouth, the mudflat formation (see Figure 3.39) and the prograded coastal lines (see Figure 3.39).

Figure 3.39: The map shows a land mass (inside the circle) at the right corner of the river mouth that came from from sediment materials dredged from the river mouth bottom. The prograded land mass is planted with mangroves and some parts remain bare due to the dumping of dredged materials.Other accreted land along the coast and banks was compacted with dredged materials for housing purposes (base map from Google Earth, 2015).

Heavy sediment deposition at the river mouth weakens the river outflow velocity and thus limits the plume extent offshore and the possible encroachment on the seagrass site. Similarly, the mudflat lying near the river mouth dissipates the impact of incoming waves and tides against the river plume located within the river mouth zone (Möller & Spencer, 2002; Cooper, 2005). The low-energy level at the river mouth further expands the mudflat-covered area. This may also increase the threat of sediment erosion and the spilling over of sediments to the reef sites, due to the constant westward river outflow.

3.4.6. Normal- and Worst-case Weather Scenarios and the Key Factors

The model results predicted both the normal- and the worst-case scenarios at the Cagayan de Oro River mouth and its coastal vicinity, based on the locality's present weather condition patterns and the study sites' existing morphological and topographical conditions.

A normal-case weather scenario consists of regular sedimentation along the ridge-river-reef continuum throughout the year. Low and average rainfall events generate a normal discharge volume and sediment load. Due to a relatively weak flow velocity and the river-to-coast gentle sloping topography, most upland-derived sediments are trapped at the river mouth. Tidal- and wave-opposing effects on river run-off also enhance increased sediment concentration and subsequent deposition at the mouth and its immediate vicinity. With this flow dynamic, sediment encroachment on seagrass site is less of a problem. However, the presence of a mudflat poses a threat to the corals due to the constant westward outflow that may erode the flat and send loose sediments to the reef site.

With heavy rainfall, particularly a tyhoon event, river discharge and sediment load can exhibit extreme volumes. As shown in the satellite images, the strong initial river outflow may encroach on the coral reefs and deposit sediments on the affected site. Mudflat erosion can worsen with increased river flow velocity. Evidently, the extreme high plume discharge eventually floods the seagrass meadows and most southeastern portions of the bay. Prolonged heavy rains contribute to persistent distribution and even deposition of sediments on the seagrass site.

Extremely high discharges could generate other environmental risks. Gentle sloping of the channel topography reduces the water flow velocity and delays the discharge of run-off into the bay. At the river mouth, extreme river water rise is exacerbated by flood tide events and strong wind-driven waves. Both forcing factors are inland bound and therefore could effectively hold back the outflow of river run-off, resulting in river swelling and flooding in the city's low-lying areas. This flood scenario has been proven in previous events such as typhoons *Washi*, *Bopha* and *Jangmi*.

In a very extreme scenario, over time the heavily silted channel bottom could disrupt the regular flow along the existing channel, forcing the river flow to shift to new exit paths to the bay; this has happened with the Agno River in the Philippines (Mateo & Siringan, 2007) and the Saraswati River in the Great Indian Desert (Ghose et al.,1979). However, both of these examples of changed river courses result from different causes. A new river route may open new possibilities, either for the preservation of existing seagrass or coral communities, or an increase in the threat from sedimentation effects on any coastal habitats.

3.5. Summary and Conclusions

A hydrodynamic model for Macajalar Bay (near the Cagayan de Oro River mouth), using a nested Delfth3D model, was developed and used to drive the current velocity circulation and TSS dispersal from the river channel to the coastal waters. Three different river discharge conditions (e.g., low, average and extremely high), with corresponding bay-forcing factors were used as model inputs to simulate the TSS dispersal pattern in the bay.

The prevailing coastal current circulation flow is towards the east and southeast, affording a net sediment distribution and subsequent deposition at these portions of the bay. Among the bay-forcing factors, the model identified tidal action as the most dominant factor in the offshore circulation pattern of coastal current flows. Nonetheless, the NE/NW wind variable also reinforced the prevailing flow direction. However, the determining factor for the initial extent and direction of sediment plume was the river discharge volume. Apart from river discharge, shelf bathymetry also exacted an influence on the extent of river outflow.

Based on the model simulated results, one potential impact area is the vast eastern and southeast portion of the river mouth, where most sediment materials are eventually driven during extreme discharge conditions. This, however, was not validated by actual survey of presence of sediments in the site. In addition, the reef site is threatened by strong initial river outflows, enhanced by weak opposing southeast currents. Another site heavily affected by river sediments is the river mouth where most flowing sediments are trapped. Constant dredging activity at the site and the ‘reclaimed land masses’ can attest to this on-going coastal process.

Thus, given an extreme rainfall condition generating a large bulging plume, two sediment-dispersal scenarios are likely to occur. First, with a dominant SE current, most river plume concentrates on the east and southeast, raising the risk of sediment encroachment on seagrass communities. Second, with reduced SE currents and exacerbated by mudflat erosion, the initial plume's westward outflow is most likely to intrude the reef site. Further, with a continuous and extreme high river discharge flow, coupled with flood tides, massive flooding is likely to occur along the river channel and within the river mouth, threatening low-lying human communities.

Generally, the Delft3D model-simulated results are acceptable as representing actual river sediment-distribution patterns under specific months of the year (November to June). However, suspended sediments are weak parameters to validate the model, due to several factors (e.g., different sources of sediments and non-synchronisation of collection of sediment samples) affecting TSS concentration in the bay. Salinity was a better indicator of the extent of river plume intrusion on the coastal sites. Heavily silted river bottom and mud accumulation near the river mouth confirmed the heavy sediment concentrations within the river channel during all river discharge conditions. Further, the presence of coral and seagrass communities nearby suggests minimal and occasional encroachment of river plume on these sites at most times during the year.

Overall, the study has provided the basic methodology and analysis that generated results indicative of the possible direction and deposition sites of river sediments within the Cagayan de Oro River mouth vicinity. However, due to a weak agreement between simulated and observed data mainly attributable to limited sediment data collected, it can be said that the findings are not yet conclusive and sufficient for future critical decisions on policy and development.

Chapter 4

The coastal marine environments as related to sedimentation dynamics of the Cagayan de Oro River catchment

4.1. Introduction

4.1.1. Coastal Marine Environments of the Cagayan de Oro River Catchment

As expected, river mouths with significant annual freshwater discharges are estuarine areas. With highly variable salinity, sediment, as well as nutrient levels related to episodic precipitation extremes, these estuarine areas are usually highly productive, even surpassing the primary production of tropical wetland forests (Donato et al., 2011) and of shelf regions (Berger et al., 1992).

The coastal water quality as influenced by the river inputs largely determines the geographical distribution and conditions of existing coastal marine habitats. Moreover, the direction and strength of plume dynamics from the closest river outlet within the estuary affects the amount of freshwater and other particulates in the marine waters (Dennison et al., 1993; McLaughlin et al., 2003). With the continuous river discharges to the inshore waters, this paper will investigate the implications of river sedimentation dynamics for the mangroves, coral and seagrass communities within the Cagayan de Oro River mouth and its vicinity.

Of the aquatic habitat types found in coastal areas, tropical estuarine areas may be colonised more abundantly by mangrove forests, as these flourish best in sheltered brackish water environments (Kathiresan & Bingham, 2001; Kathiresan, 2002). With their highly developed morphological and physiological adaptations, mangroves can thrive in extreme estuarine conditions, such as fluctuating salinity, muddy and anaerobic soils and periodic inundation (Kathiresan & Bingham, 2001). In some cases, mangroves even enhance the formation of new landforms along riverbanks and the coastal shore. This is an important ecological function: mangrove roots trap debris from the uplands, which over time leads to the formation of new soil deposits (Wernstedt & Spencer, 1967) and the further expansion of mangrove cover (Walsh & Nittrouer, 2004). The catchment size and topography, its exposed lands and the local rainfall characteristics largely determine the amount of sediment deposited along the river bank and coastal edges (Duke & Wolanski, 2001). Near the river mouth, specific conditions such as increased sediment deposits, reduced water flow and moderate nutrient input in the soils favour the colonisation and the later establishment of mangroves in the estuarine environment (Lee, S.Y. et al., 2006). Aside from reducing sediment run-off to seagrass and coral sites (Wolanski, 1995; Kathiresan, 2003) and accreting new land forms (Bird & Barson, 1977; Woodroffe, 1993), mangroves also provide other services and functions to the environment (W. E. Odum & Heald, 1975; Alongi, 1990; S. Lee, 1999; Dittmar et al., 2006).

Other important coastal habitats, such as seagrass meadows and coral reefs, which are less tolerant of salinity depressions, may also flourish at some distance from the river mouth, depending on the intensity and extent of discharge pulses (Della Grace et al., 2005; Schaffelke, Mellors, & Duke, 2005). Both these marine habitats thrive in inshore coastal waters where salinity is relatively normal and prone to less fluctuation. Other than salinity depressions, sediment-loaded river discharges also affect the occurrence and distribution of seagrass meadows and coral reefs. These two equally important coastal habitats could be highly sensitive to siltation and burial, as well as the light climate variability linked to turbid discharge waters and other nutrients.

The following authors detail the ecological significance of seagrass as breeding ground for marine animals in Calumpong and Menez (1997); for high primary production of oceans in Duarte and Chiscano (1999); for sediment stability in Hemminga and Duarte (2000); and as habitat for fishery species in Jackson et al. (2001); and of corals for fisheries yield and biotic, biogeochemical, physical structure, information and cultural services in Smith (1978), McAllister (1991), Pendleton (1995), Moberg and Folke (1999), Cesar (2002) and Brander et al. (2007). For the effects of siltation and burial on seagrass see Duarte et al. (1997); Erftemeijer and Lewis (2006); Cabaço et al. (2008); and for corals see Gomez et al. (1994); Vermaatl (1999); Fabricius et al. (2003) . For the effects of light climate variability linked to turbid discharge waters on seagrass see Dennison et al. (1993); Onuf (1994); Abal and Dennison (1996); and for corals see Dodge and Vaisnys (1977); Telesnicki and Goldberg (1995); Fabricius et al. (2003).

In the tropics, these three major coastal habitats are usually closely interlinked (Unsworth et al., 2008; Wolanski, 2000), making contributions of equal importance to the the coastal environment's overall productivity. Such interconnectivity may be severely compromised by human-induced disturbances (e.g., dredging, coastal infrastructure, harmful fishing methods, coastal pollution and eutrophication, and upland erosion and sedimentation), affecting the delicate balance (M. D. Fortes, 1988; Pringle, 1989; Duke & Wolanski, 2001; Schaffelke et al., 2005). Severe impacts on one marine habitat can also affect others in terms of the habitats' distribution, composition, abundance and function. Mangroves also maintain a symbiotic relationship with corals (Duke & Wolanski, 2001). Water clarity is essential to corals; therefore, mangroves are vital to trap, bind and hold sediments with their roots, maintaining the clarity of river discharge flowing to reef sites. In contrast, corals provide a natural barrier to reduce inland-bound wave action and are thus beneficial for seagrass stability and mangrove establishment on soft sediments along the river mouth. Interconnectivity among the three marine habitats is also demonstrated in their shared functions as spawning ground and habitats during various fish species' lives (Mumby, 2006; Unsworth et al., 2008), and in their inter-habitat nutrient exchanges (Granek et al., 2009; Kathiresan, 2014). This is despite such interactions being subject to influences by geomorphology, coastal flow circulation, seasonal changes and human impact (Davis et al., 2009).

4.1.2. Coastal Marine Habitats at the Cagayan de Oro River Mouth and Its Vicinity

Similar to many tropical coastal environments, Macajalar Bay hosts three major coastal marine habitats: seagrass meadows on the east side of the river mouth; coral reefs on the west; and mangroves on the flood plains of Bonbon (see Figure 4.1). As river run-off is drained regularly into the bay, these coastal habitats are threatened or affected by sediment and freshwater plumes from the Cagayan de Oro River catchment. With a rise in the human population and catchment land-based activities, the threats and impacts on these coastal marine habitats have also increased.

The 90 km long Cagayan de Oro River system originates from the ranges of Mt Kitanglad and Mt Kalatungan, and drains discharge into the coastal waters of Macajalar Bay (see Figure 2.1). The long and winding river channel generally flows in a northerly direction and straddles various types of land use and vegetation cover before ultimately reaching Macajalar Bay. The Cagayan de Oro River is fed by four major tributaries: Bubunawan, Kalawaig, Tagiti and Sumalaong along with several other smaller ones.

The Cagayan de Oro River's annual discharge rate amounts to some 3,883 million cubic metres (mcm), a substantial amount comparable to the annual discharge rate of the other principal intermediate rivers within the Mindanao Island. These include the Agus River in Southern Mindanao (1,910 mcm), the Davao River in Southern Mindanao (3,246 mcm); the Tagoloan River in Northern Mindanao (4,350 mcm), and the Buayan-Malungan in Southeastern Mindanao (2,879 mcm) (Alejandrino et al., 1976). River discharge rate varies according to seasons.

Such rates, affected by upstream land use and human-induced changes, including coastal infrastructural development, may have wide-ranging implications for the distribution, composition and abundance of mangroves, seagrasses and coral reefs in the Cagayan de Oro River mouth's vicinity.

4.1.3. Aims and Significance of the Study

This chapter will determine the present distribution, composition and abundance of each of the three major coastal habitats—mangroves, seagrasses and coral reefs—as they relate to river freshwater and sediment plume dynamics.

In addition, this study hopes to raise awareness among local government officials and the public, so that they understand the natural connections or relations between human activities (e.g., sedimentation) and the coastal/estuarine environment and its natural ecosystems. The local people's awareness of the three major coastal marine habitats' importance to their lives and to the entire ecosystem is negligible. A sustained and integrated coastal-river-catchment plan, based on the findings of the present ridge-river-reef connectivity research study, is also required.

4.1.4. Scope and Limitations of the Study in this Chapter

Given the limited time and the inadequacy of previous data on each of the target local coastal habitats, this study has focused on the following research concepts and related methods:

1) The study has focused on existing mangroves, corals and seagrasses, which are suspected as being associated with river plume dynamics.
2) Only temporal variations in the distribution, composition and abundance of the mangroves were investigated.
3) Only spatial variations of the composition and the abundance of corals and seagrasses were investigated. Temporal and spatial variations of their physical distributions were also examined.
4) Human interventions were analysed in coastal and bank modifications within the river mouth and its vicinity, in relation to sedimentation effects on the sites.

4.2. Materials and Methodologies

4.2.1. Study Sites: The Cagayan de Oro River Mouth and its Coastal Marine Vicinity

The study sites are located within the Cagayan de Oro River mouth and its coastal marine vicinity stretching hundreds of metres to the east (Macabalan) and to the west (Bonbon) from the river opening (Figure. 4.1).

Figure 4.1: The Cagayan de Oro River flowing out to the Macajalar Bay (white arrow direction) between the Macabalan and the Bonbon coastal areas. A large vegetation area in Bonbon (base map from Google Earth, 2015).

4.2.1.1 The Cagayan de Oro River mouth and its sedimentation patterns.

The study site (see Figure 4.1) basically lies in a flood plain zone of Cagayan de Oro City and is relatively flat, with elevation ranges from 5 to 10 m above sea level (ASL) and slope ranges from 0 to 3% (DPWH, 2000). The EIA (environmental impact assessment) report from DPWH describes the river mouth as characterised by a quaternary alluvium; the Macabalan area has an *Umingan* clay loam type and the Bonbon side features a sandy type of soil, as well as a hydrosol soil type, which is suitable for fishponds, salt production and mangroves.

The former shoreline of Cagayan de Oro City, located approximately 4 km south of the present northern tip of the Cagayan de Oro delta, has demonstrated a rapid advancement over 300 years (DPWH, 2000), particularly with the onset of increased land-based activities in the twentieth century.

4.2.2. Methodology Framework

The framework consists of the methodologies used for each coastal habitat from the actual field sampling to the analyses of both primary and secondary data (see Figure 4.2).

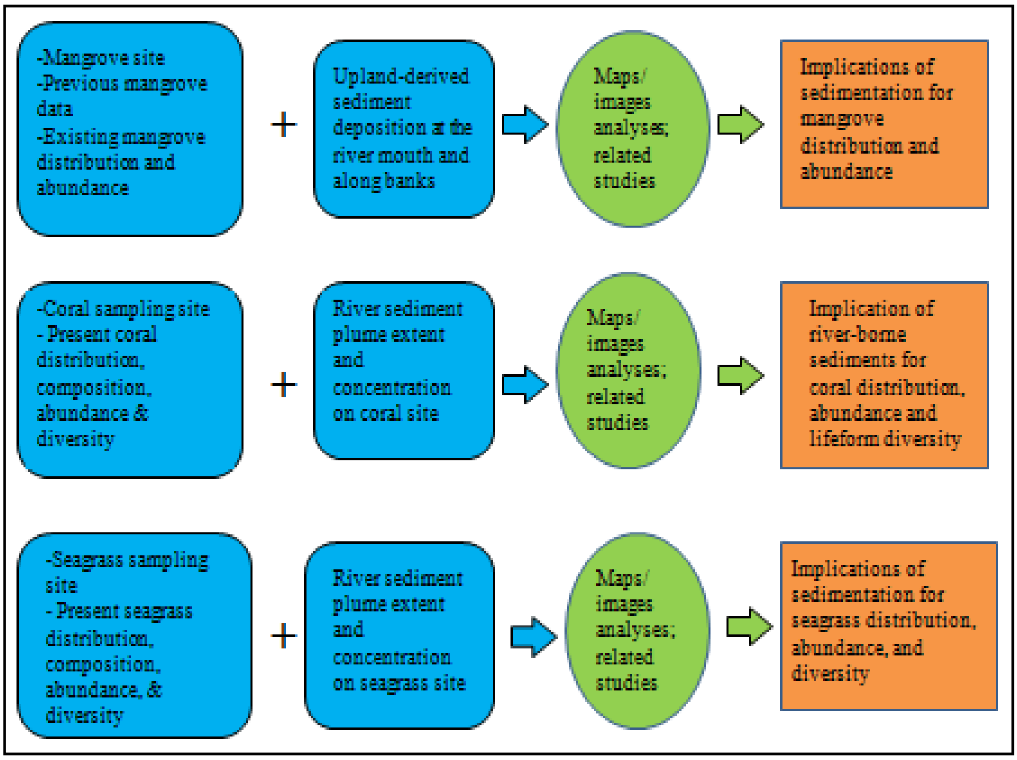


Figure 4.2: The framework shows three separate sets of methodology for each coastal habitat and its relation with river-borne sediments. The past and existing distribution,composition and abundance of each habitat (blue box) were first established, then each was compared with the extent and concentration of river plume (blue box) at the river mouth. Visual examination and previous studies (green circle) were used to determine with the results/outputs (orange box) of the relations.

4.2.3. River-Borne Sediments and Their Relations to Coastal Habitats' Distribution, Composition and Abundance

Given the river plume extent and persistence along the inshore waters of Macabalan and Bonbon (see Chapter 3 results), the existing ecological profile of each coastal marine habitat (mangroves, corals and seagrasses) was first examined for any apparent indication of changes over time that may suggest a river plume influence. As no experiment was conducted to validate cause and effect correlations, valuable data such as historical maps, satellite images, modelling results, actual observations and previous studies were used as evidence to establish the presence and extent of the relationship between river-borne sediments and the coastal habitats' profile (see Figure 4.2).

4.2.4. Mangroves at the Cagayan de Oro River Mouth

4.2.4.1. Use of historical maps and satellite images.

The following data were examined to determine the present distribution and abundance of mangroves within the Cagayan de Oro River mouth:

1) Historical maps of the Cagayan de Oro River mouth LUC, based on the Cagayan de Oro City Cadastral Survey (1932).
2) The National Mapping and Resource Information Authority or NAMRIA map (1957).
3) Google satellite images from 2004 and 2015 (Google Earth map, 2015).

Mangrove cover measurements from satellite images were compared with data from the government agency DENR. Overlaying of the 2015 satellite image and the 1957 NAMRIA map was undertaken to ascertain new land formations made within a span of 58 years. Comparison between the Cadastral Survey and NAMRIA maps was undertaken visually. Field visits validated the composition of mangrove cover in the satellite images.

4.2.4.2. On-site ocular inspection and interviews.

Two visits to Bonbon and in Macabalan sought to: a) validate information from the 2015 satellite image on the ground; b) confirm the physical and ecological changes in both areas between the 1950s and the 2010s.

The first two-day on-site visit involved interviews with the elderly residents of Barangay Bonbon who have lived there since the 1940s. The interviews were conducted to gather information on the past mangrove cover area and the physical changes it has undergone over the decades until the present. Information about past and present mangrove species was included in the interview questions. Other data and information were gathered from the local *barangay* office of Bonbon and the local DENR office.

The second two-day on-site inspection covered both Bonbon and Macabalan. In Bonbon, species validation was conducted in three locations: the largest mangrove swamp of *Nypa fruticans*; the sites marked by the DENR as different mangrove species habitats; and the sites of newly grown seedlings planted by local communities. In Macabalan, the areas inspected were the accreted coastal land and the converted residential area, a large 21 ha mangrove forest area until the 1970s.

An interview with the present city planning and development officer was conducted to gather more information about the city-initiated coastal projects in Macabalan and Bonbon.

4.2.5. Coral Reefs on the West Side of the Cagayan de Oro River Mouth

4.2.5.1. Broad area survey for coral sampling site selection.

To locate coral sites or target inshore areas that might possibly contain coral communities or reef structures within the Bonbon sampling site, a Google Earth map of the study site was examined and used as a basis for surveying the identified coral area. Enquiries from local fisher-folk were made regarding the presence and exact location of reefs within the Bonbon coastal area.

Reconnaissance surveys were made at the target site (100 to 300 m offshore of the Bonbon shoreline) and around a kilometre west of the river mouth (see Figure 4.1). A manta tow monitoring method (Hill & Wilkinson, 2004) was employed for a visual survey covering the entire delineated coral site area, beginning from some identified coral clusters nearest the mudflat and going west beyond Bonbon.

4.2.5.2. On-site photo-transect survey of corals.

To determine the composition, relative abundance and conditions of coral lifeform categories in the targeted sites, a photo-transect sampling method (Hill & Wilkinson, 2004) was conducted. Two 50 m parallel transect lines, 20 to 30 m apart, were laid within each plot on top of the reefs (Figure 4.3).

Figure 4.3: Coral sampling site on the western side of the river mouth with Plots A, B & C, and the transect lines (yellow); (base map from Google Earth, 2015).

The positions of both transect lines extended from east to west, roughly parallel to the shoreline; this was designed purposely to establish the gradational distance of the sampling plots from the Cagayan de Oro River. The entire area of the coral sampling site was divided into three plots: Plot A, Plot B and Plot C, with Plot A the closest to the sandbar and Plot C the farthest (see Table 4.1). A coral site map was created with defined outer boundaries of the entire coral site and the inner delineations of each plot. The coral sampling points of each plot were input into a GIS base map of the bay.

Table 4.1: Three coral plots and two transect lines on each plot were installed at the coral sampling site of Bonbon, Macajalar Bay, Cagayan de Oro City, Philippines.

Plot	Total plot area (sq. m)	Water depths (m)	Distance apart between transects (m)	Distance of plot from the river mouth (m)	Distance of plot from Bonbon shore	Transect number, transect (length in m) No. of frames
Plot A	842.74	~2–3	A to B = 241	1,628.34	100 m	1st T (50) = 42 2nd T (50) = 50
Plot B	733.36	~2–3	B to C = 217	1,931.77	130 m	1st T (50) = 47 2nd T (50) = 49
Plot C	3,618.75	~2–3	Same as Plot B	2,208.88	260 m	1st T (50) = 50 2nd T (50) = 43

Table 4.2: Physical parameter measurements (min to max) at the coral sampling plots during the monthly sampling period from Nov 2012 to June 2013 in Macajalar Bay, Cagayan de Oro City, Philippines.

Plot	**Salinity range (ppt.)**	**Water temp (°C)**	**TSS concentration (mg/L)**	**Water clarity (m)**
A	Surface:16–19 Middle: 36–38	26–33	6–90 Ave: 39.4	1–2
B	Surface: 19–21 Middle: 36–38	26–33	11–88 Ave: 28	2–2.5
C	Surface: 25–29 Middle: 38–39	28–34	6–70 Ave: 24	2–3

Physical parameters of the coastal sampling sites were taken every sampling day in three replicates at each station point in Bonbon. Salinity values were taken from both surface and approximated middle layer of the water using a salinity meter. Water temperature values were measured using a thermometer. Water samples from station point were filtered then sediments collected were oven dried to get the TSS values. Water clarity was determined using a Secchi disc. Minimum and maximum values for each parameter were noted.

The numbers of frames deployed along each transect line varied depending on the corals' presence. An encased digital camera was attached to a light stand, which was held against the bottom to minimise camera movement. To ensure data measurement standardisation, only two divers recorded the data for each individual line. A quick repeat survey was made for every transect line to ensure that all targeted points were photographed.

4.2.5.3. Analysis, organisation and presentation of field results.

Underwater photographs of coral lifeforms and various categories defined inside the frame were analysed and interpreted using CPCe (Coral Point Count with Excel extensions) software. A total of 150 photos were taken; 50 photos from each plot. A CPCe is a Microsoft Windows-based software with the ability to analyse and identify the coral species/lifeforms and/or substrate type lying beneath each random point and to save that data in a file (Kohler & Gill, 2006). The CPCe was employed as it could calculate the statistical coverage of each photograph of corals and other categories inside the frame quickly and efficiently. After the coral image processing, the data were automatically organised into Excel spread sheets for statistical analysis: percentages of the occurrence frequency of each major category, each coral lifeform, and each abiotic group were obtained.

The coral data results from each plot were then charted on the coastal map and presented in pie graphs to indicate a percentage abundance of categories found within the frame.

4.2.6. Seagrass Meadows on the East Side of the Cagayan de Oro River Mouth

4.2.6.1. Broad area survey for seagrass sampling site selection.

To define the seagrass area scope, three field reconnaissance surveys were conducted to locate seagrass beds and plot them using a GPS. Visual survey determined the exact locations of seagrass beds and determined where to establish the line transects (Chansang & Poovachiranon, 1994). A few visual survey methods were employed for specific needs: boat visual survey, diving and wading in the waters, from November 2012 to June 2013. Seagrass meadows were found scattered abundantly at the further eastern end of the sampling plot and several hundred metres away, east of the city shipping port site (see Figure 4.4).

Figure 4.4: Seagrass sampling site on the eastern side of the river mouth with Plots, A, B & C, and the transect lines (yellow); (base map from Google Earth, 2015).

4.2.6.2. Transect-quadrat sampling of seagrasses.

Three sampling plots, A, B and C, were established, beginning from the east to the west (see Figure 4.4). A representative suite of seagrass meadows was targeted for detailed ecological survey. Two parallel transect lines were laid on well-developed seagrass meadows stretching ≥28 m long per sampling plot. The alongshore parallel (roughly) position of the transect lines followed the direction of coastal current flow in the bay.

Table 4.3: Relevant data on each sampling plot, transect lines and quadrats

Plot	Total plot area (sq m)	Depth of water (m)	Distance apart between plots (m)	Distance from river mouth (m)	Distance from shoreline (m)	Length of transect lines (m)	Number of quadrats
Plot A	1,100	0.5–1.8	A to B = 56	780	~50	1st T = 28 2nd T = 38	1st T = 14 2nd T = 19
Plot B	2,250	2–3	B to C = 15	879	~30	1st T = 34 2nd T = 52	1st T = 17 2nd T = 26
Plot C	750	2–4.5	Same as Plot B	960	~40	1st T = 52 2nd T = 42	1st T = 26 2nd T = 21

The length of the transect lines depended on the presence of seagrass beds on the plot (see Table 4.3). Beyond the 50 m wide plot seaward at a 10 m water depth, few seagrass specimens were evident. To assess seagrass characteristics (e.g., total seagrass cover, species diversity, relative abundance and distribution) within the sediment plume zone, a transect-quadrat method was used (Campbell & McKenzie, 2004; English et al., 1994). A standard 50 cm x 50 cm quadrat (made of 5 mm diameter stainless steel), divided into a 10 cm x 10 cm grid, was placed on the seagrass meadow alongside the transect line. Due to the relatively small meadows, samples were taken at 1 m regular intervals and alternately on each side of the transect line. To estimate the percentage cover of the seagrass found in the quadrat, each species was scored based on the number of grid(s) it occupied (Saito & Atobe, 1970).

Onboard a boat, seagrass samples were sorted out, washed and placed inside a plastic ziplock bag. They were then labeled with the following identifications: a) zone number; b) transect line number; and c) quadrat number.

During reconnaissance surveys and before the start of every sampling, selected physical variables of the seawater were measured at different depths and points within the sampling plot (see Table 4.4).

Table 4.4: Physical parameters' measurements (min to max) at the seagrass sampling plots during monthly sampling from Nov 2012 to June 2013 in Macajalar Bay, Cagayan de Oro City, Philippines.

Seagrass plots	**Salinity range (ppt)**	**Water temperature (°C)**	**TSS concentration (mg/L)**	**Clarity (m)**
A	Surface–14 to 16 Middle–31 to 36	25–29	4.6–115 Ave: 34.0	0.2–1
B	Surface–14 to 20 Middle–35 to 36	25–29	4–53 Ave: 25.65	0.5–3
C	Surface–25 to 29 Middle–35 to 39	27–29	4.8–173 Ave: 52.15	0.3–4.5

Physical parameters of the coastal sampling area were taken in three replicates at each station point within the seagrass plot every sampling day. Salinity values were measured at surface and middle layers using salinity meter; water temperature was measured with a thermometer; TSS values were computed in the lab after samples were filtered and oven dried; and water clarity was determined with a Secchi disc.

4.2.6.3. Review, organization and presentation of field results.

The species of identified seagrass samples were confirmed using published seagrass references. Percentage cover results from each quadrat were input into the Excel format with proper labeling of the species name, the quadrat and transect numbers, and the plot letters.

Using topographical coordinates taken from actual sampling, the seagrass plots (A, B and C) were mapped. This was done to indicate the geographical locations and distributions of all seagrass species in the Macabalan coastal water in relation to the Cagayan de Oro River's main outlet.

The seagrass data results (i.e., composition and relative abundance) of each plot were then presented in pie graphs and plotted on the Bonbon-Macabalan coastal map.

4.3. Results

4.3.1. Present Mangrove Cover and its Historical Changes

4.3.1.1. Present mangrove habitat distribution and composition.

The ground-truth activity yielded important information validation. The present mangrove forest consists mainly of *Nypa fruticans* (local name: *Sani*, *Nipa*) (see Figure 4.5). This comprises the largest mono-specific vegetation cover on the Bonbon flood basin. North of the *Nypa* cover and adjacent to the river mouth are newly planted mangroves of *Rhizophora* sp. (local name: *Bakhawan*). Along the riverbanks are stands of naturally grown *Sonneratia* sp. (local name: *Pagatpat*).

Figure 4.5: Distribution of coral reefs, seagrass meadows and mangroves within the vicinity of the CdeO River mouth (base map from Google Earth, 2015).

4.3.1.2. Present mangrove composition and abundance.

Rhizophora species grow generally in brackish to full saline water, in sandy to muddy substrates, at the downstream part of the estuary and along tidal creeks and sheltered sites (Primavera et al., 2012). *Sonneratia* species prefer full seawater salinity, sandy to muddy substrates, a lower estuarine location, and a coastal front line position (Primavera et al., 2012). Therefore, *Sonneratia* sp. are supposed to colonise the coastal area, but were instead mostly grown along the edges of the riverbank, most likely a result of fruit-eating birds' droppings (Gracella Mendoza, interview with author, 27 August 2015). The *Rhizophora* can grow anywhere. They were planted on the Bonbon foreshore in 2009 and 2014, as part of the city's mangrove-planting project (Rogelio Daang, interview with author, 27 August 2015). Within the *Nypa* vegetation are scattered individual *Sonneratia* that grow with non-mangrove trees like tropical almond, coconut and mangoes. Scattered mixed stands of *Sonneratia* and non-mangrove trees were sighted on the far southern side of Bonbon beyond the bridge.

A letter from Mr Jose Reyes (Chief Enforcement Officer, DENR-10), dated 19 August 2015 detailed the following mangrove data (see Table 4.5):

Table 4.5: Present composition and abundance of mangroves within the vicinity of the Cagayan de Oro River's mouth (source: DENR-10)

Mangrove and other vegetations found	Bonbon (ha)	Macabalan (ha)
Nypa fruticans	31.54	none
Sonneratia sp.	4.41	0 .06
Rhizophora sp.	2.0	none
Other mangrove species	No data	No data
Scattered mangroves	~2.0	none
Total	~39.95	0.06

Very few remaining mangroves were sighted along the riverbank on the Macabalan side. The entire Barangays Macabalan and Puntod are currently composed mainly of built-up structures (see Figure 4.5). Near the houses, a few individual trees were sighted. Another prominent piece of infrastructure traversing the Macabalan-Puntod riverbank is the 1.4 km long concrete dike. It was built to reinforce the bank and to ward off high-rise floods resulting from river swelling during typhoons and heavy rains (Isidro Borja, pers. comm., 4 Nov 2015).

4.3.2 Mangrove Cover: Then and Now

4.3.2.1. Land and mangrove cover changes within the Cagayan de Oro River mouth vicinity between 1932 and 2015.

Eroded upland sediment is transported to the lowlands and is ultimately deposited in estuaries, particularly along the riverbanks and coastlines. In the present study, a comparison of the 1932 Cadastral Map, the 1957 Cagayan de Oro City Map, and the 2015 satellite images, revealed that within a span of 83 years, major physical changes occurred along the coast and riverbanks in both the Bonbon and the Macabalan-Puntod areas (see Figures 4.6, 4.7 and 4.8). These changes were brought about both by natural processes, such as erosion and accretion, and by human intervention as part of the city's coastal development program in the 1980s (Rogelio Daang, pers. comm., 27 Aug 2015; Isidro Borja, pers. comm., 4 Nov 2015). In Bonbon, the major physical land changes observed were (see Figure 4.7):

A) an expanded left bank near the river opening that is presently fully vegetated;

B) 'reclaimed' land (dredged materials) that extends foreshore seaward;

C) the formation of mudflat areas on the Bonbon foreshore.

In Macabalan, major physical coastal changes include (see Figure 4.8):

D) a stripped side of the right bank, presently reinforced with a concrete dike;

E) a prograded coastline that extends seaward and is presently occupied with built-up structures;

F) what was formerly a large mangrove area (*Avicennia sp*. or *Piapi* in the local dialect) is now *barangay* Macabalan and *barangay* Puntod.

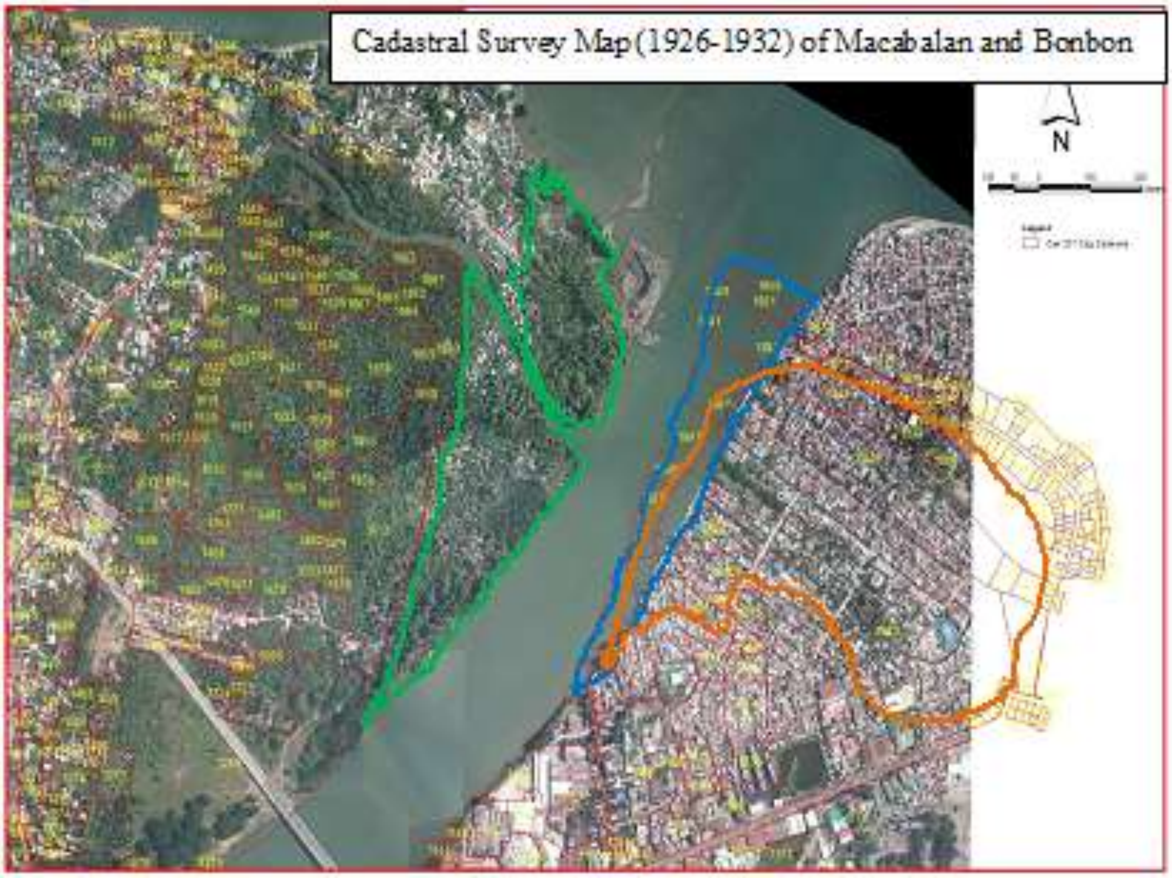


Figure 4.6: Land progression and regression in 83 years (1932–2015) showing expansion of mangroves (green outlines) at the west side of the river bank but also losing some at the east bank (blue outline). The 21 ha of mangroves (brown outline) on the east side has been converted into human settlements (source: Cagayan de Oro City Planning and Development Office, Cagayan de Oro City).

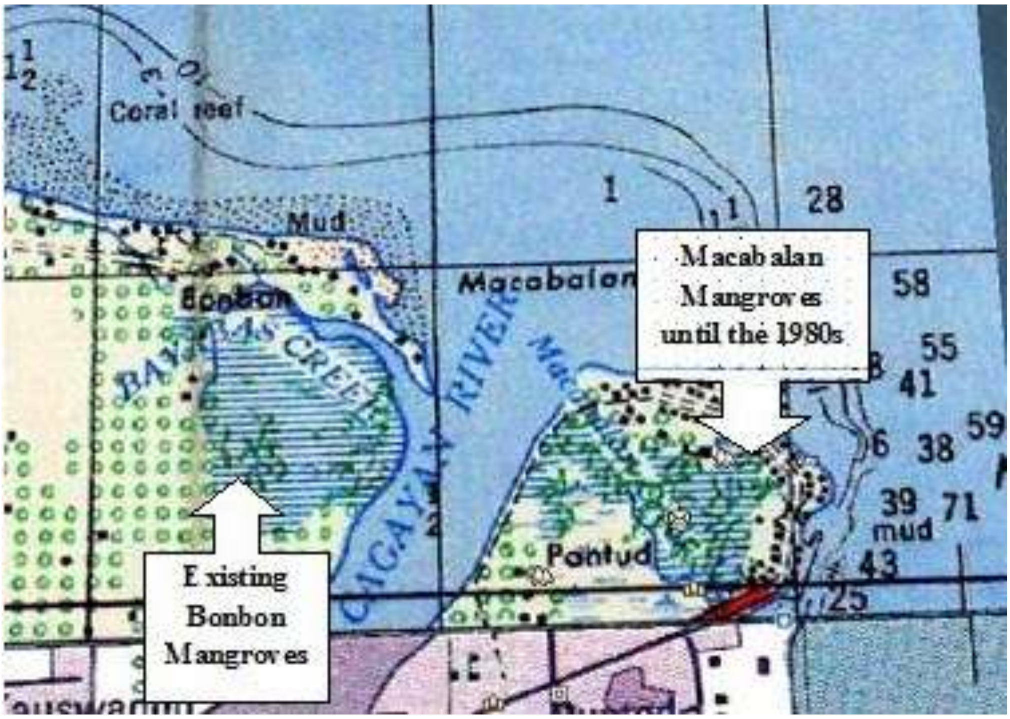


Figure 4.7: Cagayan de Oro River mouth morphology (inc. coastal vicinities) from the 1957 NAMRIA map (scale of 1:50,000) showing large mangrove swamps on both Bonbon and Macabalan (and partly Puntod) sides. Coral reefs are found offshore of the Bonbon coast.

Figure 4.8: Physical and biological changes (1932–2015) within the Cagayan de Oro River mouth and vicinity showing land progression (red); land regression (blue) and land conversion (yellow) due to natural processes and human intervention (sources: 1957 NAMRIA map and Google Earth 2015 base map).

Table 4.6: Physical and biological changes in both Bonbon and Macabalan-Puntod: their locations, estimated size of affected lands and causes of changes (based on interviews with local residents and government officials) (see Figure 4.8).

Temporal land changes and their locations	Processes of land changes from 1932 to 2015	Estimated size of area affected by changes (ha)
A) Bonbon: river bank	Initial land accretion and later expansion due to dumped dredged materials	14.57
B) Bonbon: foreshore	Initial deposition and later compaction and expansion due to dumped dredged materials	15.61
C) Macabalan: river bank	Natural bank erosion and later dredging	5.10
D) Macabalan: coastline progredation	Natural land accretion and later compaction due to human habitation	5.03
E) Macabalan-Puntod inland	Denudation and mangrove conversion to human settlements site	21.0

4.3.2.2. Physical changes from 2004 to 2015.

Between 2004 and 2015, both satellite images from Google Earth map (2015) revealed several physical changes that occurred (see Figure 4.9). Actual visits validated the map's information as specified in Fig. 4.7: beyond the 2004 coastal shore is an extended compacted land formed from dredged materials from the river mouth and dumped on the site (F); the 2004 map showed an islet in the middle of the channel, whose size was reduced in 2015 (G).

The new land mass on the foreshore of Bonbon was formed over time from initial soil accumulation, which was later expanded and compacted with dredged materials from the river channel. This rapid coastal sediment deposition is supported by the present study's results on the high-sediment yield potential of a number of sub-catchments (see Chapter 2) and on the highest sediment concentration near and within the river opening (see Chapter 3). The river islet could have existed long ago and was previously long and narrow in shape (see

Figure 4.9). At present, the islet is reduced in size, and is shorter and narrower than before, due to gradual erosion caused by strong river currents.

Table 4.7: Land changes in Bonbon (between the 2004 and 2015 satellite images) due to natural processes and human action (dredging and filling) (see Figure 4.9).

Sites examined and visited	**Land area changes between 20014 to 2015 due to natural formation or human-induced intervention**		**Estimated difference due to extension (metres)**
	2004 map	**2015 map**	**10 years**
F) Bonbon: coastline progradation due to disposed dredged materials (white and orange outlines)	92.59 ha	95.9 ha	3.31 ha
G) Reduced islet along the CdeO River channel (white & blue outlines)	3.0 ha	1.02 ha	1.98 ha

Figure 4.9: Temporal changes (2004–2015) along Cagayan River and its mouth showing land progression (F - yellow) and land erosion (G - blue) due to river sedimentation and human intervention (base map from Google Earth, 2015).

4.3.3. Existing Coral Reefs in Bonbon and River-borne Sediments

4.3.3.1. Coral habitat distribution near the Cagayan de Oro River mouth.

On the west side of the river mouth, coral reefs were found ~100 to ~230 m off the Bonbon coastline (see Figure 4.5). The nearest reef is around 1.6 km west from the river sediment source (see Table 4.8). The absence of corals between the river opening and the nearest reefs suggests the presence of unfavourable conditions, such as persistent high concentrations of freshwater and sediments from the river. On the east side, no reefs exist between the river opening and the seagrass meadows.

The reef study site has a total length of 610 m parallel to the Bonbon coastline. The approximate total area of the three coral reef plots is 5,194 sq. m. Transect lines were purposely deployed on the sites with a relatively high coral presence.

Table 4.8: Coral distribution, composition, abundance and diversity from field samplings

Plot	**Coral distribution and distance from river mouth (m)**	**Coral abundance (%)**	**Coral life form diversity** (SI = Shannon)	**Coral life form dominance** (D = Simpson)	**Silt cover (%)**
None	0–1,627	0	0	0	-
A	1,628	7	1.18	0.269	48
B	1,932	32	1.26	0.371	41
C	2,209	64	0.749	0.612	0

Shannon Index of Diversity (Eq. 4.1) and the Simpson Index of Dominance (Eq. 4.2)

$$SI = \sum_{i=1}^{s} pi \; lnpi \qquad \textit{(Eq. 4.1)}$$

Where *pi* = total number of individuals of species divided by total number of samples

ln (pi) = natural logarithm of sample/sum

Σ = summation

$$D = \sum_{i=1}^{s} (n/N)^2 \qquad \textit{(Eq. 4.2)}$$

Where n = number of individuals of species

N = total number of samples

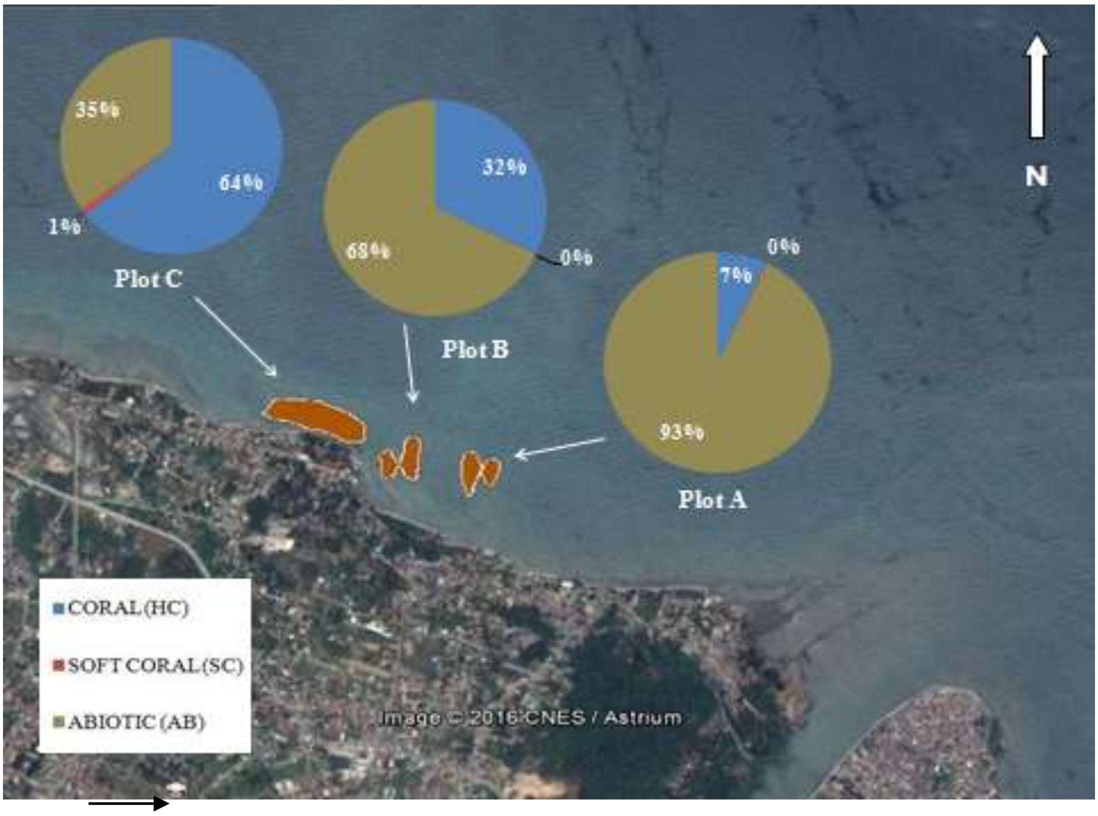


Figure 4.10: Coral composition showing gradational variations in relative abundance of two major categories in relation to the reef distance from the river mouth: coral cover increases with distance, while the abiotic component decreases as distance increases (base map from Google Earth, 2015).

Figure 4.10 shows large variations in hard coral abundance (in percentages) among the three sampling plots located at the same inshore site, and with relatively short distances between one another. Corals were classified based on their morphological and structural forms (see Appendix C). Variations in silt cover value (%) suggest some influence of river sediments on the coastal marine habitat abundance, but not on the lifeform's diversity, based on the Shannon Index (SI).

4.3.3.2. Coral abundance in relation to river-borne sediments.

Based on a linear scale of coral cover evaluation (Gomez & Yap 1988), the three plots of corals in Bonbon with a population (by frequency of occurrence) of 34% of the sampling area is rated as fair. It is noteworthy that Plot A, which is closest to the source of river plume has the lowest value of 7%; then Plot B, the next furthest from the opening is fair with 32%;

and Plot C, the furthest, is rated as good with 64% (see Figure 4.10). This large variation in the abundance of coral lifeforms within a relatively short distance of half a kilometre from Plot A to Plot C suggests the likely influence of river sediment concentration on marine habitat abundance (see Figure 4.11).

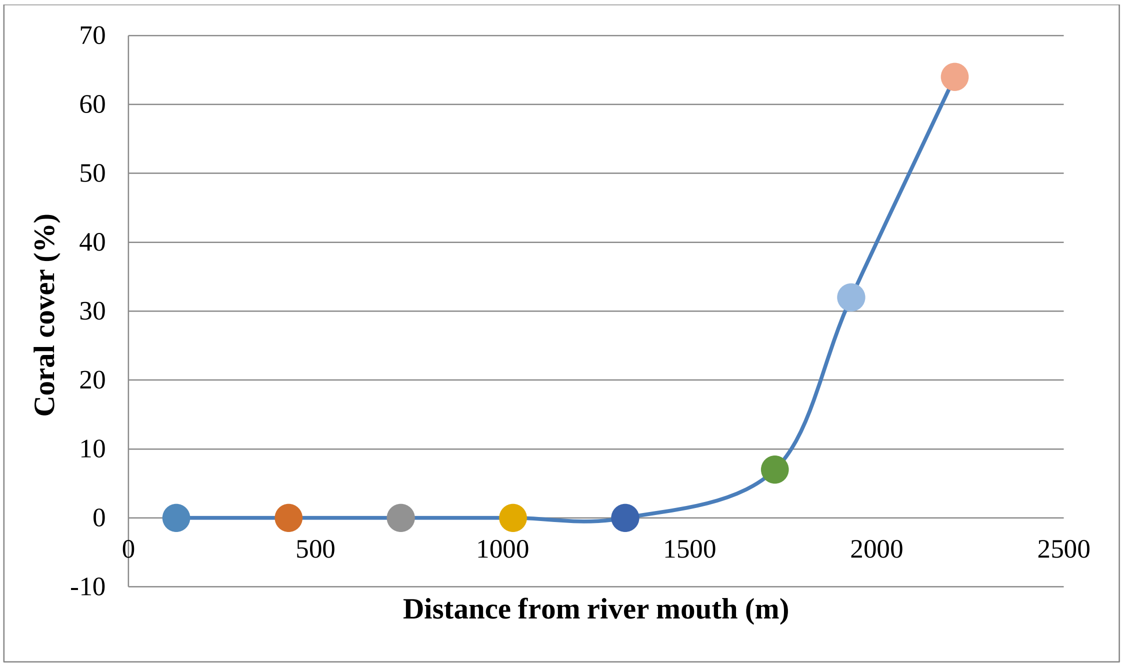


Figure 4.11: Coral distribution in Bonbon coastal waters showing a 1.6 km stretch of a river-associated coral-free zone, beyond which coral cover steeply increased.

4.3.3.3. Reef composition and relative abundance of major lifeform categories.

The two major categories of reef were identified during sampling: hard coral lifeforms and consolidated abiotic materials (dead coral, rock, rubble, sand and silt). Soft coral was represented by very small percentages in all reef plots. For the overall average, abiotic materials comprised the largest percentage cover, while hard coral lifeforms made up about one-third of the total coral reef area surveyed.

Sampling Plot A exhibited a very high percentage of abiotic materials over the sparse coral population; but in the next two sampling plots (B and C) hard coral populations showed an increased percentage cover, with decreased abiotic percentages. The soft coral population was highest in both transect lines of Plot C.

4.3.3.4. Coral lifeform diversity and relative abundance in relation to river-borne sediments.

The hard corals were described according to their abundance relative to other major categories found along the transect lines, the diversity of coral lifeforms, and the relative abundance of each. Diversity and the relative abundance of coral lifeforms varied with their location in the sampling site (see Table 4.8). Six coral forms were identified in Plot A, with branching coral as the most dominant form. In Plot B, eight coral lifeforms were found and the most common was the massive form. Plot C had the lowest diversity, with only four coral forms: the massive form had the highest frequency at 77%.

Hard coral diversity indices for each plot based on SI were highest in Plot B and lowest in the farthest plot, Plot C (see Figure 4.12).

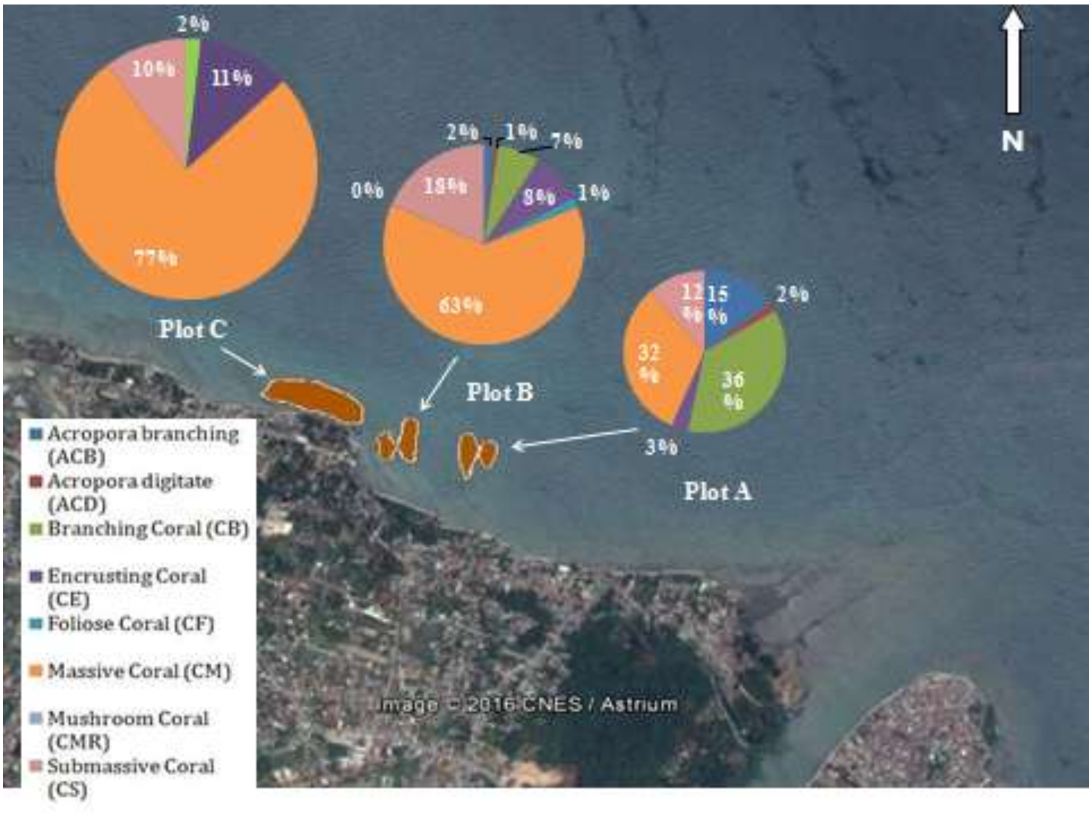


Figure 4.12: Coral composition showing coral massive as the overall most dominant lifeform, except in Plot A where coral branching has the highest cover. Massive-type coral abundance increases, while branching coral decreases with reef distance from the river mouth (eastern side); (base map from Google Earth, 2015).

As shown by the line graph, no positive correlation exists between coral lifeform diversity and river sedimentation (Fig. 4.13). The diversity indices accounted for both the number of coral lifeforms (richness) in the plot and the relative abundance of each existing lifeform (evenness).

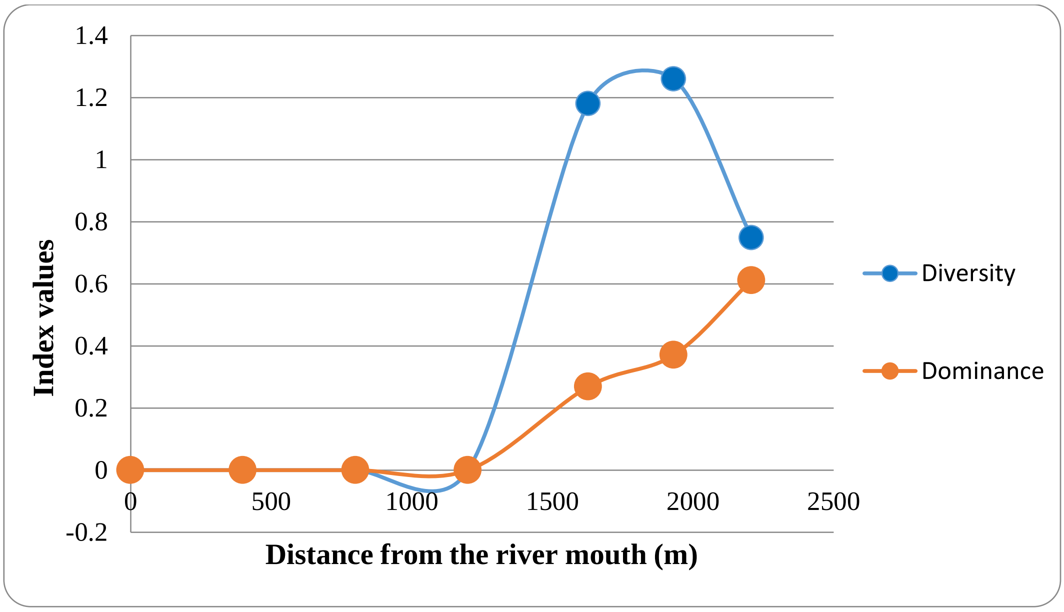


Figure 4.13: Coral dominance following similar trends as in Fig. 4.11, although the coral diversity shows higher values, but unclear variability beyond the coral-free zone.

4.3.3.4. Coral and silt covers in relation to distance from river mouth.

Among the abiotic factors (see Figure 4.14), silt constituted the highest amount of upland terrigenous materials from the river. The line graph shows contrasting trends between coral abundance and silt cover (%) in relation to river sedimentation (see Figure 4.15). Even with only three sampling plots, both variables demonstrated close to a straight-line trend.

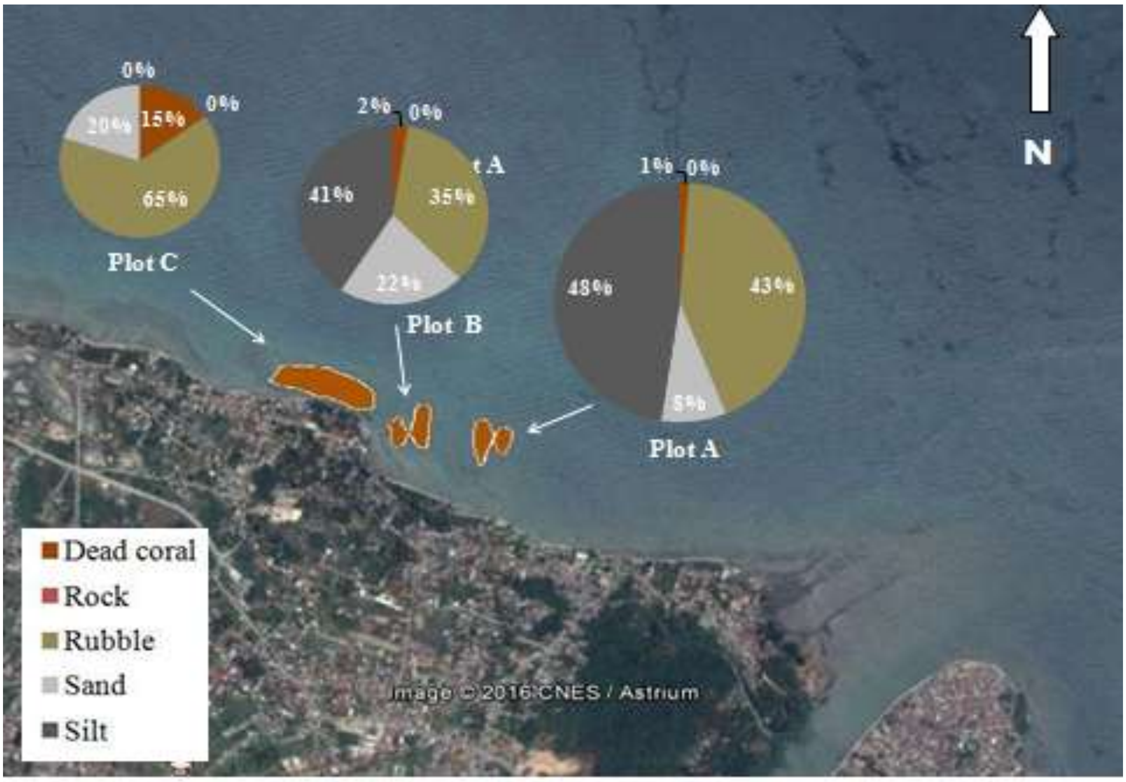


Figure 4.14: Silt percentage cover showing a decline trend as coral plot distance from the river mouth decreases. The abiotic elements on the reefs do not show a clear variability trend with distance from the source of river sediment (base map from Google Earth, 2015).

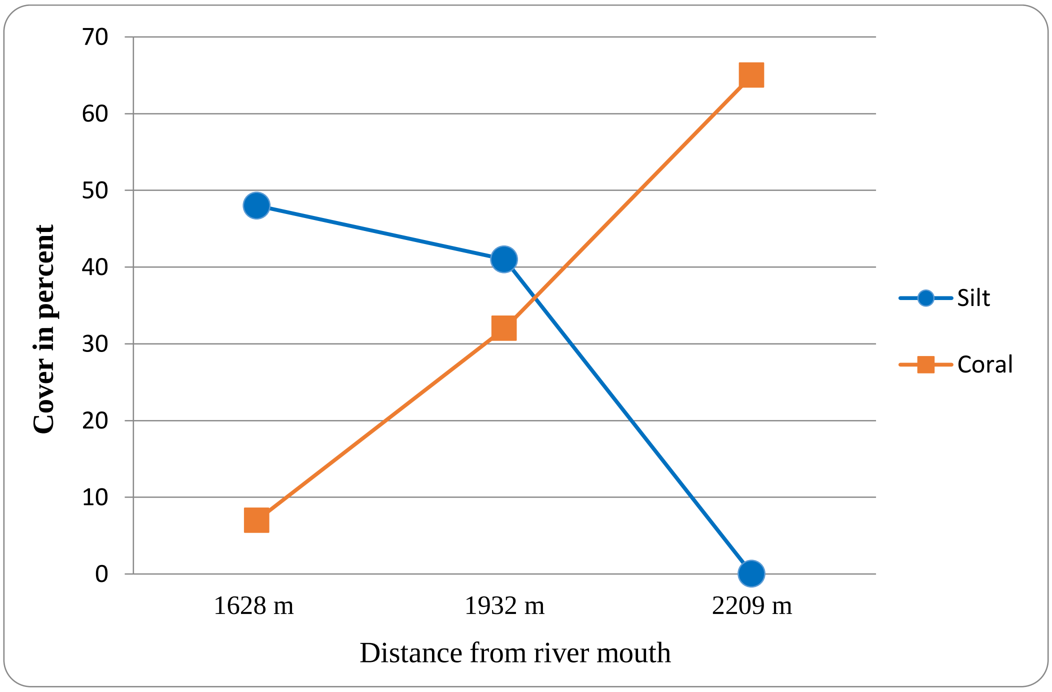


Figure 4.15: Coral abundance showing an increasing trend, while silt cover exhibits opposite results in relation to the increasing distance of the reef plot from the river mouth.

4.3.4. Seagrass Meadows in Macabalan and River-borne Sediments

4.3.4.1. Seagrass distribution and composition near the river mouth.

Plot A was established about 780 m east of the river mouth on seagrass beds located nearest the source of river sediments (see Figure 4.5). No seagrasses were found within a distance of around 780 m east of the river mouth. On the Bonbon side, no seagrasses existed within 1,500 m west of the river opening. The seagrass meadows stretch perpendicular to the coastline, beginning from the intertidal zone to around 6 m depth (20 to 75 m seaward). In large and small patches, the entire seagrass sampling area within the Macabalan coastal water is about 4,100 sq m or 0.41 ha. Three sampling plots revealed various seagrass percentage covers along six transect lines (see Appendix D).

Table: 4.9: Seagrass distribution, composition, abundance and diversity from field samplings

Plot	Seagrass distribution % Distance from river mouth (m)	Seagrass abundance (%)	Species diversity (Shannon)	Species dominance (Simpson)
None	0–779	0	0	0
A	780	25.7	0	1
B	879	32.8	0	1
C	960	18.0	0.68*	0.51

Shannon Diversity Index = see Eq. 4.1
Simpson Dominance Index = see Eq. 4.2

The absence of seagrasses within certain distance on both sides from the river mouth suggests the presence of conditions unfavourable to the coastal marine habitat (see Figure 4.5). It can be posited that relative proximity to the river opening constitutes very high freshwater and sediment concentrations detrimental to any seagrass species in the bay.

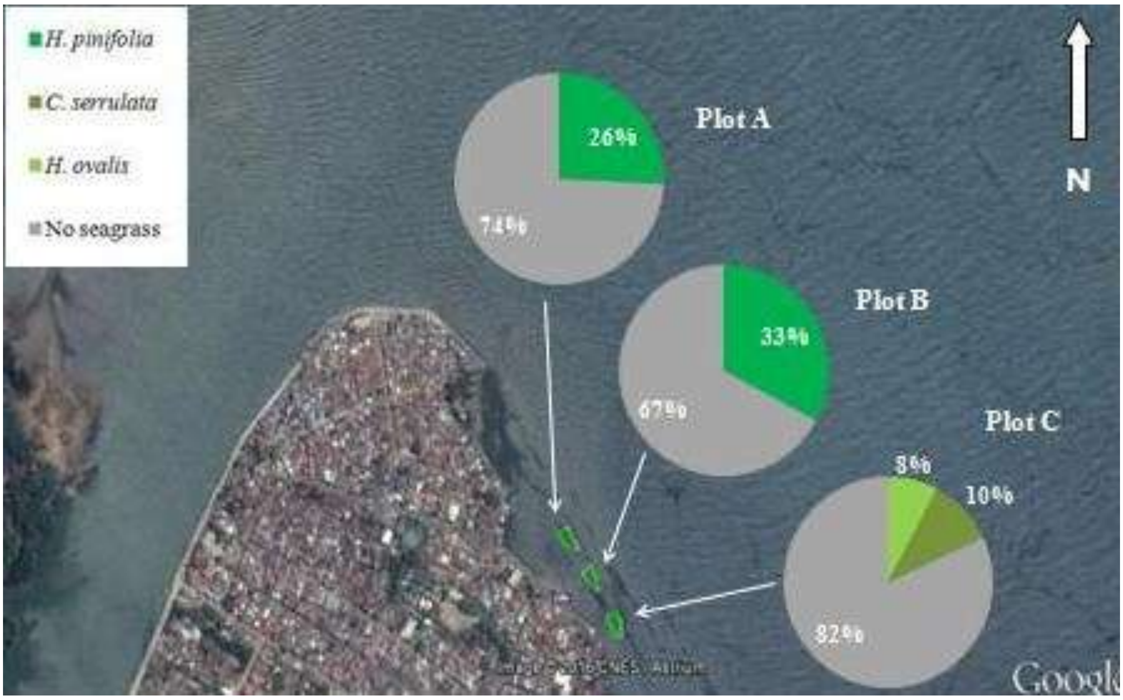


Figure 4.16: Seagrass species distribution in Macabalan inshore waters showing one species found on the first two plots (A, B) while two different species were identified on the third plot (C). Larger portions of the plot in gray colour are non-seagrass zone. The river mouth is on the western side (base map from Google Earth, 2015).

4.3.4.2. Seagrass abundance in relation to river-borne sediments.

Overall, seagrass abundance in Macabalan is considered less dense (<30%), with an average cover of 26% per sampling plot. The most dominant species, *Halodule pinifolia*, has a relatively low average cover of only 33% (Plot B). It is also found at a lower average cover of 26% on Plot A while *Halophila ovalis* and *Cymodocea serrulata* combined are at an even much lower average cover of 18% on Plot C (see Figure 4.16).

In relation to the river opening, Plot C, the most distant plot, has the lowest average cover of 18%, and Plot A, the nearest, has the second highest average cover of 26% (see Figure 4.16). No positive correlation was exhibited between seagrass abundance and the plots' distances from the river mouth (see Figure 4.17). The minimal number of sampling plots and the minimal plume encroachment on the plots might explain the failure to establish any relationship trend between seagrass abundance and river-borne sediments.

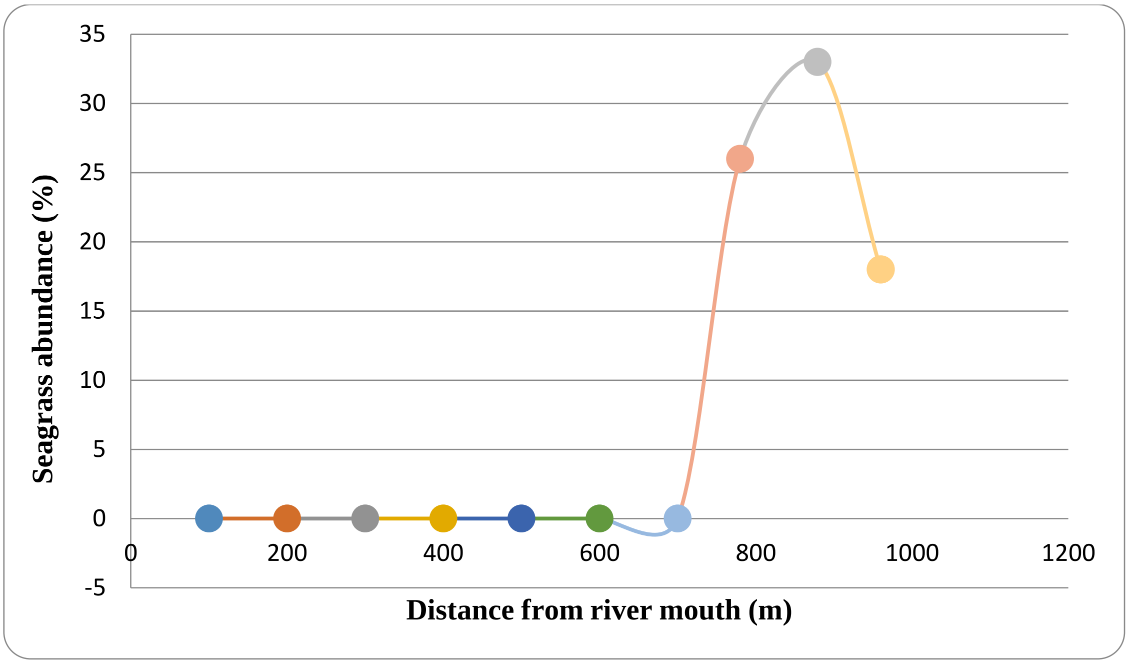


Figure 4.17: Seagrass total abundance showing a 700 m stretch of river-associated seagrass free-zone beyond which seagrass cover exhibits an unclear variability trend.

4.3.4.3. Seagrass species diversity in relation to distance from the river mouth.

Three seagrass species were identified during the broad surveys and the on-site sampling activities. *Halodule pinifolia,* commonly known as eel grass, was the lone species found and assessed in Plots A and B and established within 780 to 880 m east of the river mouth. Marine plants occupy the soft muddy shore in shallow waters (0.2 to 1.8 m depth) forming like green mats that stabilise some portions of the Macabalan mud-silt intertidal zone. *Halophila ovalis* and *Cymodecea serrulata* were located along the same two transects of the same Plot (C), but each species grew in separate patches. They inhabited the deeper parts of the coast (2 to 4.5 m depth) within 30 to 40 m of the shoreline.

No clear positive correlation was exhibited between species diversity and the distance of each plot from the river mouth (see Figure 4.18). Plots A and B have zero diversity value as only one species (*Halodule pinifolia*) is present on each plot. Plot C has two species *(H. ovalis* and *C. serrulata*) with a diversity index of 0.68 and a very high evenness value of 0.98, indicative of almost equal abundance (%) between the two existing seagrass species. The SI accounted for both the number of seagrass species present in the sampling plot and the abundance of each species in relation to other species.

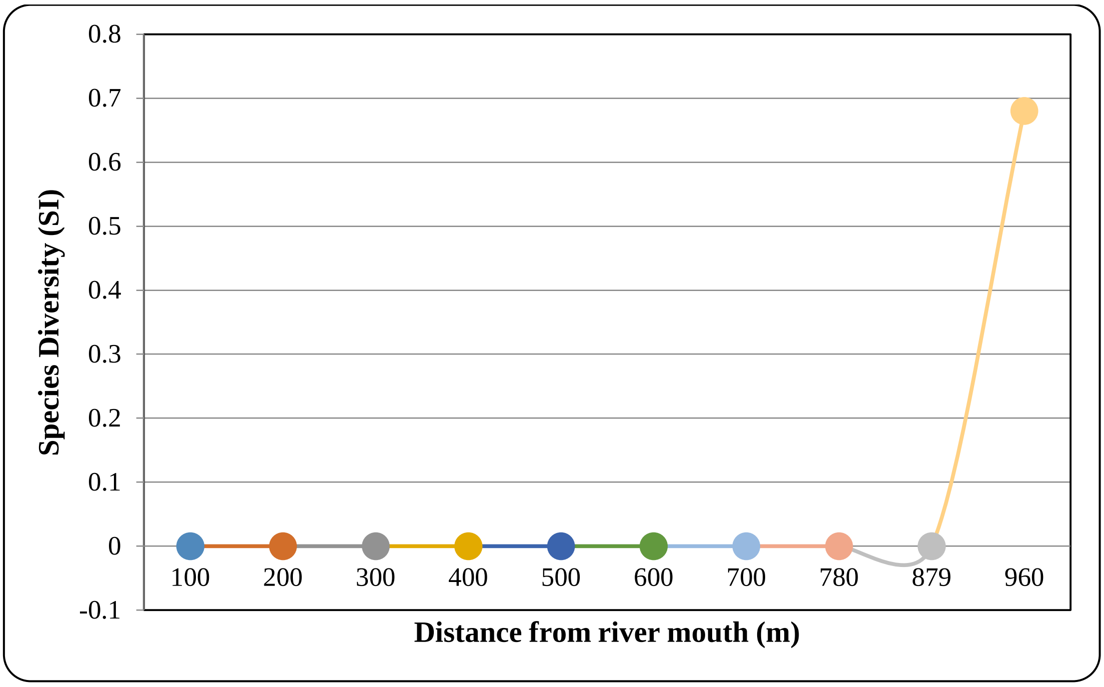


Figure 4.18: Seagrass communities showing zero diversity on the first two plots (A & B) and exhibiting a very high diversity index on Plot C.

4.3.5. River Sediment Plume and its Implications for Mangroves, Corals and Seagrasses

In general, sedimentation processes in the Cagayan de Oro River mouth have a relatively low accretion rate along the riverbank edges (e.g., 5 to 6 ha in 89 years), but a high one in the foreshore zone (e.g., mudflats). A minimal land accretion process may have limited the colonisation of natural mangrove growths along the banks. Instead, sediment siltation of the river and sea bottoms is high and these require constant dredging. Dumping and compacting has formed new masses of land from dredged materials (sourced from the channel and the river mouth) which could become new sites of human settlement or mangrove colonisation. Further, the continuous expansion of mudflats indicates the high erosion rate in the uplands.

Figure 4.19: River sediment plume, its distance from plots, and its implications for coral and seagrass distribution and abundance in the Macajalar Bay, Cagayan de Oro City, Philippines (base map from Google Earth, 2015).

Levels of river plume encroachment on both coral and seagrass communities have established the relationship between sedimentation and the condition of each marine habitat (see Figure 4.19). Areas at a certain distance to the river mouth, and which are most likely to experience plume encroachment on a regular basis) do not have corals and seagrasses. In areas where sediment plume encroachment is normally minimal to moderate, and heavy only a few times a year, existing seagrass and coral communities showed low abundance and low species diversity.

4.4. Discussion

4.4.1. Mangroves and Sedimentation

4.4.1.1. Physical land changes at the river mouth due to natural processes and human interventions.

Physical changes in the river mouth and coastal landscapes were due initially to natural processes and then to subsequent major human interventions. Over time, the slow flow of sediments along the Bonbon bank and at the river mouth, exacerbated by the rising tide, have enhanced the deposition and siltation processes that result in coastal progression (Site A) and bank expansion (Site B).

Site A (see Figure 4.6) appeared on the 1957 NAMRIA map as a large swamp of mangrove palm trees on the Bonbon flood plain, adjacent and directly connected to the main channel. Given such proximity, the mangroves with their roots and pneumatophores slowed down the flowing river water and effectively trapped sediments (Scoffin, 1970; Wolanski et al., 1993). Continuous accretion and later human intervention over time formed the eastern and northern expansions of the bank, extending from the bridge to the creek mouth. At present, Site A is fully vegetated with mixed stands of trees and other plants, mostly *Sonneratia* sp. and *Nypa fruticans.* The new land expansions have partly protected the swamp from the direct influx of flowing river water. As a result, the amount of flowing sediments trapped at the swamp is much reduced.

Site B was not yet present on the 1932 Cadastral Survey Map. On the 1957 map, a small piece of mud-clay flat was identified along the Bonbon foreshore near the left edge of the river mouth (see Figure 4.7). Over time, this mud-clay formation has grown due to the accumulated terrigenous materials deposited by deflected river flow. Near the river mouth, the silted sea bottom required dredging. To normalise river flow, the city government undertook dredging and stockpiled the dredged materials on Sites A and B (Isidro Borja, interview with author, 4 Nov 2015). At present, Site B is now a compacted mass of prograded coast, which on one side (further west) is densely populated with human settlements, and on the other side (near the river mouth) is a mangrove plantation (see Figure 4.7). This new coastal development has greatly reduced the mangrove swamp area that used to trap sediments and was a natural sediment deposition site in the past. Instead, the mudflat now acts as the natural trap for flowing sediments deflecting northwest. Therefore, the foreshore has become soft and mud-dominated, indicating the large amount of sediment imported to the site (Duke & Wolanski, 2001). Previously, the foreshore was all sand, a notable characteristic of the landscape, and which earned the *barangay* its name in the local dialect, *Bonbon*, meaning 'sand'. The mangrove plantation on this site acts as a sediment stabiliser against tidal receding action (Furukawa & Wolanski, 1996), enlarging the accreted land mass and most probably also expanding the mangrove site. Mangroves thrive in areas of mud accumulation (Woodroffe, 1993) and their establishment in turn enhances faster land accretion (Thom, 1967; Carlton, 1974). Presently, the mangrove plantation may help arrest further sediment dispersal towards the reef site.

On both the 1932 and the 1957 maps, Site C formed a part of the riverbank on the Macabalan side. In fact, it consisted of some titled plots under the 1926–1932 Cadastral survey. However, over time the stronger river water velocity on the far right side of the channel has slowly eroded the edges of the Macabalan-Puntod banks. Later, human intervention removed a long strip of land (~1 km) along the bank to widen the channel and river mouth (see Figure 4.7). To prevent bank erosion, a concrete dike was constructed to reinforce the bank (see Figure 4.8). The paved bank increased the extent of discharge flow off the river mouth.

On both the 1932 and the 1957 maps, Site D was non-existent and the Macabalan coastline was then several metres landward (see Figures 4.6 and 4.7). The initial occurrence of land accretion along the coastal front prompted the city government to 'reclaim' the portion of the seashore as an extended coastal land area. The 'reclaimed' area formed the prograded coastline of Macabalan, which at present is densely populated with human settlements (see Figure 4.8). Its present coastal formation (extending seaward) partly impedes the alongshore flow of the eastern river current towards the seagrass site. This has also resulted in increased river outflow to the other side, the northwest direction.

Site E was a 21 ha of mangrove palm cover until the early 1980s (see Figure 4.7). Its conversion into a residential area incurred a huge loss of a low-lying mangrove region, where catchment water and sediments were impounded to regulate upland-based pollutants in the bay. The rise of coastal population in Macabalan has also increased the threat of domestic waste and other human-induced disturbances being introduced to the coastal water and its natural resources.

Another noteworthy coastal land formation is the mudflat, which was formed from the gradual accumulation of terrigenous materials brought by the river outflow. The sediment deposition is enhanced by a reduced river flow velocity due to the SE current and to inland bound tidal and wave forces (see Figure 4.7). Moreover, the silted shallow depth water increases the bed friction of flowing suspended sediments and therefore the deposition rate. On the 1957 map (see Figure 4.6), mud deposition on the Bonbon foreshore was already noted. Its expansion seaward indicates a continuous sediment import from the catchment, but it is uninhabited by mangroves due to the site's mostly submerged condition (Duke & Wolanski, 2001). The mudflat's westward expansion has heightened the sedimentation threat to the corals.

4.4.1.2. Changing bank and coastal morphology, mangrove cover and catchment soil loss.

The changing coastal and riverbank morphology, and the variation in mangrove distribution, suggest the influence of land-based processes in the catchment (Duarte et al., 1998; Duke & Wolanski, 2001) and within the coastal areas over 89 years. Apparently, increased soil erosion in the uplands has affected the coast's physical and biological conditions due to sediment deposition along the banks and coasts, mud accumulation on the tidal zone and river channel siltation. The initial deposition of sediments paved the way for land accretion along the edges of both the riverbank and the coastal foreshores of Bonbon and Macabalan. Human intervention through dredging, land filling and compacting, dike construction, and human habitation in both Bonbon and Macabalan have caused major physical modifications of the river mouth environment and its vicinity.

It is generally believed that bank and coastal morphology, and vegetation dynamics are interrelated (E. P. Odum, 1971; Souza Filho et al., 2006; Thampanya et al., 2006). This is the case with the Cagayan de Oro River mouth and its mangroves. River bank expansion in Bonbon has become colonised by naturally growing mangroves (e.g., *Sonneratia* sp.), which continue to thrive in the site with other vegetation species. As the mangrove cover grows denser, it also traps more sediment and initiates further land accretion. On the Bonbon foreshore, dense vegetation of Bakhawan (*Rhizophora* sp.) mangroves have stabilised site's muddy soil and have further accumulated river sediments during tidal fluctuations. In the case of Macabalan, where infrastructure (e.g., dikes, paved spaces) is evident across the coastal village, sediment deposition has become minimal and mangrove establishment within the area is not possible anymore.

Based on the maps and on-site inspections, it is clear that physical changes at the river mouth (due mainly to sedimentation and subsequent sediment deposition) are indirect measures of the catchment's soil loss (Duke & Wolanski, 2001). Within 89 years, the

Cagayan de Oro River catchment has lost thousands of tons of terrigenous materials, which has resulted in the establishment of approximately 36 ha of coastal and riverbank expansion (excluding silted river bottom). With these new landforms, mangrove vegetation has also increased to a few ha (approx. 6 to 8 ha in Bonbon). Overall, the mangroves have suffered losses, the biggest of which was due to coastal development in Macabalan and Puntod.

4.4.2. Corals and Sedimentation

4.4.2.1. Coral reef distribution in relation to river-borne sediments.

The coral reefs in Bonbon are of a barrier reef type. They border the shoreline at around 100 to 250 m distance of seawater expanse. The reef length of around 650 m parallel to the coastal shore extends far to the west of the bay. No survey was conducted to determine the exact distance covered by the reef structures beyond Bonbon. In the present study, the three coral sampling plots lie from ~1600 m to ~2200 m west of the river opening. The geographical distribution of the reefs in the bay exposes the corals to direct westward sedimentation flow coming from the river mouth (see Figures 4.20 a, b and c). The natural formation and distribution of coral reefs at the present locations have been largely determined by the level of stress from freshwater and sediment inputs tolerated by the marine habitat. This infers that coral establishment was enhanced by environmental conditions in the reef that were favourable or at least tolerable for coral growth and development.

To show the existing coral site's vulnerability to river sediment plume flooding, three snapshots are presented. Figures 4.20 a, b and c show satellite images from Google Earth (2015) of a river plume flooding the bay and the reef plots nearby from different rainy season dates. These satellite images were taken from three separate dates during the southwest monsoon months, which also fell within the local rainy season: a) 20 June 2011; b) 16 July 2012; c) 23 August 2014.

Figure 4.20 a, b & c: River sediment plumes from different dates and their corresponding flow extent towards the coral reef sites (base maps from Google Earth, 2015).

The recorded daily rainfall totals in the catchment (PAGASA), taken a few days after each river plume image was photographed, were relatively low. It is highly probable that noon-gauged rainfall inputs from much larger parts of the catchment could have contributed additional discharge to the formation of the three huge sediment plumes in the bay. Moreover, the rain (although in low volume) was sustained for days and this could have facilitated the persistent and continued frontal expansion of the large sediment plumes in the bay.

Two of the snapshots of plume images (b & c) clearly show river plume encroachment on the reef plots. In fact, even with the first image (a), it is more likely that sedimentation intruded on the reef, given the continuing expansion of the river plume. In the present study, the threat of plume encroachment on the reef plots is heightened by the following factors or conditions: a) extreme volume of river discharge in the bay; b) weakened tidal forcing towards the coast; and c) proximate location of the reefs from the river mouth. However, due to the coastal current movement, which is mainly east or southeast, the river plume threat on the corals is reduced. Additionally, low and average river discharges do not pose a serious threat to the corals. Thus, two important conditions remain crucial to assess the sedimentation effect on the corals: a) the amount or volume of sediment that has encroached on the reefs (Cortés & Risk, 1985); and b) the length of residence time of plumes within the reef site aggravating the turbidity and/or burial effect on the corals (Philipp & Fabricius, 2003as cited in Fabricius, 2005).

Sedimentation is a major limiting factor in the development of corals and in their geographical distribution (Hubbard, 1986; Fabricius, 2005; Weber et al., 2006), as evidenced by the coral-free zone near the river mouth. For existing reefs encroached upon by river plume, attributing coral decline or underdevelopment solely to sedimentation must be done cautiously (Rogers, 1990). In fact, river run-off consists of several materials and substances, and each component may separately affect coral survival and growth. The other common limiting factors with direct or indirect effects on corals are salinity (Coles & Jokiel, 1978; Muthiga & Szmant, 1987), temperature (Dana, 1843; P. Jokiel & Coles, 1990), nutrient loading (Hunter & Evans, 1995; Stimson et al., 2001; Loya et al., 2004) and chemicals (Rubec, 1986; Shafir et al., 2007).

4.4.2.2.1. Sampling site water salinity as favourable to corals.

Corals thrive in high salinity water within a range of 34 to 39 ppt. Low salinity reduces the ability of corals to endure short-term exposure to elevated temperature (Coles & Jokiel, 1978). Overall, measured salinity in the mid-layer of the present coral study site was within the normal range of 36 to 39 ppt. This is obviously favourable to coral growth (see Table 4.2). However, the surface layer had a lower temperature range of between 16 and 29 across the three plots, most likely due to freshwater intrusion from the river and to the effects of evaporation.

Heavy and prolonged rains could reduce water salinity due to high river freshwater inputs. Constant moderate wave action driven by the northwest wind, especially from mid-morning to late afternoon, ensures normal salinity levels in the entire plot most of the time.

4.4.2.2.2. Sampling site water temperature as favourable to corals.

Generally, optimal coral growth occurs within a temperature range between 26 and 29° C (P. L. Jokiel & Guinther, 1978). Changes in temperature outside the range may reduce corals' capability to withstand other environmental stresses, such as bleaching and bacteria attack (Barber et al., 2001). Prevailing water temperature levels during actual sampling were within the desirable range for coral growth, ranging from 26 to 33 °C (see Table 4.2). Water temperature fluctuations could be influenced by certain conditions during sampling: first, freshwater run-off and cooler morning temperatures lower the temperature in certain parts of the plot (e.g., 26 °C); second, shallow depth layers at ~0.5 m from the surface level are normally warmer (30–33 °C) than the deeper parts of the coral habitat.

The occurrence of very high and low temperature values recorded in some portions of the coral site was not pervasive and persistent. Further, moderate wind-driven waves ensured continuous vertical circulation of coastal waters within the site and its vicinity.

4.4.2.2. Coral abundance in relation to river-borne sediments.

Regarding nutrients and toxic chemicals from the uplands, it is correct to consider that each may have its own separate influence on the coral reef conditions. However, these factors are beyond the scope of the present study. Nonetheless, sedimentation is considered the most potent stressor on corals. This is confirmed by several studies, such as those of Rogers (1990), and Ginsburg (1993) as cited in McClanahan & Obura [1997]). Actual TSS values measured in the site under study confirmed the expected impact of sedimentation on the corals (see Table 4.2). Sampling was conducted once a month and in all the eight months of sampling, the prevailing TSS values recorded were higher than the minimum 10 mg/L of ambient water. In addition, large amounts of silt were found settled on the reefs, which is evidence of the encroachment of terrigenous materials on the coral site (see Figure 4.14).

The relatively high-TSS concentration in the coral site (see Table 4.2) is partly due to the relatively strong initial river outflow and the reefs' proximal location from the river mouth (see Figure 4.20). It could be due also to bottom sediment re-suspension, owing to the site's dynamic wave action. In fact, even during normal weather conditions, on the average the prevailing TSS concentration values in the coral site ranged between 20 and 50 mg/L. In some portions of the plot, the TSS level could even be double or triple the dominant concentration value. The worst condition is when an abnormal rainfall event generates a very high increase in river discharge. Based on Pastorok and Bilyard's (1985) study, which used the data from Randall and Birkeland (1978) (as cited by Rogers [1990]), 1 to 10 $mg/cm^2/day$ of sedimentation rate (or 100 to 1000 mg/L) has a slight to moderate impact on coral (decreased abundance, altered growth forms and decreased growth rates).

The positive correlation between river sedimentation and the decline in coral abundance could be explained by certain conditions or a combination of them. First, extreme rainfall events in the uplands generate strong surges of river discharge into the bay, coupled with sharp rises in terrigenous loads (see Figure 4.20). Second, the impact of river discharge surges and of tidal action on the mudflat may initiate erosion and facilitate the spilling over of loose sediment particles towards the coral site. Third, continuous river outflow may flood the coral site through the gradual transport of sediments from the nearby mudflat during prolonged rains. Fourth, a weak NW wind during high river discharge, particularly in the rainy months from June to October, allows most sediment particles to persist longer on the western side of the river mouth. Even with a brief dwelling time, suspended sediments could have direct adverse effects on the corals' photosynthetic performance (Revsbech, 1995).

The present study conducted no further investigation to determine the specific effect of sedimentation on coral. However, the adverse effects of sedimentation on coral occurs in one or more ways (R. P. Bak, 1978; Lasker, 1980; Cortés & Risk, 1985): First, sediments, particularly fine ones like silt and mud, may have choked the coral polyps and expelled the symbiotic *zooxathellae*. Second, sediment-laden water could have scoured the reefs through strong waves during low tides. Third, silting of the bottom area may have deprived larvae of suitable places for recruitment. Fourth, suspended sediments could have increased water turbidity and consequently reduced the coral's light supply for photosynthesis. Fifth, coral energy may have been used up to remove sediments, resulting in a decline of polyp vitality. Sixth, the unfavourable effect of sediments on plankton may have also adversely affected the coral organisms.

4.4.2.3. Coral lifeform diversity in relation to river-borne sediments.

To explain the variations of coral lifeforms and their relative abundance in the three different plots as being due to differences in sedimentation effects, the ruderal-competition-stress classification of coral communities was used (Edinger & Risk, 2000). This ternary classification is mainly based on Grime's (1979) theory that organisms develop their adaptive strategies in response to the primary controlling factors present in their natural communities. These three primary factors limit or control the growth and diversity of plants and animals: disturbances, competition and stress (Huston & Huston, 1994). Applying this to coastal marine habitats, Edinger and Risk (2000) defined *Acropora* corals as disturbance-adapted ruderals (r), the non-Acropora and foliose corals as competitors, and the massive and sub-massive corals as stress tolerators (due to their high tolerance of sedimentation and/or eutrophication).

In Plot (A) nearest the river mouth, the most dominant coral forms (38%) are the branching corals (CB) (non-*Acropora*, e.g., *Porites cylindrica*), indicating a more silted environment; however, the light supply is adequate (see Figure 4.12). This coral lifeform is adapted to waters with high-sediment loads due to their branching morphology that allows suspended silt to fall easily (Aliño, 2002). However, their slender branching structures are not very efficient at harnessing sunlight, so they prefer shallower and less turbid waters. Additionally, these lifeforms are competitive dominants (Moll [1983] & R. Bak and Povel [1989] as cited in Edinger & Risk [2000]), as they are very good at harnessing resources and/or adjusting morphologically or physiologically to compensate for the lack of needed resource(s). For example, their numerous branches allow the coral polyps to catch floating planktons in the flowing water easily (Aliño, 2002). Comparatively, they grow and recruit more slowly than the *Acropora* corals, which have light stony skeletons. In the plot, however, *Acropora* (another branching species) (ACB) makes up only 16%, which indicates their susceptibility to physical disturbances such as strong waves, given their long thin branches.

Massive coral forms dominated Plot B (at 63%) and Plot C (at 77%) and were the second-most dominant (33%) in Plot A (see Figure 4.13). In Plot B, sub-massive corals came second with 32%, making up the stress-tolerator presence to 84%. In Plot C, the sub-massive corals comprised 10%; but when added to the massive corals, this would total an 87% prevalence of stress tolerators. The dominance of massive and sub-massive corals and the exclusion of most ruderals (branching, 7% in Plot B and 2% in Plot C) and competitors (encrusting, 5% in Plot B and 11% in Plot C; foliose, 4% in Plot B) could be attributed to stress factors related to wave strength, sediment load and light supply in the environment.

Massive and sub-massive corals are usually abundant in all habitats (in this study, in all plots) due to their high tolerance to stressful environments, but they dominate only when heavy stress overtakes ruderal and competitor corals (Rogers, 1990). Veron (1986) and Rogers (1990) identified a heavy stressor as high sedimentation. However, in the present study, it is more likely that in Plots B and C, the heavy stressors that were intolerable to branch and ruderal corals included direct exposure to strong waves and limited food and light supplies. The highest sedimentation occurred in Plot A. In fact, slightly reduced sedimentation in both Plot B and Plot C favoured the dominance of massive and sub-massive coral forms.

Relatively high sedimentation in Plot A is clearly demonstrated by the lowest frequency of occurrence of hard coral at 7%, and the dominance of branch corals (ACB). Moreover, the plot itself contains the highest percentage of silt deposit on the reefs, at 48% of the total abiotic materials present, compared to 41% in Plot B and 0% in Plot C (see Figure 4.14). The volume of silt deposit on the reef and the substrate is a function of the TSS concentration encroaching on the reefs. Finally, the non-existence of coral reefs between Plot

A and the river mouth indicates the presence of very high-sediment concentrations that provide unfavourable conditions for coral growth.

4.4.2.4. Coral lifeform diversity and dominance indices.

Plot B has the highest diversity value (SI = 1.26) (see Table 4.8), which means that its coral lifeforms (8) were the least affected among the three plots by river sedimentation. Plot C's lowest diversity value (SI = 0.749; 4 coral liforms) is due to the dominance of massive coral lifeforms (77%) that thrive in less sediment-laden water. Plot A's coral lifeforms (SI = 1.18) are relatively resilient to the stress from sediment encroachment that occasionally could become heavy in concentration.

Nonetheless, no clear relationship was exhibited between coral lifeform diversity and the distance of coral sampling plot from the river mouth. The reasons for this could be the inadequate number of plot samples (three) that were subjected to sedimentation treatment and the various stress factors aside from sedimentation, such as light supply, food availability and wave/tidal action that could also have had separate effects on the corals.

The relationship of coral lifeform dominance with river sediment source shows a pattern: the dominance value increases as distance from the river mouth progresses among the three given plots. The high tolerance of massive coral to stress factors has enabled them to dominate in areas where other coral lifeforms are less tolerant to the present stresses. The decline of other lifeforms in the other two plots, B and C, suggests the presence of other stress factors.

4.4.2.5. Future of corals under existing morphological and weather conditions.

Without appropriate intervention, several existing sedimentation risk factors will continue to increase in the future. These may include: a) more frequent extreme rainfall events in the Cagayan de Oro River catchment; b) increased land-based activities, both in the uplands and in urban areas, owing to the increasing human population; c) expansion of the mudflat; d) faster flow and longer plume trajectory reach beyond the river opening out to the coral reef site, due to concreted river bank.

Moreover, given that the main coastal current circulation is east/southeast, the reefs are also threatened by sediments coming from the Iponan River, which discharges large sediment volumes from hydraulic mining activities in the catchment. Here, the reefs are under threat from sediments coming from both rivers (see Figure 4.21).

Figure 4.21: CdeO River plume westward expansion, threatening the Bonbon coral reefs and east-bound currents potentially transporting sediment from Iponan River (far west) towards the reef site (base map from Google Earth, 2015).

Other risk factors include rising thermal stress, given the increased sea surface temperature instigated by changing weather conditions (e.g., climate change). Thermal stress experienced by corals may be induced by sea warming by extended droughts resulting from strong to very strong El Niño events (e.g., 1997–1998, 2002–2003, 2009–2010, 2015) (ggweather.com/enso/oni.htm). River discharge from plantations also brings heavy nutrients and toxic chemicals detrimental to corals. In addition, local fishing methods, particularly 'sudsud' (net dragging) and spear fish hunting (as per interview with local residents) are destructive to coral.

Protecting and rehabilitating the coral reefs is important, as they are part of a much larger reef structure along Bonbon and its adjacent villages westward. The large coral reef community, if well rehabilitated and managed, can host and supply a sizeable number of fish and other marine products to the community. This may also improve the quality of the coastal marine environment and the various ecosystems therein.

4.4.3. Seagrasses and Sedimentation

4.4.3.1. Previous coastal structure and seagrass distribution along the coast.

Existing seagrass meadows were found contained on the far eastern side of the Macabalan coastal area. The absence of seagrasses was noted within a kilometre east of the river mouth. On the old map (NAMRIA 1957) the Macabalan coast was slightly flat from one end to the other, except for the slightly pointed middle part (see Figure 4.22).

With the old coastal structure, river outflow could have easily flowed downstream eastward. Therefore, the coastal water, particularly up to the mid-part, could have been low-saline zone most of the time. Heavy sediments could have also encroached on the same coastal site during strong rainfall events in the catchment. Naturally, seagrasses, which cannot usually withstand prolonged exposure to low salinity and high sedimentation, were unable to colonise the area. Consequently, the site was conducive for seagrass establishment and later developments are located further from the river opening. The present prograded coastline in Macabalan has significantly reduced the downstream flow from the river and has consequently concealed the seagrass meadow site from direct river plume encroachment.

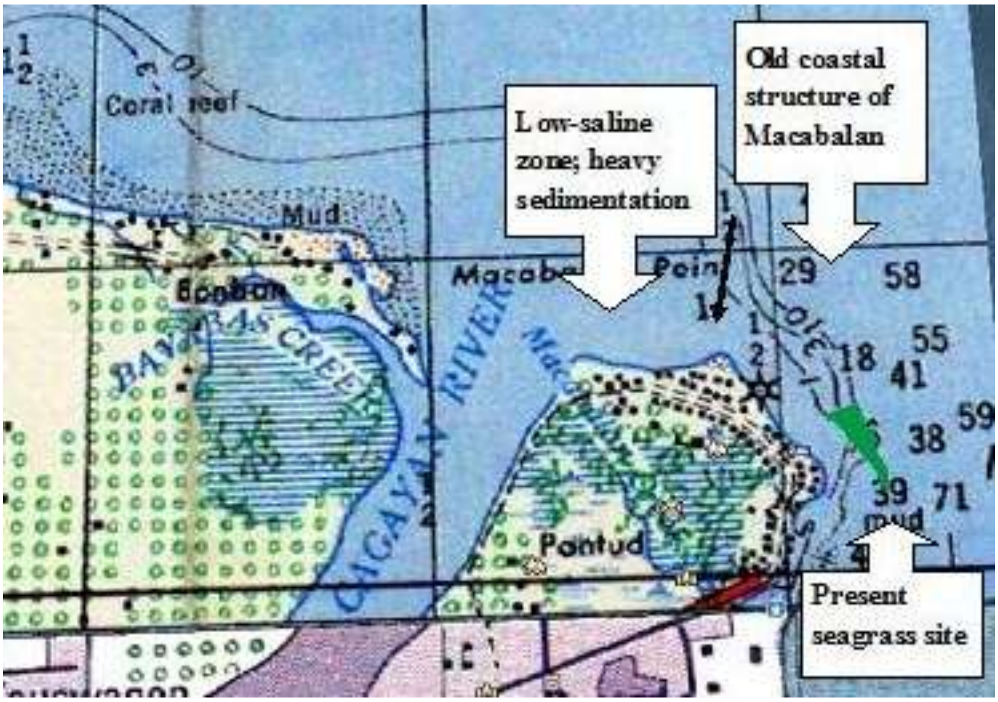


Figure 4.22: Old coastal structure of Macabalan and the low-saline zone as influenced by run-off from the Cagayan de Oro River, which has resulted in the present seagrass distribution (NAMRIA map).

On the opposite side of the river mouth, the nearest seagrass site is located in Bayabas (a *barangay* unit adjacent to Bonbon) around 2 km from the river mouth. Local residents have attested the absence of seagrasses in Bonbon from at least within the past 50 years. It is speculated that river plume intrusion in areas some distance westward has always been unfavourable to seagrass establishment. Thus, the present seagrass meadows are found at locations far enough from the river run-off for them to exist.

4.4.3.2. Present seagrass distribution in relation to river plume encroachment.

Existing seagrass meadows are located in an embayment with both sides open to eastward and westward currents. However, seagrass sites experience mostly light to moderate inshore currents. The downstream current is relatively weak, owing to the Macabalan coastal morphology, which partially hides the seagrass meadows from the long reach of downstream flow. Inshore seagrass sites are characterised as low-energy zones, being located closely to the mainland.

To demonstrate river plume encroachment on seagrass sites via the downstream flow, plume snapshots are shown below. Figures 4.23a, b and c show the formation of initial bulges of sediment plume off the river mouth with low encroachment on the eastern side.

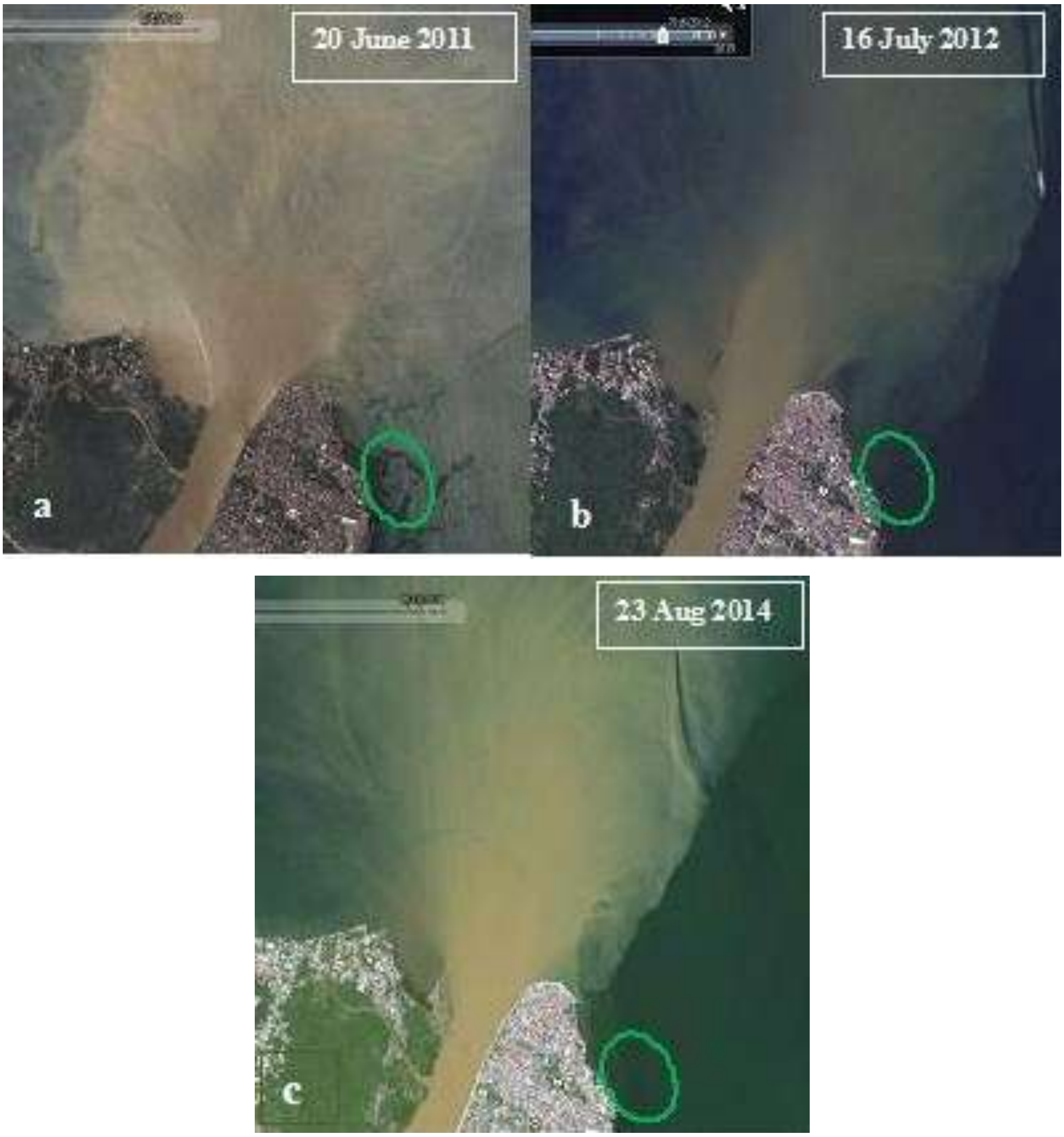


Figure 4.23a, b, & c: River sediment plumes from three different dates showing minimal encroachment on the seagrass meadow site (inside green circle (base map from Google Earth, 2015).

However, the net deposition effect of sediment flow is on the southeast portion of the bay (see Chapter 3 modelling results), which potentially transports sediment to the seagrass sites during very high river discharge events.

4.4.3.3. Seagrass abundance and diversity in relation to river plume encroachment.

The relationship between seagrass abundance (cover in %) and the distance of sampling plots from the river mouth did not show any pattern of direct correlation. Similar results were obtained from the relationship between seagrass diversity and plots' distance from the river opening. The primary reason for this is the minimum amount of river-suspended sediments that reach the meadows via the downstream flow. Additionally, sediment sources could come from the southeast side, following the coastal current circulation pattern and from the bottom due to re-suspension.

4.4.3.4. The three seagrass species in relation to some potential limiting factors.

Based on the sampling results, the seagrass condition in Macabalan is low fair (25% to 50% is a fair condition) in terms of the total bottom area coverage. Only three species of seagrasses were found and identified in the sampling site close to the river mouth. The most dominant among all species is *Halodule pinifolia*, which comprises two-thirds of the entire identified seagrass population in the sampling plots and about one-third (29%) of the surveyed seagrass cover in Plots A and B. The other two species, *Halophila ovalis* and *Cymodocea serrulata*, make up the Plot C seagrass community. All the three species are listed in the IUCN's least concern (LC) category due to their stable global population (Short et al., 2011). Given the mostly minimal and occasionally heavy encroachments, it was suspected that other variable(s) within the immediate Macabalan vicinity could also have influenced the distribution and abundance of seagrasses.

The survival, growth, abundance and distribution of seagrasses are largely influenced by several variables, such as salinity levels (Walker & McComb, 1990; Lirman & Cropper, 2003), water temperature (Campbell et al., 2006), light intensity (Dennison & Alberte, 1982; Dennison, 1987), nutrients (Short, 1987), current regimes (Fonseca & Kenworthy, 1987), and substrate type (De Silva & Amarasinghe, 2007). In the present study, these environmental parameters were presumed to be similar in all the three plots, due to their relatively close proximity. One variable (light intensity) varied considerably across the plots, due primarily to water depth changes. Some seagrasses inhabit the intertidal zone and during low tides are exposed to the sunlight, yet remain partly wet in the muddy substrate. Other seagrasses occupy the deeper part of the water (2 to 4.8 m).

Thus, four physical variables, potentially limiting to seagrass survival and colonisation, were investigated as either favourable or unfavourable to seagrass conditions. The first is the salinity range, between 16 and 39 ppt., for both surface and middle/bottom layers (see Table 4.4). Prevailing salinity values in the sampling area within the normal range of 31 to 36 ppt. are favourable to seagrass growth and development (Greve & Binzer, 2004). Seagrasses adapt to a wide range of salinity values (Estevez, 1999). *H. ovalis* is euryhaline but has been observed with better growth performance at 25 ppt. (Sidik et al., 2010). *H. pinifolia* are found in wide-ranging salinity conditions between 25 to 34 ppt. and certain variants can withstand salinity fluctuations from 0 to 34 ppt. (Sidik et al.,1999). *C. serrulata* grow in water with a high salinity range of 35 to 45 ppt. and are highly tolerant to high salinity conditions (Jayasuriya, 2013).

Second, similar to salinity, the prevailing seawater temperature range was favourable for seagrass growth and abundance. The site's surface-water temperature range was between 25 and 30 °C. *H. pinifolia* were found to grow in sub-tidal areas where temperatures ranged from 27 to 33 °C (Sidik et al., 1999). *C. serrulata* has a high tolerance to seawater temperature changes (Campbell et al., 2006) and *H. ovalis* increases its productivity at temperatures from 15 to 20 °C; its highest observed growth has occurred at 25 °C (Hillman et al.,1995).

Third, most seagrass species are adaptive to a wide range of substrate types (Chansang & Poovachiranon, 1994; Sidik et al., 1999). Further, all three seagrass species possess morphological and physiological plasticities, as adaptive mechanisms to specific habitat conditions (M. Fortes, 1986). In the study, the seagrass sampling sites were mostly soft muddy substrates throughout the sub-tidal zone and the lower deeper part of the intertidal zone. Some portions of the substrate underwater had silt sediments, indicating the encroachment of sediment plume in the area through a gradual flow from coastal sources. In shallow waters, the substrate is also covered in some parts with plastic and other non-biodegradable garbage materials. On the exposed seashore zone, the substrate is a mixture of mud, sand and silt, due to the influence of offshore activities

Fourth, the SSC at the seagrass meadows was relatively high. TSS concentration values in most sampling stations (nos. 9 to 19) from all the samplings months were above 20 mg/L. Moreover, average TSS values from all months were within a range of 25 to 52 mg/L. However, TSS values do not show a gradational pattern to indicate the location of the sediment source. The random distribution of high-TSS values within the plot strongly suggests heavy bottom sediment re-suspension in certain parts, due to shallow depth waters and coastal wave action. Therefore, sedimentation stress in the meadows could be less likely caused by the river plume. The three seagrass species have adapted to the sedimentation levels prevalent on the site for their respective survival and growth.

Given their inshore location, the seagrasses were quite exposed to various threats from the adjacent coastal communities, such as destructive human activities, freshwater influx, nutrient overload and pollution (Livingston et al.,1998).

4.4.3.4.1. Halodule pinifolia.

The survival and dominance of *H. pinifolia* in the Macabalan site (see Figure 4.16) is explained by some of its important characteristics. *H. pinifolia* is a common seagrass species and is relatively widespread in the Pacific and mid-western Australia. The species is easily removed completely during small sedimentation events, but grows quickly and recovers its abundance within a short period (Duarte, 1991).

Two previous studies demonstrate the high tolerance of the species to light deprivation and suspended sediments. In the first study, its response (together with *Halophila ovalis*) to total light deprivation was examined using in situ shade screens for 80 days (Longstaff & Dennison, 1999). No decline in biomass was observed before 38 days of no light supply. Only after 38 days were the reduction of biomass, canopy height and shoot density observed, as the effects of zero available light supply. The second (laboratory-based) study examined the level of suspended sediments that could be tolerated by *H. pinifolia* (Satumanatpan & Saenwong, 2006). Using 1–64 mg/L sediment concentration for 30 days, *H. pinifolia* survival was not affected. However, beyond 66 mg/L of suspended sediments, the plant started to show a decline of survival rate at day 20[t] to 25, and all plants died after 40 to 45 days of exposure to suspended sediment concentration.

4.4.3.4.2. Halophila ovalis.

H. ovalis were assessed in Plot C at a distance of around 960 m east from the river mouth's midpoint (see Figure 4.16). This seagrass species was found in both Transect 1 and Transect 2, together with *Cymodecea serrulata*. Overall, *H. ovalis*'s percentage cover comprised one-fifth (21%) of the entire Plot C site and only 7% of the total surveyed seagrass area. It inhabited the deeper part of the sampling site, up to 4 m depth (rising tide). *H. ovalis* is described as highly tolerant and resilient to disturbances; it is widely distributed in the

Pacific and southwest Australia. It grows rapidly and its population is increasing in many parts of the globe.

The high tolerance of *H. ovalis* to certain disturbances enables it to survive in the Macabalan coastal waters, albeit its low percentage cover and the limited habitat distribution. Moreover, unlike the most dominant species, it is susceptible to thermal stress outside its optimum photosynthetic range of 20° C to 30° C (Ralph & Burchett, 1998). In a laboratory, acute changes were easily detected in the *H. ovalis* at a temperature of ± 2.5°C. Extreme temperatures outside its optimum range caused a complete collapse of the PSII electron transport system. This susceptibility to thermal stress explains the natural habitat locations of the seagrass species in deeper areas. Theoretically, *H. ovalis* should be found further beyond the sampling plots in deeper water (15 to 30 m), due to its strong opportunistic character (Erftemeijer & Stapel, 1999). Actual observations from field sampling, however, revealed that the sparse distribution of *H. ovalis* in the Macabalan waters was only up to ~5 m depth. This could indicate the relatively high turbidity of coastal waters, which limits the availability of light to the plants. *H. ovalis* exhibits little tolerance to light deprivation compared to *H. pinifolia* (Longstaff & Dennison, 1999). In the same experiment, the seagrass samples died after being subjected to 38 days of total darkness. In Macabalan, high turbidity could be due to various organic and inorganic particles coming from adjacent coastal human communities. Finally, competition with other seagrass species, such as the dominant *H. pinifolia*, may have limited the growth and abundance of *H. ovalis* (Rollón, 1998).

4.4.3.4.3. Cymodocea serrulata.

C. serrulata is common and widespread in its distribution, particularly in the Indo-Pacific and northern Australia. Reports claim a decline in numbers of this species locally (e.g., Bolinao, Northwestern Philippines, Tanaka et al. (2014). The species grows on muddy sand, fine sand and sand with coral rubble substrate. They grow fast and colonise rapidly and are quick to recover from the effects of disturbances such as burial and light attenuation (Duarte et al., 1998).

C. serrulata comprised the smallest cover, with 5% of the total Plot C sampling site (see Figure 4.16). They were found growing along the same transect line with *H. ovalis*, but in separate patches (quadrats). In Transect 1, *C. serrulata* covered a longer stretch of area (16 quadrats) than *H. ovalis* (10 quadrats), but the former had lower average percentage cover compared to the latter, with 16% and 23% respectively. In Transect 2, *C. serrulata* had both a shorter extent of reach and a lower percentage cover compared to *H. ovalis*. The results indicate a greater impact of the same environmental stress factors on *C. serrulata* than on *H. ovalis*.

Theoretically, under similar stresses, *C. serrulata* has a higher tolerance than *H. ovalis* (Cabaço et al., 2008). Given a 2 cm sediment burial, *C. serrulata* experienced 50% mortality, while *H. ovalis* all died. Moreover, Fortes (2001) has cited the work of Bach et al. (1998) at Cape Bolinao on the reduction of mixed seagrass bed diversity with increasing silt loads: from the most to the least tolerant species, *C. serrulata* was ranked second, while *H. ovalis* was placed fifth among the seven species. In another experiment, *C. serrulata* was observed to have grown and colonised in both shallow water (low tide and below 2 m) and deeper areas (Hena et al., 2001). It is most likely that stressors other than sedimentation have influenced *C. serrulata*'s abundance.

Even with relatively high-sediment concentrations recorded in seagrass sampling sites, re-suspended sediments do not persist long enough in one location to reduce light supply considerably, due to the constant current flow and transport of sediments (Terrados & Duarte, 2000). Moreover, sediment burial of seagrass plants has a minimal impact due to the inshore waves and shallow depths that enhance continuous vertical water circulation and sediment re-suspension (Carper & Bachmann, 1984; Sheng et al.,1994). Finally, the limited population and composition of each seagrass plot could be due to the presence of other environmental stressors in the site.

4.4.3.5. Seagrass composition and abundance in relation to coastal activities.

The threats to seagrasses from anthropogenic activities in Macabalan have been around for many years, but have worsened recently. Due to the physical proximity, the increase in coastal activities is more likely to increase water turbidity and physical disturbance in inshore waters. The absence of past seagrass monitoring in this part of the bay has made it very difficult to determine the impact of human settlements on marine plants over the years. Nonetheless, it could be inferred from several actual observations in the field that some urban coastal activities have a detrimental effect on seagrass meadows, and have very likely limited the abundance and diversity of marine plants.

In a sense, the seagrass meadows and human population form one interconnected coastal community in Macabalan. In fact, many coastal houses are built on stilts right above the water inhabited by seagrasses. It is very likely the case that domestic waste, rubbish and sewage are flushed down directly into the seawater (Harah et al., 2015). Sediment run-off from construction works and flood water run-off are also washed down to the same site (S. Y. Lee et al., 2006). Nearby is the city's port, where large ships and boats are docked. Shipping operations and port activities produce various wastes and debris that are dumped into the water. This may be transported by the circulating current to the seagrass site (O'Brien, 2009). The daily activities of coastal residents have had a detrimental effect on coastal waters and seagrasses. following are some actual observations made during the seagrass field sampling: fisher-folk use long fish nets and drag them underwater to catch fish, potentially cutting seagrass leaves or uprooting shoots (Fonseca et al., 1984). Dumped garbage loads litter the sea bottom, which buries and suffocates the submerged plants and also damages the substrate (M. D. Fortes, 1988). Human trampling on the meadows breaks seagrass shoots and stems

(Eckrich & Holmquist, 2000). Further, 'unfriendly' boat mooring randomly scours the seagrass beds (Walker et al., 1989; Sargent et al., 1995).

Combinations of various stress factors exacerbate the adverse impacts on the marine habitat (Short & Wyllie-Echeverria, 1996) and could place additional pressure on seagrasses already under stress from periodic surges of salinity, temperature and sediment concentration. The adaptive capabilities of seagrasses are only effective against recurring environmental impacts up to a certain threshold.

4.4.3.6. The future of seagrasses in Macabalan.

The strong SE current flow disperses high-TSS concentrations on the southeast portions of the bay, which also encroaches on seagrass meadows. However, this happens only occasionally during an extreme river discharge event. Under normal weather conditions, the potential threat to seagrass communities comes from anthropogenic sources, given the open and direct access of the coastal community to the seagrass site (see Figure 4.24a). At present, human-induced threats continue, and their effects on coastal water are apparent. In the future, two scenarios are possible. The continued rise of the human population means more coastal-based activities generating increased stress and disturbance on the sea and its coastal habitats. Extreme pressure may then go beyond the threshold levels of seagrass adaptive capacities. Reduced water clarity may pose the gravest threat, as increased human activities in the coastal water will enhance bottom sediment re-suspension, shoreline erosion and debris run-off.

Increased physical disturbance is the second grave threat, which consists of burial, suffocation, uprooting, breaking and cutting of seagrasses due to destructive fishing methods, recreational activities, rubbish dumping and boat mooring. The third threat may be the degradation of seawater quality, mainly due to increased domestic waste, sewage and various pollutants from coastal communities and the port site (see Figure 4.24b). Seagrasses are generally resistant to these toxic elements, but an overload of these substances may disrupt the food chain or break the natural recycling or regeneration process; this may lead to alterations in the particular ecosystem structure (M. D. Fortes, 1988).

Figure 4.24: a) Stilt houses built over the seagrass meadows site, showing direct vulnerability of marine plants to domestic wastes and pollutants; **b)** shipping port of the city, which can be sources of pollution for the seagrasses located nearby (source: Tan, 2014)

However, the proximity of the seagrasses to coastal communities may heighten the local people's awareness of the importance of the marine/coastal environment and resources. They may be moved to take action regarding environmental protection and management. One example is Seagrass Watch (*BantayIsay*) in Puerto Galera, Mindoro, Philippines. This program was initiated by students. It is fully supported by the municipality through a municipal ordinance and by scientist; it seeks to conserve seagrasses in the area (www.seagraswatch.org/Philippines). Seagrass monitoring is a regular activity of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Club of Puerto Galera Academy students and other community volunteers.

Another example is in Australia, where coastal communities across New South Wales have become members of a community-based monitoring network, called the Community

Environmental Network, to monitor seagrasses (www.cen.org.au). Every community member (after required training) is tasked to keep watch on human-induced disturbances that have influenced changes in the seagrass community. The collective information becomes the basis for expert opinions and community action to stop further seagrass degradation.

These activities highlight a community's collective responsibility for the environment. They are beneficial to the seagrass meadows, to the coastal environment and to the human community as a whole.

4.5. Summary and Conclusions

Within natural locations, each marine habitat has survived and developed as an important part of Macajalar Bay’s ecosystem. However, the proximity of the Cagayan de Oro River mouth to these natural sites increases the possibility of encroachment and the influence of river run-off on the coastal marine habitats.

This chapter has shown that river sedimentation enhances soil deposition at the river mouth, resulting in slightly increased mangrove cover, while sediment plume exhibits a light to moderate encroachment on both coastal habitats and occasional heavy flooding on the seagrass meadows.

Among the three coastal habitats, mangroves (being located inland) are the most exposed to sedimentation and direct human intervention effects. Through the years, catchment erosion and subsequent sedimentation have contributed to the changing coastal and riverbank structures of Bonbon, Macabalan and Puntod, and to the mangrove’s abundance and distribution in Bonbon. Major coastal developments are a result of deliberate human intervention. These coastal changes indicate the huge amount of catchment soil that has been eroded and transported to the river mouth and the coasts.

However, land accretion at the site has resulted in small natural mangrove colonisation. Nonetheless, mangrove planting is being undertaken along the coast of Bonbon. Consequently, coastal changes resulting from mangrove losses or expansion could influence the plume flow and the fate of sediments in the bay where seagrasses and corals exist.

Physical encroachment, and the possible effects of river-borne sediments on the three coastal habitats, is largely influenced by the interactive effects of river discharge and other bay-forcing factors. The absence of corals within 1.6 km from the river mouth is mainly influenced by the TSS concentration and the persistence of river plumes in the area. The existing coral's low abundance (at an average of 34%), its relatively low lifeform diversity (SI, average = 1.063), and the overall dominance of the most stress-tolerant massive coral seem to indicate a relationship between sedimentation dynamics and coral conditions. Certain existing conditions may increase the sedimentation risk for corals in the future: mudflat erosion, paved banks on the Macabalan side and an increased sediment discharge from the Iponan River.

Similarly, the natural distribution of seagrasses beyond 780 m from the river mouth indicates the influence of TSS concentration and of river plume persistence within the site. The survey results, which revealed limited seagrass habitat distribution, low species diversity (SI, average = 0.23) and sparse species abundance (<30%), do not indicate that river sediment plume is a possible key stressor. Downstream flow of sediments to the meadows was minimal, while heavy plume encroachment on the site during extreme rainfall events was occasional. Thus, it is more likely that present seagrass conditions have also been affected by anthropogenic activities within the meadows' vicinity.

Chapter 5:

General conclusions and key principles in the management of the Cagayan de Oro River catchment and its coastal marine environments

5.1. Conclusions and Summary of Results

5.1.1. Major Findings across the Ridge-River-Reef Continuum

Rainfall in the Cagayan de Oro River catchment is governed by a seasonal shift that is generally moderate all year round. However, a few extreme and prolonged rainfall events or typhoons also occur in the region, particularly during the rainy months and towards the end of the year. Therefore, the catchment is largely stable, but possesses a small number of erosion-prone sub-catchments (see Figure 5.1), which have a high potential to cause massive floods of water and mud during extreme rainfall events.

In both average and extremely high river discharge conditions, the sediment and associated materials were highest in concentration at the river mouth (see Figure 5.1). Regarding the dispersed offshore sediments, the flow direction was predominantly east and southeast, following the general coastal current circulation. In extreme discharge events with high-sediment volumes, sedimentation poses a direct threat to both corals and seagrass communities, but not to mangroves.

The distribution and abundance of mangroves, corals and seagrasses within the Cagayan de Oro River coastal environment indicates their response to the sedimentation dynamics they experience (see Figure 5.1). Therefore, this study acknowledges the need to conduct management interventions at different points along the ridge-river-reef continuum where sedimentation has become anomalous.

Four key management principles—integration, sustainability, precautionary and adaptive (Boesch, 2006)—are proposed here as overarching themes to address the ridge-river-reef continuum challenges in an integrated way. In particular, through this approach the study hopes to reduce the erosion-sedimentation process and its effects on the ridge-to-reef continuum (see Figure 5.1). These four principles serve as normative guides for every proposed management or rehabilitation activity.

5.1.2. Highlights of Ridge-to-Reef Sedimentation and Some Management Implications

The diagram below shows the entire flow and summarizes the highlights of methods, results, and outcomes of the three main chapters with recommended management measures.

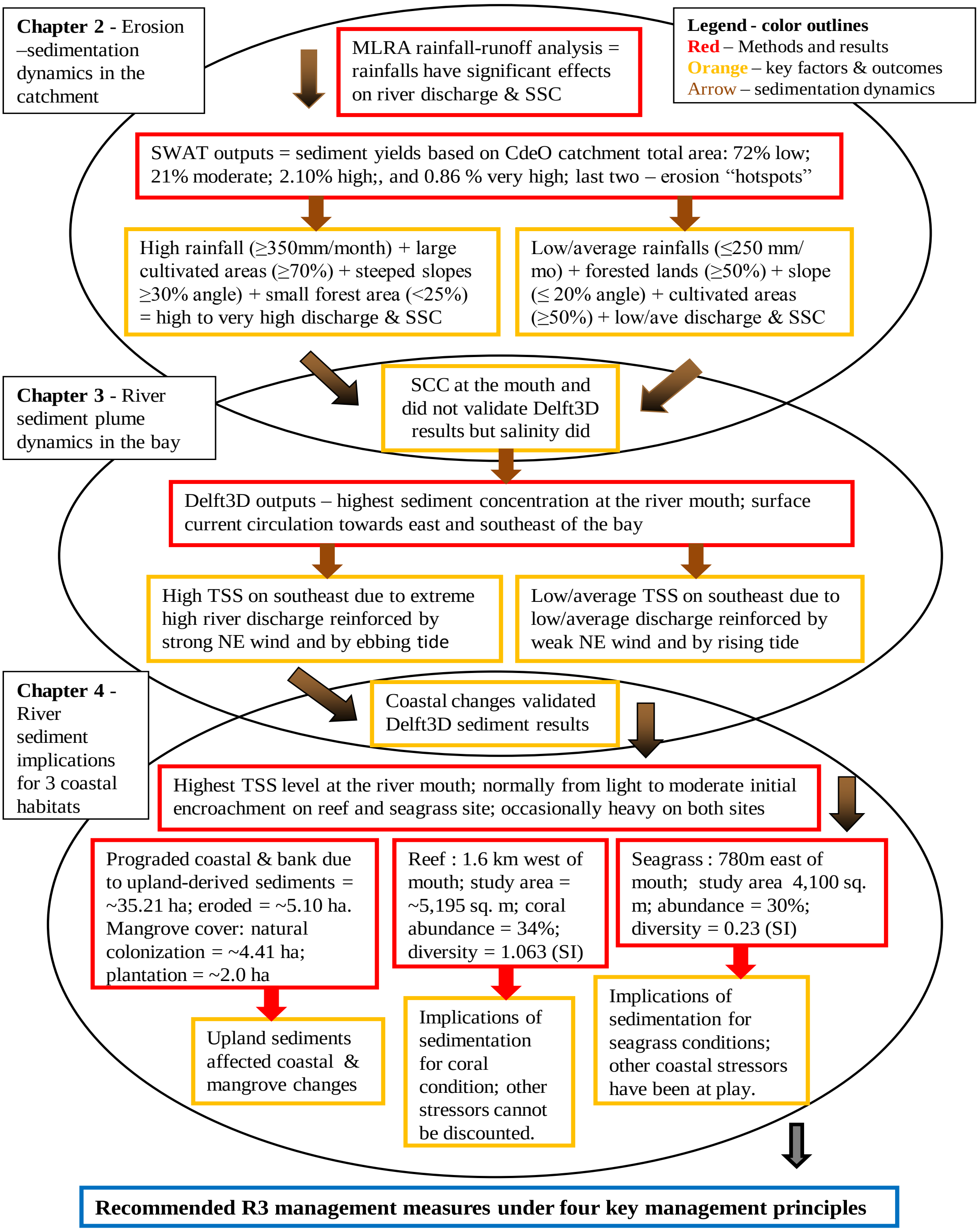


Figure 5.1: Flow diagram of the three main chapters: each chapter contains the specific methods used and their corresponding results, and the key factors that have influenced or not influenced the outcome of the process. The brown arrows indicate the flow direction of sediments with river discharge. Final outcomes are the recommended management programs for the entire continuum.

5.1.2.1. Erosion and river sedimentation: key management challenges.

Erosion and sedimentation rates in the Cagayan de Oro River catchment vary from sub-catchment to sub-catchment, due to the diverse characteristics of HRUs comprising a sub-catchment. Catchment erosion-sedimentation dynamics are initially dictated by extreme rainfall input or typhoon events (see Figures 5.2a and b), as discussed in Chapter 4. However, more importantly for management intervention, catchment physical features, particularly steep slopes (≥30%) and vast areas of cultivated land/pasture land (>70%) or the lack of forest and dense vegetation, have largely determined the rain factor's influence on soil erosion and subsequent sedimentation.

Generally, the model has assessed the Cagayan de Oro River catchment as mostly made up of slightly erosion-prone sub-catchments (107,014 ha or 76% of the total catchment). However, several moderately erosion-prone (28,798 ha or 20.5%) sub-catchments could become highly vulnerable to severe and widespread erosion during extreme rainfall events. Fortunately, the catchment has mostly average monthly discharges; however, extremely high discharge events do occur intermittently a few times during the year.

According to the SWAT model results, one key potential contributory risk to severe erosion in the catchment is the unstable 'disturbed' land cover. This instability may be exacerbated by extreme rains and continuing anthropogenic pressure. Thus, the foci of management intervention should be both the land cover component and destructive land-based activities. Another key risk factor for massive flooding in lowland areas is the increasingly shallow river water depth caused by the gradual deposition of sediments on the river bottom. This is due to the river's sloping topography and unstable banks, where houses and human activities proliferate. Here, the focus is river rehabilitation from abnormally high-sediment deposition caused by both natural processes and human activities. The riverbanks and the human activities within the vicinity need to be well managed.

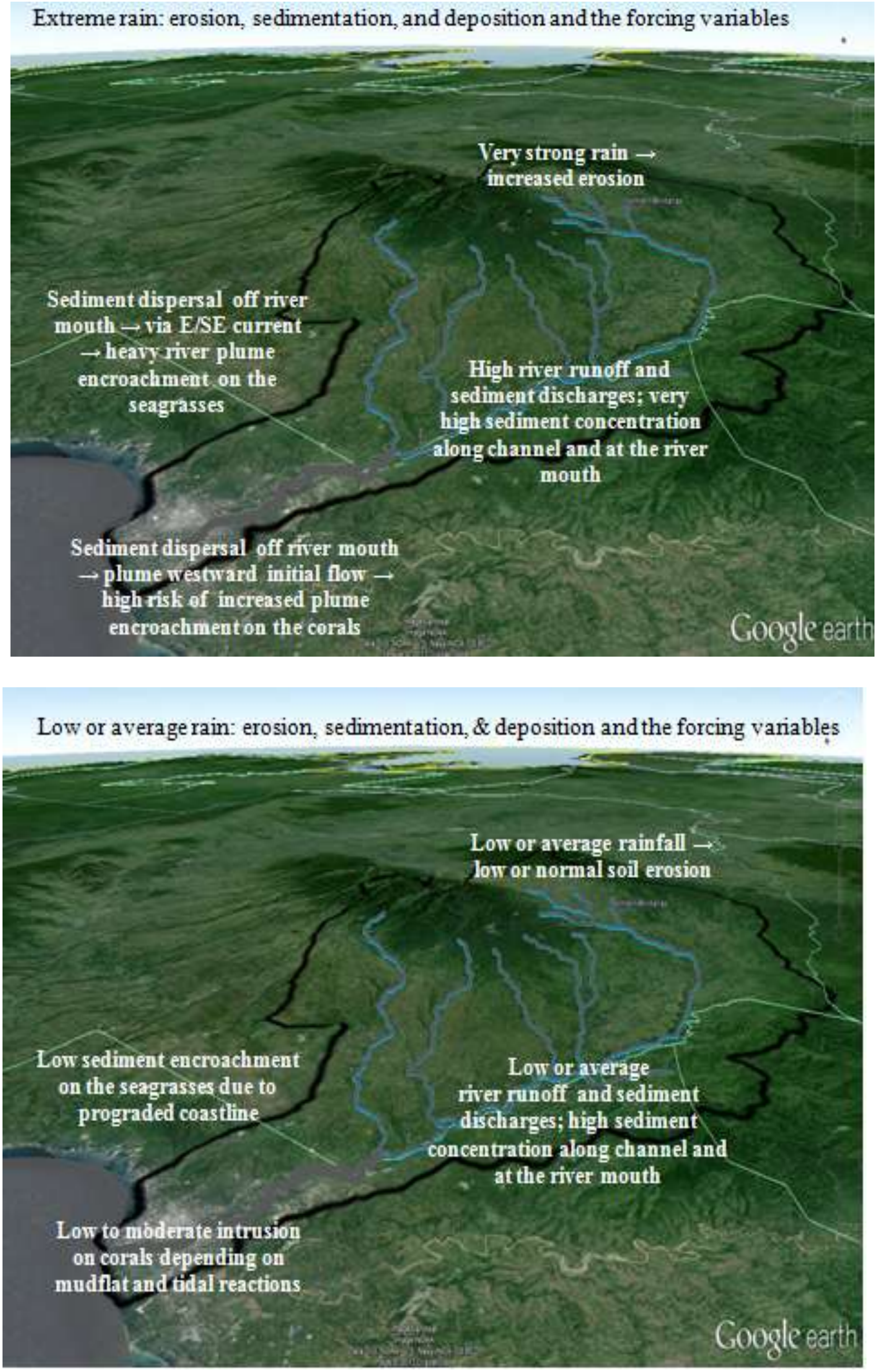


Figure 5.2a and b: Two scenarios: (top) strong rain and high discharge posing high-risk encroachment of river plume on both corals and seagrasses; (bottom) low and average rains and discharge resulting to high-sediment deposition at the river mouth and minimal encroachment on corals and seagrasses (base map from Google Earth, 2015).

5.1.2.2. Coastal sedimentation dynamics: key management challenges.

Comparison between river plume and ambient coastal waters for TSS and salinity values using the December 26 and April 22 sampling results revealed the presence, albeit limited, of river plume in the coastal sites. For salinity, freshwater intrusion into coastal sites was exhibited on both sampling dates. Thus, under average discharge conditions, river plume did encroach on some areas of the sampling plot close to the river mouth. It is expected that increases in river discharge and sediment load will result in a greater extent of plume coverage along inshore waters.

Based on the Delft3D modelling, the heaviest sediment concentration under all discharge conditions was within the river mouth and its vicinity. In fact, heavy sediment depositions on the river bottom have made the river mouth zone very shallow. Additionally, upland-derived sediments that have accumulated over time at the river mouth have formed into a large mudflat. Other coastal manifestations exhibiting the deposition of eroded catchment sediments included the accreted landmasses and dumped dredged materials. This particular issue necessitates a two-pronged remedy: rehabilitation of the affected sites and similar intervention measures for the erosion sites.

Finer river sediment particulates were dispersed on the east and southeast portions of the bay. With extremely high discharge from Typhoon *Washi*, model simulations suggest dispersed sediment concentration along inshore waters at 300 to 400 mg/L or 20% of the total TSS input value. Receding ebb tides carried more sediment materials seaward than did the flood tides. Thus, there is a looming threat to seagrass and coral communities from river-borne sediments during high and continuous rain events exacerbated by ebb tides and mudflat erosion. This issue must be addressed at the sediment source and along the banks where most terrigenous materials can be trapped and impounded.

5.1.2.3. Sedimentation, coastal changes, and the marine coastal habitats: key management challenges.

Through the years, river sedimentation has brought benefits to the coastal environment, due to the accretion and expansion of landmasses, and later the subsequent colonisation of mangrove trees. However, it has also paved the way for major physical modifications to the coast and riverbank, facilitated by human intervention at the expense of naturally growing mangroves.

Moreover, physical and vegetation cover changes demonstrate some influence on the extent and direction of river discharge and sediment dispersal in the bay. With the Cagayan de Oro River coastal environs, these changes have exacerbated river sedimentation, as well as plume dispersal off the river mouth. For example, the continued westward expansion of the mudflat inflicts a high-sediment encroachment on corals, particularly during erosion and the further transport of loose sediments to the reefs.

Coastal and bank changes may not have exacerbated the river plume encroachment and concentration on seagrass meadows. In fact, the prograded coastline of Macabalan has partly impeded the downstream flow eastward towards the meadows. However, coastal development, particularly of Macabalan, has also resulted in a much larger current coastal population and human activities close to the seagrass sites.

The issue here is the lack of integration of coastal habitats—such as mangroves, corals and seagrasses—as important components into the city's coastal development program. This gap has led to the loss of mangroves and the continuing decline of corals and seagrasses, due to pressure from human-induced activities and other related stressors. This can be addressed by effort from the coastal communities themselves and by the local government prioritising its concern for coastal and marine ecosystems, even as the city's coastal development continues.

5.2. Key Management Principles for Ridge-River-Coastal Challenges

Four key management principles are used to examine each management measure recommended by the present study (see Figure 5.3). These principles are important requirements for any ecosystem-based management and can be used to assess rehabilitation and management plans (e.g., Chesapeake Bay and Louisiana Coast) (Boesch, 2006).

Integration is understood as multi-dimensional: a management approach is interdisciplinary (science, management, sociology), the employed variables are inter-medium (land and water), and the stakeholders originate from different sectors (multi-sectoral and intergovernmental) (Knecht & Archer [1993]), as cited in Boesch [2006]). Sustainability is intergenerational, ensuring that the needs of the present generation are met without compromising the ability of future generations to produce enough for themselves (Brundtland et al., 1987). The precautionary principle is another management requirement; it prevents any potentially harmful action to proceed, even without an established cause and effect relationship. Finally, the adaptive management principle requires continuous learning and refining of management strategies, based on set goals while trying to reduce uncertainties by constant monitoring/assessment or experimenting (Lee, 2001).

In the present study, the scientific findings are crucial inputs for an effective management plan based on these four key principles. According to the integration principle, erosion-sedimentation as a common stressor must be addressed appropriately, while also considering human needs and uses. Therefore, any rehabilitation activities such as land use conversion, riparian vegetation, coastal clean-up programs and dredging should be assessed in terms of their impacts on the lives and needs of the affected human communities.

5.2.1 Sedimentation, its Factors and the Four Key Management Principles

Sedimentation as influenced by rainfall events and other factors is shown below.

Extreme high rainfall + very steep slopes + large cultivated areas + minimal forest cover → high river discharge and severe and massive erosion in the sub-catchments.

Heavy and prolonged rainfall in the upland → very high volume of river runoff and of suspended sediment concentration in the river

High discharge carries more sediment particles dispersed far out into the bay with initial route of river outflow is NW but net circulation effect is SE; highest sediment concentration is at the river mouth.

Extreme sediment runoff + mudflat erosion → increased river sediment encroachment on coral sites; extreme high sediment runoff + strong SE/E current flow → heavy sediment encroachment on the seagrass sites

Normal and low rainfall volume + steeped slopes + reduced forest cover → average volume of river discharge and localized and slow soil erosion

Normal or low catchment rainfall input → average/low volume of river discharge and average/low sediment concentration in the river.

Normal river runoff results to sediments largely concentrated within the channel and at the river mouth; little sediments are dispersed with the E/SE current flow.

Sediment deposition mostly along banks and coast → land accretion → mangrove expansion OR sea floor or river bed siltation → dredging → coastal filling → human settlements or mangrove expansion

Key management principles overarching the rehabilitation of the ridge-river-reef continuum
1) Integration
2) Sustainability
3) Precautionary
4) Adaptive

Figure 5.3: Sedimentation processes under two scenarios and the factors influencing each; the four key management principles proposed to mitigate erosion and sedimentation effects.

For sustainability, catchment rehabilitation initiatives should be able to lessen the vulnerability of each system and increase its resilience against stress from erosion-sedimentation effects. Regarding precaution, rehabilitation plans should include strict bans on activities that may increase erosion and sedimentation rates, such as steep-slope cultivation, large-scale plantation, near-bank human settlements, riverbank concreting and mangrove cutting. Finally, adaptive management calls for setting clear goals for rehabilitating the Cagayan de Oro River catchment and its river system. These goals must be revisited or revised if required. Such revision should be based on the results of constant sedimentation impact monitoring in relation to the coastal environment and habitats, and on the overall effectiveness of management strategies applied to the entire ridge-river-reef continuum.

5.2.2. The Cagayan de Oro River Catchment Management and Rehabilitation Measures as Guided by the Four Key Management Principles

The primary culprit for high soil loss in certain sub-catchments (from a management perspective) is the sub-catchment's very low forest density, which is due mainly to large-scale plantations, logging and other destructive practices in the catchment.

Rehabilitation of the river catchment should include all moderate- and high-sediment yielding sub-catchments and their adjacent sub-catchments (see Figure 5.4). First, this should be applied on the identified 'erosion hotspots'. Then, on the moderately sediment-yielding sub-catchments, with relatively low rainfall inputs (≤287 mm/day), but with characteristic very steep slopes, large cultivated areas and much-reduced vegetation cover.

Following the integration principle, on-going rehabilitation initiatives include the greening of sites, involving the organised communities who are co-owners of the commodities and beneficiaries of the fruits of their labour. Therefore, rehabilitation programs must take a multi-sectoral and interdisciplinary approach. Further, rehabilitation efforts should consider the establishment of various conservation practices across all highly erosion-prone parts of the catchment.

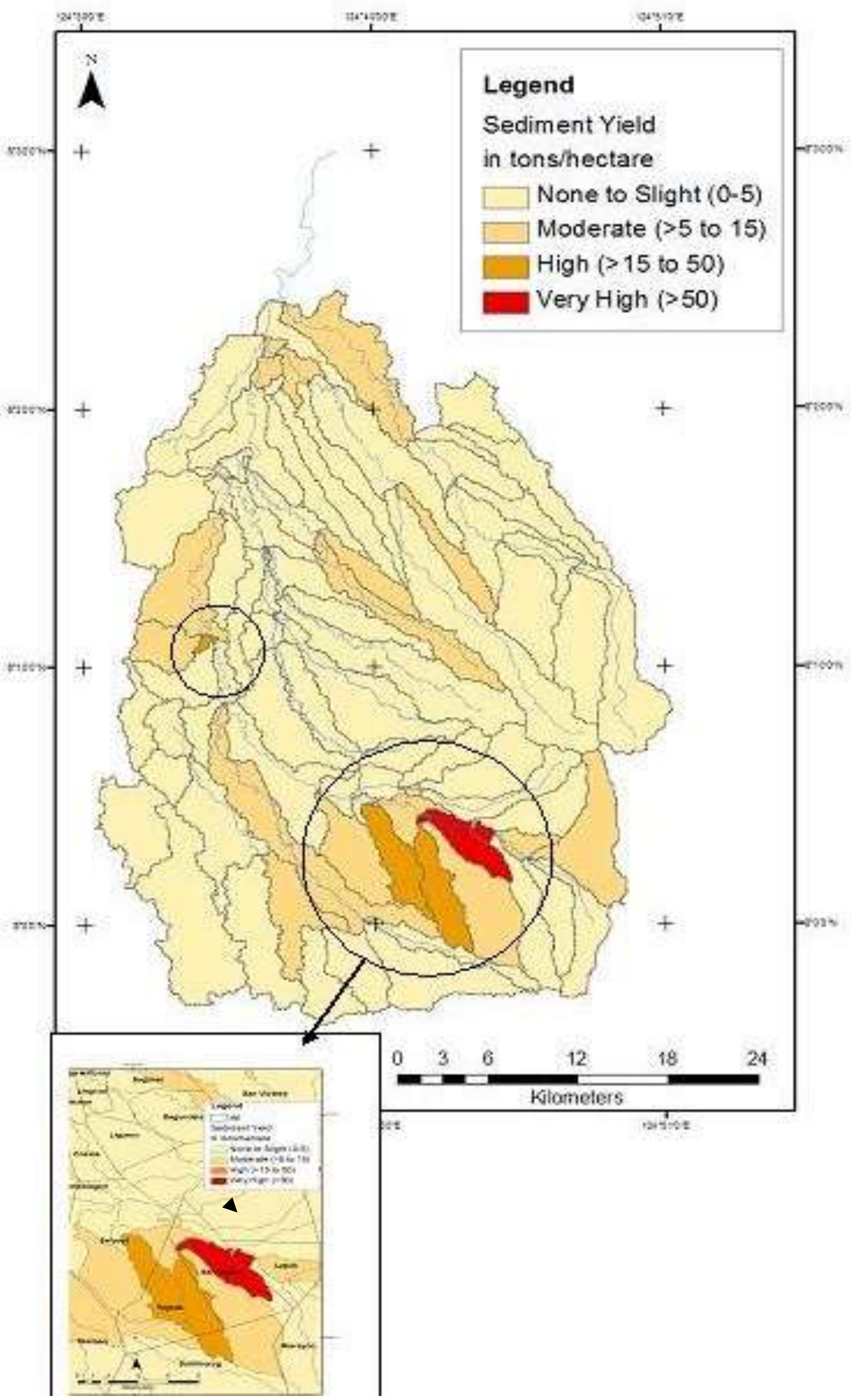


Figure 5.4: High and very high sediment-yielding sub-catchments as 'erosion hotspots' (encircled) in *Barangays* Tagbak and San Miguel in Talakag, Bukidnon Province.

The sustainability principle means that each sub-catchment must be stable enough to withstand severe erosion and resilient enough to return to its normal functioning after physical disturbances. Therefore, catchment stability entails dense forest cover, particularly on steep slopes, effective conservation methods on large areas of cultivated lands and minimal destructive land-based activities. A dynamic, stable and less-disturbed catchment will be sufficiently resilient to withstand physical disturbances.

The precautionary principle in catchment management calls for the banning of any activity that is potentially destructive to the catchment's physical landforms and its vegetation cover. This specifically includes deforestation activity in any part of the catchment, along with agricultural cultivation and human settlement on the slopes and sites near the riverbanks.

Finally, adaptive management requires constant monitoring of rain and river measurements to assess quantitatively the rainfall seasonality response of given sub-catchment land features and management practices. This may require more SWAT modelling in the future. Specific management strategies applied to sub-catchments should be constantly evaluated against established goals. New data from regular monitoring activities will be used to refine or readjust the present management plan for the Cagayan de Oro River catchment and for other study sites.

5.2.2.1. On-going rehabilitation activities in the Cagayan River Catchment.

The National Greening Project is an-going activity of the Cagayan de Oro River Basin Management Council (CDORBMC) for rehabilitating the river catchment. It is spearheaded by the DENR-Region 10 in partnership with various community-based organisations in the three local government units—Talakag, Baungon and Libona—within the catchment. The project, which started in 2011, includes planting of timber, cacao, coffee and rubber in selected sites within each municipality (see Figure 5.5).

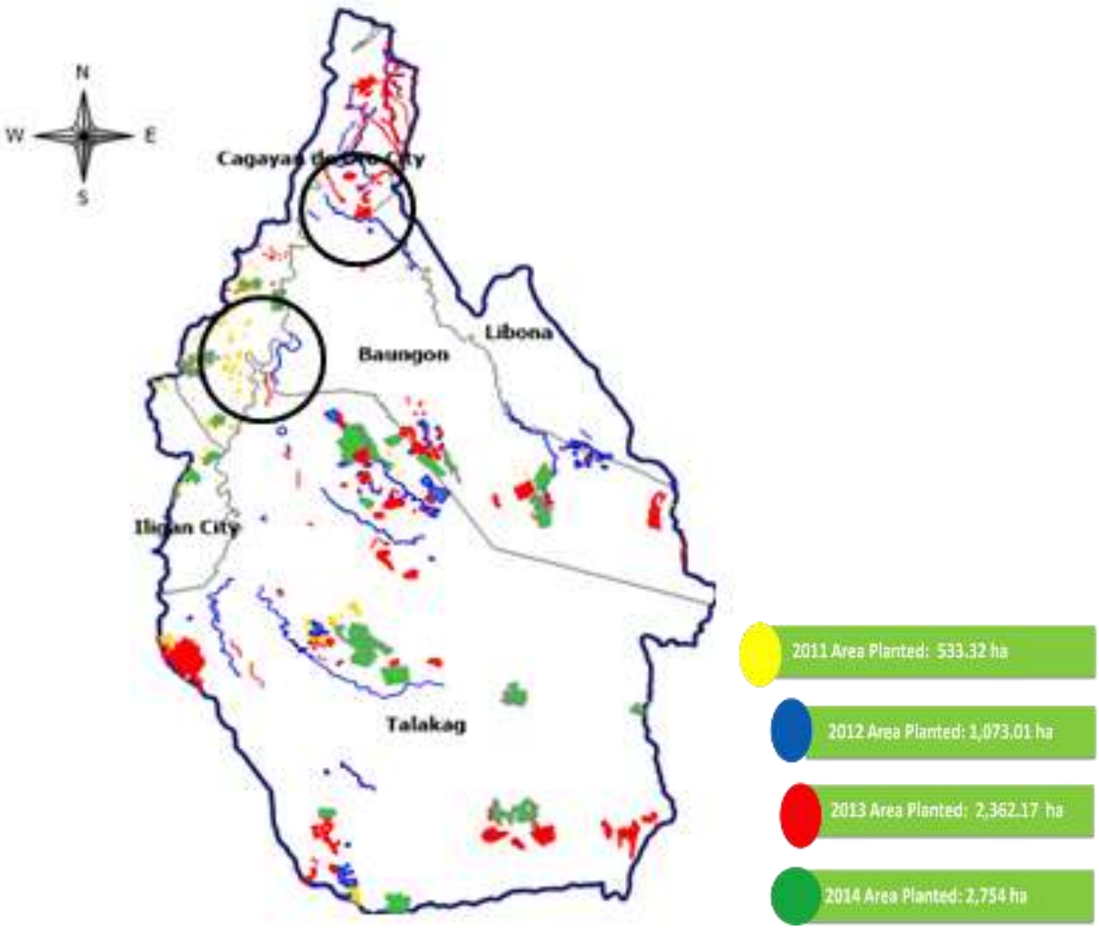


Figure 5.5: Cagayan de Oro River catchment with the various locations of on-going greening projects from 2011 to 2014. Encircled sites are 'erosion hotspots' (source: DENR-10)

The project is commendable as it empowers local communities to plant and grow commodities, and take their due share after harvest. This is based on the belief that local communities will conserve natural resources that are integrated into their economic and social life (Brandon et al, 1998). However, as with previous practices, this integrated conservation and development approach may encounter certain problems for various reasons, such as exploitation and alteration of commodities (Ludwig et al., 1993; Soulé & Lease, 1995; Langholz, 1999; Redford & Richter, 1999). In light of this, adaptive management (e.g., regular evaluation) is even more important (Walters, 1997).

The Greening Project also includes sub-catchments identified by the present study as being highly prone to erosion (encircled in Figures 5.4 and 5.5). However, it is not clear within the project what contribution of site attributes to erosion risks (e.g., steep slopes, barren spaces) would be addressed by planting selected commodities. Further, greening activity could be limited to sites close to human communities for effective support and maintenance at the expense of 'erosion hotspots' in more isolated sites.

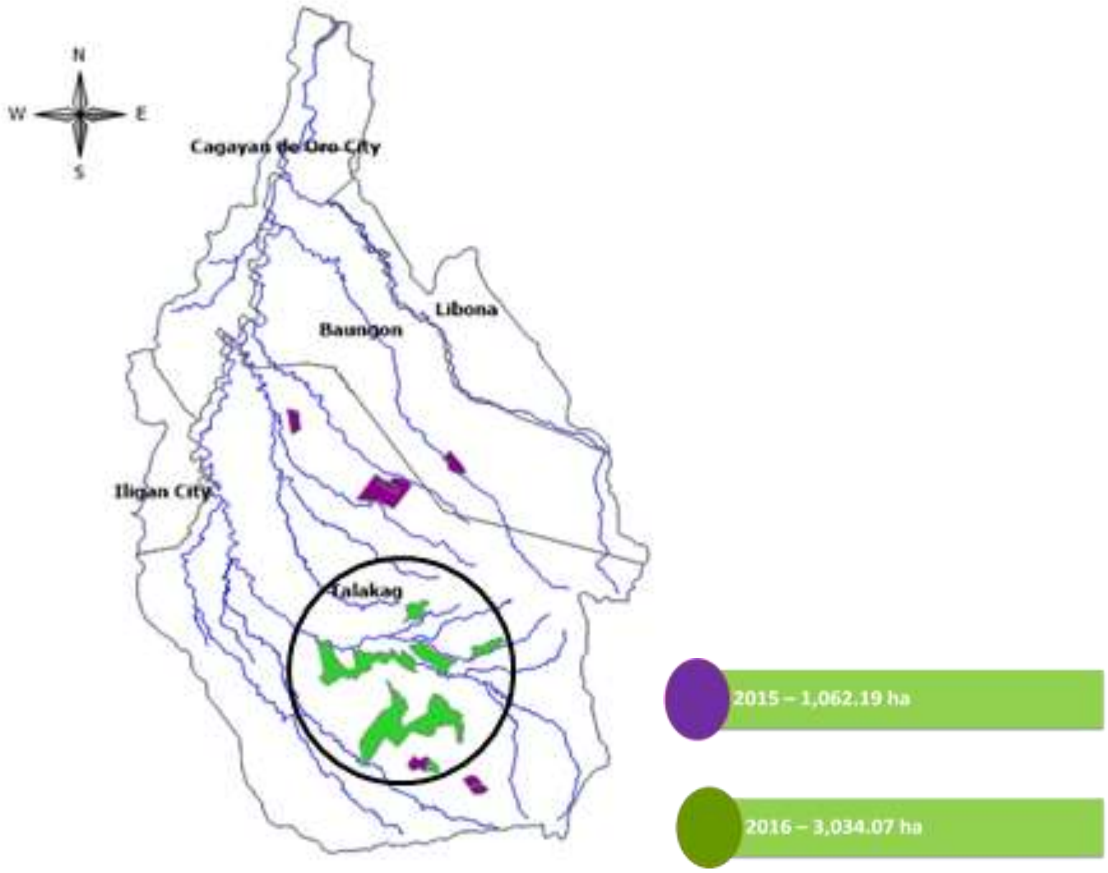


Figure 5.6: The Cagayan de Oro River catchment with locations of sites targeted for future greening projects. Encircled sites are 'erosion hotspots' (DENR-10).

Regarding the 2016 Greening Project, it is notable that the targeted areas for development (see Figure 5.6) are located within the same sub-catchments identified by the present study (see Figure 5.4) as very high in sediment yields. These sites are located at the foot of Mt Kitanlad and lie within the confluence zone of a tributary/stream network.

5.2.2.2. Recommended management measures for the Cagayan de Oro River catchment.

This study recommends the following concrete management measures, guided by the four key management principles. These measures are also recommended for incorporation into the Integrated River Basin Management and Development Master Plan for the Cagayan de Oro River Basin (see DENR-RBCO, 2015).

1) Public education and awareness building. This includes explaining the contextual perspectives on disaster risk and involving local people in the interactive process of awareness raising (Burningham et al., 2008). The present SWAT map of the sub-catchments' sediment yield values (t/ha/yr), and their corresponding geographical locations within the *barangay* and municipality, should be made publically accessible. In this way, the local people can realistically appraise the gravity of the risk and their possible contribution to it.
2) Banning large-scale cultivation in 'erosion hotspots'. The strict enforcement of prohibited plantation expansion in 'erosion hotspots' should be established. To reduce the impact of slope cultivation on food production (Pimentel et al., 1987), government should prioritise the farming of staple plants and high-value crops in available agricultural lands.
3) Improve slope conservation efforts. Appropriate conservation practices and planting systems (e.g., contour farming) (Mercado Jr et al., 2001; Poudel et al., 2000) should be enforced in cultivated lands along sloping or hilly areas (≤15%). Training and actual field demonstrations on conservation practices can be initiated by local government technical officials to help local farmers increase food production and minimise soil erosion. Soil conservation and food production must be carefully balanced for sustainability (Partap, 2004).
4) Removal, transfer and resettlement of informal bank settlers (Kothari, 2007). The identification of new safer resettlement zones through city mapping and land surveys is

vital, as is the preparation of resettlement areas through various activities such as construction of basic infrastructure facilities. Informal settlements should be removed from hazardous sites and a strict enforcement of a ‘no human settlements’ policy on these sites should be established. Finally, evicted informal settlers can be resettled in new homes.

5) Implement land use conversion. Appropriately sized ‘hotspots’ can be converted into forested areas. Appropriate soil conservation measures can be implemented. The proposed plan consists of tree planting/growing on bare or grassy portions of the following SCs:

    a) SC 66 (very high) = 470 ha of pasture land
    b) SC 68 (very high) = 70 ha of pasture land
    c) SC 63 (very high) = 557 ha of pasture land
    d) SC 62 (high) = 761 ha of pasture land
    e) SC 65 (high) = 1,122 ha of pasture land

6) Immediate rehabilitation of mountain and bank slopes (e.g., tree planting, bank reinforcement and bans on cultivation). All ‘priority’ sites for rehabilitation are within the vicinities of river/stream confluence zone at the base of Mt Kitanlad. This action should target ‘erosion hotspot’ areas, particularly the mountain and river banks with ≥30% slopes:

    a) SC 66 = 247 ha
    b) SC 68 = 100 ha
    c) SC 63 = 29.7 ha
    d) SC 62 = 161 ha
    e) SC 65 = 168 ha

7) Dredging in shallow parts of the river channel. A bathymetric survey of the entire river channel should be conducted to identify ‘priority’ parts close to human communities. Proper dredging guidelines should be followed (DPWH, 2000).

5.2.3. The Cagayan de Oro River Mouth and Its Coastal Marine Habitat Management Measures as Guided by the Four Key Management Principles

Major research findings have revealed that sedimentation exhibits different levels of association with each of the three coastal habitats. Sedimentation's beneficial effect is through land accretion and land filling, which subsequently become new mangrove-colonised sites (e.g., *Sonneratia sp.*). With corals and seagrasses, sediment plume encroachment on the coastal habitats' sites during heavy catchment rains may affect either community.

Based on the four key management principles, rehabilitation plans should sustain the 'healthy' condition and expansion of each coastal habitat. First, the coastal environment itself must be sustainably stable and resilient, which means it can receive sediments and other stressors but can later restore itself to normal functioning conditions. This means the ecosystem should have components such as mangrove trees to mitigate the harmful effects of sediments. Second, the coastal habitats themselves should be sustainably resilient and balanced to withstand disturbances adequately. Thus, there is a need to rehabilitate the three coastal habitats and their environs and then to manage their succeeding growth and development appropriately.

The principle of integration requires that rehabilitation of the coast and its marine habitats should first consider the needs of coastal human communities. It presupposes active participation of concerned stakeholders in both planning and execution phases. Important concerns such as resilience, coastal habitat diversity, human consumption and needs, coastal development, disaster preparedness, and financial/economic implications should be properly established for discussion and so that decisions can be made.

For the precautionary principle, it is imperative to ban certain human activities that are potentially destructive to the ecosystem and to its coastal habitats, such as waste production or disposal in coastal waters, using illegal fishing methods, converting mangrove swamps into human settlement areas, direct deliberate disturbance of corals and seagrasses, and extensive upland land-based activities.

As for the adaptive management principle, this requires continuous learning about the river mouth and the coastal habitat conditions in response to sedimentation's impact. This can be done through a constant assessment of the distribution, abundance and diversity of each major habitat, while also monitoring sedimentation flow patterns and where high concentrations are located in coastal waters. Tests for other limiting variables must also be undertaken to determine the sources of variation in the results. Overall management strategies should be evaluated based on the targeted goals. This knowledge can then be used to correct or refine present management plans or to apply strategies to other study sites.

5.2.3.1. Management plans and on-going rehabilitation activities for the Cagayan de Oro River mouth and its coastal marine environments.

1) *Barangay* Bonbon has implemented advocacy and education programs to raise awareness among the population. This includes regular rubbish collection, proper waste disposal, sanitation-related projects and a coastal clean-up drive (Barangay Peace and Development Plan, 2015–2020). The plan identifies certain limitations to the program's success, such as the lack of funds and the minimal cooperation from local inhabitants. Monitoring and evaluation for a sustained effective program is not discussed in the plan.
2) The city government, in collaboration with the DENR-10, is undertaking a mangrove-planting project under its integrated coastal management project along the Bonbon coasts (Jose Reyes, personal communication, 19 Aug 2015).
3) *Barangay* Macabalan has planned and initiated a program for a clean environment, including solid waste management, a coastal clean-up drive, repair of existing drainage systems, and the installation of sanitary toilets for all residents (Barangay Development Plan, 2016). It also adapted, through a *barangay* resolution, a disaster-risk reduction

program that includes construction of a dike and a breakwater seawall, and the relocation of residents from identified danger areas. However, there is no mention of a plan or activity for the coastal waters and its marine resources under any of the *barangay* programs; namely, clean environment, healthy population and productive constituency.

4) Under the flood-risk management project for the Cagayan de Oro River (FRIMP CDOR), a 12 km flood control structure will be built from the Pelaez Bridge up to the river mouth (see Figure 5.7). The mega dike project is expected to mitigate risks in flood-prone areas along the CdeO River. The construction of the dike will affect 15 *barangay*s and might displace over a thousand households. The P5-billion project was proposed by the Japan International Cooperation Agency (JICA) after Typhoon *Washi* (*Sendong*) devastated Cagayan de Oro City in 2011. The mega dike is expected to protect people and properties from large floods in the future. However, the dike will be detrimental to the river ecosystem, isolating it from the rest of the larger terrestrial ecosystem. It is also unfavourable to groundwater replenishment and storage. Finally, the sediment load dispersed into the bay will increase. Nonetheless, this present study suggests that natural buffers, such as dense riparian vegetation should be planted between the wall and the inland communities on both sides of the bank along the entire extent of the dike (Wolanski, 2006). The forest serves as a second barrier after the dike, in case the concrete wall gives way to large floods. The vegetation also maintains the bank's soil stability and intactness against erosion.

5) Dredging activity at the river mouth continues up to the time of writing. Dredged materials (240 m3/hr; 80% liquid and 20% solid) (DPWH, 2000) are stockpiled on Bonbon coast and are supplied to the city for various purposes (DPWH engineer, personal communication, 27 Aug 2015). A pre-dredging report identified no corals or seaweeds at the dredging site; seagrass had only 2.57% cover, while fish species numbered six, with

Bolinao (Stolephorus sp.*)* as the most abundant. Given the flow dynamics of river discharge and bay currents, monitoring of potential sedimentation impacts should include the existing corals and seagrasses during the actual dredging phase. Regular assessments of dredging impacts on the Bonbon and Macabalan coastal population should also be conducted.

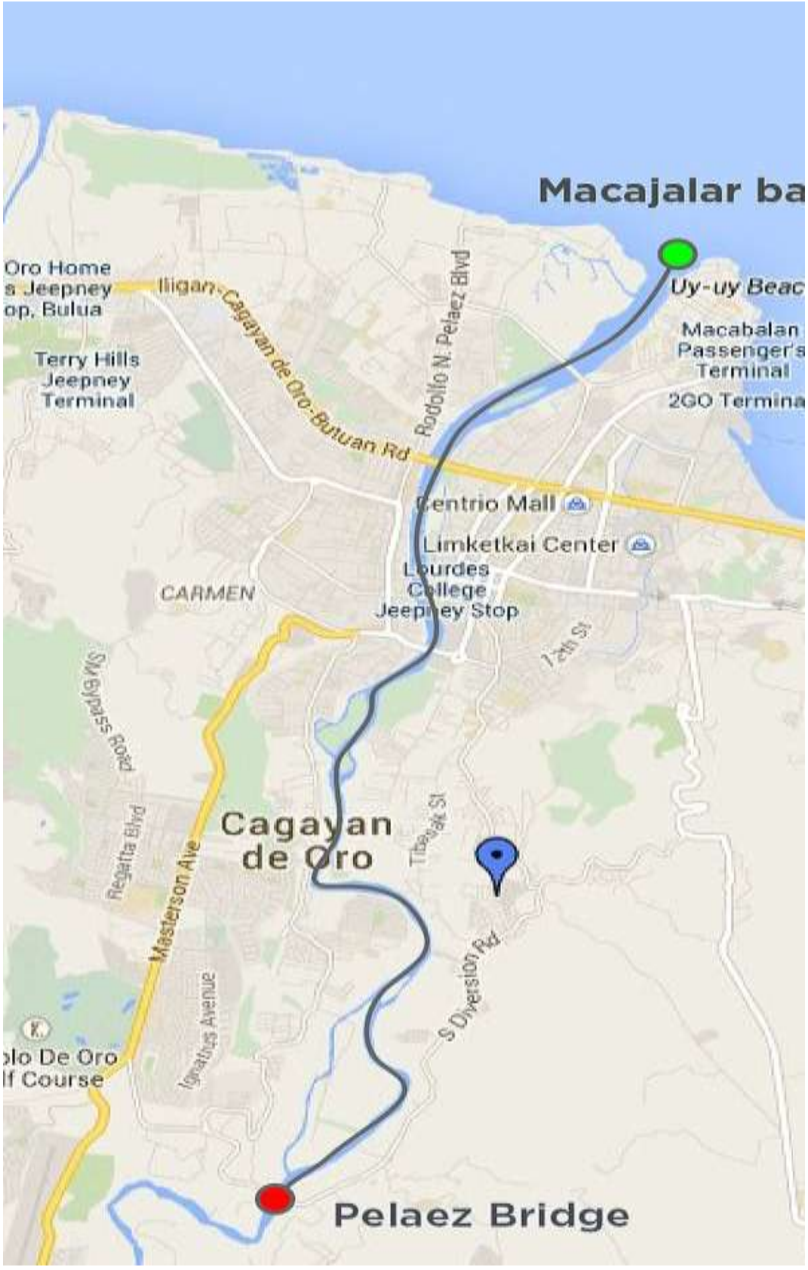


Figure 5.7: Map showing the proposed 12 km mega dike straddling the Cagayan de Oro River from the Pelaez Bridge to the river mouth (Tolinero, 2014).

5.2.3.2. Recommended management measures for the Cagayan de Oro River mouth and its coastal marine environments.

Based on the four key management principles and on-going programs, this study offers some concrete proposals on river mouth-coastal management that includes mangroves, corals and seagrasses:

1) Public education and awareness building. Owing to the lack of community concern for their coastal environment, the development plans of *Barangay*s Macabalan and Bonbon should include: regular intensive education campaigns on the existing threats to their marine and coastal resources; the exact locations of high-TSS concentration sites; and the various benefits of healthy marine resources to human communities. Disaster risks should be presented and understood from the perspective of local inhabitants (Burningham et al., 2008). The city government should coordinate similar efforts with the Macajalar Bay Development Alliance (MBDA) and ensure that various stakeholders participate in the campaign. The MBDA, established in 2008, is composed of 14 coastal cities and municipalities within the bay. It hopes to forge collective efforts and resources with other stakeholders to rehabilitate and manage Macajalar Bay.
2) Integrated urban and coastal development programs. In view of the continuing urbanization of the city and its coastal areas, it is imperative that the city and local governments, following the integration principle, should incorporate sustained coastal and marine resource management strategies into their development plans for the *barangay*s of Bonbon, Macabalan and Puntod There should be no conflict between urban/city development and natural resource conservation and protection. The human population's welfare and protection, situated in a specific natural environment, should be the government's paramount concern.
3) Implementation of action plans and public participation. Accumulation of garbage on seagrass sites should lead to concrete activities that are initiated and monitored at the

barangay level with identified people in charge, and small target communities. Regular (from weekly to annual) activities should include the following: coastal clean-up programs, proper rubbish disposal, coastal water quality monitoring, mangrove planting and maintenance, seagrass (small- and medium-size scales, percentage cover, canopy height, composition and depth limit) (Neckles et al., 2012) and coral monitoring (small- and medium-size scales, percentage cover, composition, coral health condition and new recruits) (Muhando, 2008).

4) Repair and reinforcement of river banks. The repair of eroded riverbanks and levees within the city is vital. This can be done by replanting trees and enforcing natural erosion control measures to reduce considerably further erosion and sedimentation along the river channel and its mouth. Specifically, a natural buffer should be established between the Cagayan de Oro River and the houses alongside the channel (city proper to Macabalan) to reinforce the existing concreted river dike (see Wolanski, 2006).

5) Increase mangrove cover along the banks. Continuous land progradation but slow mangrove colonization needs planting of riverine mangroves along the river banks, which will serve as natural sediment traps and a buffer against floods caused by river swelling (see Ewel et al.,1998). The increased mangrove area will reduce the sedimentation effect on coastal waters and consequently increase the river mouth's capacity to absorb pollutants, yet remain functionally stable (see Duke & Wolanski, 2001).

6) Increase mangrove cover along the coast. Expanding the fringe mangrove plantation along the foreshore will reduce shore erosion and protect coastal human communities from extreme wave impact (Ewel et al., 1998). Presently, the DENR-10 and coastal residents have planted *Rhizophora* on Bonbon's lowest intertidal zone. However, previous studies have proved the high mortality rate of *Rhizopora sp*. in most planting sites (Primavera & Esteban, 2008; Samson & Rollon, 2008). This study strongly suggests

transplanting existing *Rhizopora* trees to sheltered coastal sites and planting the more locally adapted *Sonneratia alba* and *Avicennia marina* on the lowest coastal zones, based on recommendations in Primavera and Esteban (2008) and in Samson and Rollon (2008).

7) Rehabilitation of coral reefs. Corals on Plots B and C have a relatively high potential for survival, due to the dominance of massive and sub-massive coral life forms. Further research can be pursued to determine the best rehabilitation techniques (Yeemin et al., 2006) (see also artificial reefs, Rilov &Benayahu (2002) and coral transplantation (Clark & Edwards, 1995) for the remaining coral, with the given freshwater and sediment inputs at the reef site.

8) Total ban of coastal waste disposal and other anthropogenic-based disturbances. Due to the present poor conditions of corals and seagrasses, the city and *barangay*s must enforce a ban against the disposal of any kind of waste from domestic households, ports, industries, agricultural farms and other sources into the coastal shore and waters (Islam & Tanaka, 2004). The ban should include any potentially destructive activities (e.g., dynamite fishing) threatening seagrasses and corals and associated fauna.

9) Establishment of MPAs. Further study can be done to determine the feasibility of establishing the coral and seagrass sites as MPA, to sustain coastal integrity and increase food production (Roberts et al., 2001; Weeks et al., 2010) within the overall context of an integrated ridge-to-reef rehabilitation and management plan (Cicin-Sain & Belfiore, 2005). As this will affect socioeconomic concerns, multi-sectoral interests should be considered and wide stakeholder consultations should be conducted before decisions are made (Klein et al., 2008; Pollnac et al., 2001). Concrete, alternative livelihood projects should be incorporated into the rehabilitation plan.

5.3. Some Recommendations to Further Improve the Present Study and Similar Research Initiatives

5.3.1. Chapter 2: Erosion-Sedimentation Process in the Catchment

Chapter 2's strength lies in its concepts and modelling work. The field data collection provided initial insights into catchment rainfall-river dynamics and final evaluations of the closeness between the simulated results and the actual conditions. The SWAT model itself generated reasonably good estimations of discharge volumes and sediment yields from each HRU. The variability of discharge and sediment yield results across the catchment reflected the unique condition of each unit's vulnerability to erosion. With these data, catchment rehabilitation measures became more direct and specific in their applications. However, the prescribed model data inputs, which were then limited, could be improved:

1) Increase the duration of rain and river gauge data collection to three years or beyond. The SWAT model simulations need adequate time to adjust to the changing performance of input variables. A longer period of simulation run will provide a better appraisal of the actual rain and river processes.
2) Increase the frequency of river data collection to an hourly rate, using an automatic data logger/s. A daily single-event measurement does not capture the complete pattern of performance exhibited by a river parameter during an entire day and night. Further, river dynamics, particularly during rainfall events, are characterised by high and low flows that must be accounted for in the study.
3) Enhance the prescribed data inputs for better representation of the entire catchment characteristics, especially the spatial heterogeneity of each unit being studied. In particular, these model data inputs should include rainfall, LUC, soil condition and topography.

5.3.2. Chapter 3: River-Suspended Sediment Distribution in the Bay

Using the Delft3D as the modelling tool, Chapter 3 demonstrated the general coastal surface current circulation (near the river mouth) as influenced by the bay-forcing factors in Macajalar Bay. The tool also kept track of the physical movement of river plume from the river opening to the site of persistent concentration and subsequent deposition under different discharge conditions. Simulated outputs helped locate the sites most likely affected by river-borne sediments in view of the presence of coral and seagrass communities within the river's coastal environs. However, the results and analyses could still be further improved; hence, the following recommendations:

1) Extend the sampling period for both river and coastal data collections to include the southwest monsoon months of July, August, September and October. This may show variations in coastal surface current circulation and sediment-dispersal patterns with the prevalence of strong southwest winds in the bay.
2) Use a floater with an attached GPS to track the surface current flow from the river mouth towards the sea. This exercise will provide insight into the actual flow velocity and directional patterns of surface current circulation. Field results will be used to validate the Delft3D model's simulated results.
3) Identification of river-borne sediments from bottom re-suspended ones. Proper classification of sediments, based on their immediate sources, cans clarify the extent and concentration of river sediment plume in inshore waters during actual field sampling.

5.3.3. Chapter 4: Implications of River and Coastal Sedimentation for the Distribution, Composition and Abundance of the Three Coastal Marine Habitats

Chapter 4 included the three important existing coastal communities at the mouth of the Cagayan de Oro River, and their basic ecological conditions in relation to the extent and concentration of river sediment plume. Temporal and spatial variations in the distribution, abundance and diversity of coastal habitats were accounted for in the case of mangroves. However, in relation to the coral and seagrass communities, their temporal variations were not included. This was due to the limited time for monthly sampling and the unavailability of previous studies and reports. Hence, the following recommendations are made to increase data inputs:

1) Establish monthly monitoring of the growth (morphometrics) and cover percentages of seagrass and of the health condition and recruitment rate of corals for one year or more. Monitoring results will show temporal variations in seagrass and coral growth and abundance due to sedimentation effects. Sedimentation rates in the site will also be measured monthly.
2) Conduct regular water quality monitoring of the sampling sites (seagrass and coral). Parameters of the seawater quality analysis should include the ff: salinity, temperature, TSS, water clarity, dissolved oxygen, nitrite, nitrate, ammonia, grease and trace metals. The results will give vital information about the level of coastal water pollution that may account for the limited distribution and low abundance and diversity of seagrass and coral habitats.
3) Use geochemical tracing method to identify and compare upland-derived sediment deposits in accreted coastal and bank landforms with the sediment types in eroded sub-catchments. This will confirm the specific upland sites as sources of sediments concentrated and deposited within coastal marine environs.

5.4. Relevance of the Study in International Context

This present study which investigated the erosion-sedimentation processes from the uplands down to coastal waters and its habitats, using different methodologies and models, is perhaps one of the few in the whole world. Most previous science studies, both local and international, confined their scope within a single unit (catchment or bay) or two adjacent units of systems (river mouth and coastal waters) which inevitably exclude parts of the catchment-coastal connectivity.

The present study hopefully opens new interests and opportunities among researchers across the globe to do catchment to coastal investigation of the effects of specific stressor on the entire natural landscapes. Its main relevance lies in the fact that with the ridge-rive-reef research framework, it is possible to conduct a science-based investigation on large connected landscapes and its complex systems with reasonably good results. The study highlighted the importance of a mixed yet integrated approach of analyses on various natural factors and their interplay for complete accounting of each effect on the others.

Applying the ridge-river-reef approach in local or in international contexts, important research and management initiatives are conducted at reasonably good accuracy level of predicted results. Thus, early appropriated intervention is specifically introduced at each affected part or component of a system. For example, in the uplands identified “hotspots” are priority sites for rehabilitation while other areas are placed under a protected zone. Rehabilitation and reforestation efforts will include priority sites along the natural continuum such as the river banks and the estuarine areas. In the river mouth-coastal waters, proper zoning is introduced as part of the integrated management plan of the area. Moreover, climate change effects on the local weather conditions are taken into account for better management of its adverse effects on the physical habitats and the ecosystems along the ridge-river-reef landscape and seascape. Finally, the integrated science approach has specifically identified (in the recommendations) ways to protect and promote the welfare and interest of human community vis-à-vis the natural and human-induced problems within the ridge-river-reef connectivity.

5.4. References

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List of Figures

List of Tables

Appendix A

Table 3.4: Key parameters of a hydrological process that were calibrated for simulations of water discharge and sediment yield processes

Parameter (Par)	Par Code	Min Value	Max Value	Initial Value	Calibrated
Surface runoff lag coefficient	SURLAG	1	12	4 hrs	1 hr
Curve Number	CN2	35	98	76	60.88
Ground Water Delay	GW_Delay	0	100	31 d	60 d
Base flow alpha factor	Alpha_BF	0	1	0.048	0.038
Soil available water content	SOL_AWC	0	1	0.45	0.20
Soil evaporation compensation factor	ESCO	0	1	0.95	0.60
Maximum Canopy Interception	Canmx	0	10	0	10
Deep aquifer percolation factor	RCHRG_dp	0	1	0.05	0

Appendix B:

List of sub-catchments with moderate to very high sediment yield values and their corresponding key attributes

Sub-basin no.	Potential risk	Sub-catchment	Land use/cover in %	Slope percent/ class	Rainfall input in 10 mos
66	Very high	Batang	32% is agriculture & 44% is pasture land; no forest cover	23% of land has > 30% slope	>3,787.91
68	Very high	Batang	49% of brushland; 46% of pasture lands; no forest	67% of land has ≥ 30 slope	>3,787.91
63	Very High	Batang	67% of brushland; 28% of pasture land	79% of land has ≥ 20% slope	>3,787.91
62	High	Batang	46% of brushland; 38% of pasture lands, 0.8% forest cover	35% of land has ≥ 20 % slope	>3,787.91
65	High	Batang	75% is pasture land; 21% of forest cover	37% of land has ≥ 20% slope	>3,787.91
52	Moderate	Batang	66% of brushland; 7% of agricultural lands; 4.27% of pasture lands; 22% forest cover	70% of land has ≥20% slope	2,657 mm
61	Moderate	Batang	70% of pasture land; 27% brushland	45% of land has ≥ 20% slope	2,657 mm
67	Moderate	Batang	73% is brushland; 26% is agricultural land; no forest cover	29% of land has ≥ 20 % slope	3,788 mm
70	Moderate	Batang	54% of agricultural lands; 38% of pasture land; 5.4% brushland; no forest cover	46% of land has ≥ 20% slope,	2,657 mm
72	Moderate	Batang	33% of agricultural lands, 33% of pasture land; 5.48% of brushland; and 26% of forest land	43% of land has ≥ 20% slope	2,665 mm
73	Moderate	Batang	41% is agricultural lands; 26% brushland; 2.5 pasture lands; 12% forest cover	43% of land has ≥ 20%	2,665 mm

Note: *Names of the sub-catchments followed the local names designated by the DENR for easy identification of sites on any published Cagayan de Oro River Catchment map.*

Tikalaan, Batang, and Pigcutin

Sub-basin no.	Potential risk	Sub-catchments	Land use/cover in %	Slope percent/class	Rainfall input in 10 mos
77	Moderate	Tikalaan & Batang	58% is agricultural land; 26% of brushland; 2.5% of pasture lands; and 12% forest cover	24% of land has ≥ 20 % slope	3,788 mm
79	Moderate	Tikalaan & Pigcutin	20% is agricultural land and 49% is brushland; 3.7% of pasture lands; 26% forest cover	30% of landscape has ≥ 20% slope	3,788 mm

Tumalaong and Tagiti

Sub-basin no.	Potential risk	Sub-catchments	Land use/cover in %	Slope percent/class	Rainfall input in 10 mos
21	Moderate	Tumalaong	66% of agricultural land; 29% pasture land; 2.7% of forest cover	27% of land has ≥ 20% slope	2,134 mm
25	Moderate	Tagiti	80% is pasture land; 0.8% of agricultural lands; 11% forest cover	42% of land has ≥ 20% slope	2,134 mm
35	Moderate	Tagiti	57% of agricultural lands; 42% of pasture land.	58% of land has ≥ 20% slope	2,134 mm

Pigcutin

Sub-basin no.	Potential risk	Sub-catchment cluster	Land use/cover in %	Slope percent/class	Rainfall input in 10 mos
36	Moderate	Pigcutin	47% is brushland; 32% pasture land & 17% agricultural lands; 0.026% of forest cover	55% of land has ≥30% slope	3,046 mm
37	High	Pigcutin	63% is agricultural; 29% are pasture land and brushland; no forest cover	45% of land has ≥30% slope	3,046 mm
40	Moderate	Pigcutin	57% of brushland; 35% of pasture land; 1.7% of forest cover	33% of land has ≥30% slope	3,046 mm

Bubunawan-Tumalaong-Munigi

Sub-basin no.	Potential risk	Sub-catchments	Land use/cover in %	Slope percent/class	Rainfall input in 10 mos
2	Moderate	Tumalaong & Munigi	89% of agricultural lands; 4.9% is barren; no forest cover	43% of land has ≥20% slope	2,844 mm
3	Moderate	Tumalaong & Tagiti	90% of agricultural lands; 7.1% is barren; no forest cover	30% of land has ≥20% slope	2844 mm
4	Moderate	Munigi & Pigcutin	93% agricultural lands; 6.3% is water; no forest cover	43% of land has ≥20% slope	2,844 mm
8	Moderate	Bubunawan	75% of agricultural lands; 15% of pasture land; 5.8% of brushland; 2.11% barren land	22% of land has ≥20% slope	2,844 mm

All values are based on the SWAT modeling results for each HRU/sub-catchment

Appendix C

Coral Cluster A (closest to the river mouth), Transect 1

CATEGORIES	**# Points**	**%**	**SW Index**	**Simpson (1-D)**
Coral lifeforms				
Acropora branching (ACB)	9	2.17	0.32	0.04
Acropora digitate (ACD)	1	0.24	0.08	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	22	5.30	0.35	0.23
Encrusting Coral (CE)	2	0.48	0.14	0.00
Foliose Coral (CF)	0	0.00	0.00	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	5	1.20	0.24	0.01
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	0	0.00	0.00	0.00
Submassive Coral (CS)	7	1.69	0.29	0.02
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	2	0.48	0.00	1.00
Abiotic				
Dead Coral (DC)	6	1.45	0.07	0.00
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	182	43.86	0.35	0.25
Sand (SA)	10	2.41	0.10	0.00
Silt (SI)	169	40.72	0.36	0.21
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	415.00	100.00		

Coral Cluster A (closest to the river mouth), Transect 2 –

CATEGORIES	# Points	%	SW Index	Simpson (1-D)
Coral lifeforms				
Acropora branching (ACB)	0	0.00	0.00	0.00
Acropora digitate (ACD)	0	0.00	0.00	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	0	0.00	0.00	0.00
Encrusting Coral (CE)	0	0.00	0.00	0.00
Foliose Coral (CF)	0	0.00	0.00	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	14	2.92	0.00	1.00
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	0	0.00	0.00	0.00
Submassive Coral (CS)	0	0.00	0.00	0.00
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	0	0.00	0.00	0.00
A				
Abiotic				
Dead Coral (DC)	3	0.63	0.03	0.00
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	171	35.70	0.37	0.14
Sand (SA)	63	13.15	0.27	0.02
Silt (SI)	228	47.60	0.35	0.24
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	479.00	100.00		

Coral Cluster B - Transect 3

CATEGORIES	# Points	%	SW Index	Simpson (1-D)
Coral lifeforms				
Acropora branching (ACB)	0	0.00	0.00	0.00
Acropora digitate (ACD)	0	0.00	0.00	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	4	1.02	0.20	0.01
Encrusting Coral (CE)	2	0.51	0.13	0.00
Foliose Coral (CF)	0	0.00	0.00	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	36	9.14	0.23	0.54
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	0	0.00	0.00	0.00
Submassive Coral (CS)	7	1.78	0.28	0.02
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	0	0.00	0.00	0.00
Abiotic				
Dead Coral (DC)	10	2.54	0.10	0.00
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	153	38.83	0.36	0.20
Sand (SA)	63	15.99	0.31	0.03
Silt (SI)	119	30.20	0.37	0.12
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	394.00	100.00		

Coral Cluster B – Transect 4

CATEGORIES	# Points	%	SW Index	Simpson (1-D)
Coral lifeforms				
Acropora branching (ACB)	2	0.49	0.04	0.00
Acropora digitate (ACD)	3	0.74	0.06	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	13	3.21	0.17	0.00
Encrusting Coral (CE)	12	2.96	0.16	0.00
Foliose Coral (CF)	10	2.47	0.15	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	97	23.95	0.36	0.22
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	1	0.25	0.03	0.00
Submassive Coral (CS)	70	17.28	0.37	0.11
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	1	0.25	0.00	1.00
Abiotic				
Dead Coral (DC)	4	0.99	0.08	0.00
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	35	8.64	0.31	0.03
Sand (SA)	55	13.58	0.36	0.08
Silt (SI)	102	25.19	0.34	0.27
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	405.00	100.00		

Coral Cluster C (farthest from the river mouth) – Transect 5

CATEGORIES	**# Points**	**%**	**SW Index**	**Simpson (1-D)**
Coral lifeforms				
Acropora branching (ACB)	0	0.00	0.00	0.00
Acropora digitate (ACD)	0	0.00	0.00	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	2	0.69	0.04	0.00
Encrusting Coral (CE)	30	10.34	0.27	0.02
Foliose Coral (CF)	0	0.00	0.00	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	162	55.86	0.23	0.54
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	0	0.00	0.00	0.00
Submassive Coral (CS)	26	8.97	0.25	0.01
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	2	0.69	0.00	1.00
Abiotic				
Dead Coral (DC)	25	8.62	0.37	0.14
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	40	13.79	0.31	0.35
Sand (SA)	3	1.03	0.14	0.00
Silt (SI)	0	0.00	0.00	0.00
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	290.00	100.00		

Coral Cluster C (farthest from the river mouth) – Transect 6

CATEGORIES	# Points	%	SW Index	Simpson (1-D)
Coral lifeforms				
Acropora branching (ACB)	0	0.00	0.00	0.00
Acropora digitate (ACD)	0	0.00	0.00	0.00
Acropora encrusting (ACE)	0	0.00	0.00	0.00
Acropora submassive (ACS)	0	0.00	0.00	0.00
Acropora tabulate (ACT)	0	0.00	0.00	0.00
Branching Coral (CB)	3	1.39	0.10	0.00
Encrusting Coral (CE)	8	3.70	0.19	0.01
Foliose Coral (CF)	0	0.00	0.00	0.00
Heliopora (CHL)	0	0.00	0.00	0.00
Massive Coral (CM)	93	43.06	0.16	0.68
Millepora (CME)	0	0.00	0.00	0.00
Mushroom Coral (CMR)	0	0.00	0.00	0.00
Submassive Coral (CS)	9	4.17	0.20	0.01
SC				
TP (Tape)	0	0.00	0.00	0.00
00FFFF				
Soft Coral (SC)	3	1.39	0.00	1.00
Abiotic				
Dead Coral (DC)	4	1.85	0.13	0.00
Rock (RCK)	0	0.00	0.00	0.00
Rubble (R)	68	31.48	0.26	0.46
Sand (SA)	28	12.96	0.36	0.08
Silt (SI)	0	0.00	0.00	0.00
OT				
TP (Tape)	0	0.00		0.00
Total pts. minus (tape+wand+shadow):	216.00	100.00		

Appendix D

Plot A - Seagrass sampling site in Macabalan

H pinofolia **n= 17**

Transect 1	**1**	**2**	**3**	**4**	**5**	**Ave**	**% Cover**
Q1	28	15.8	14.7	16.5	29.3	20.86	25
Q2	18.6	23.1	15.3	27	10.4	18.88	29
Q3	21.1	20	26.4	18.1	12.9	19.7	38
Q4	25.5	23	19.1	25.1	19.4	22.42	25
Q5	23	21	28.5	17.9	25.8	23.24	36
Q6	16.8	24.2	16.9	24.7	19.8	20.48	31
Q7	13.6	16.4	21.5	27.8	17.3	19.32	2
Q8	17.3	32	34.7	26.8	21.6	26.48	20
Q9	15.3	21.8	19.8	17.3	20	18.84	25
Q10	20.2	15	15.5	18.9	18.1	17.54	37
Q11	15.5	21.4	18.5	19.5	20.8	19.14	30
Q12	26.4	25.2	16.9	12.3	20.7	20.3	11
Q13	14.8	22.8	18.8	22.8	23.3	20.5	15
Q14	20	17	22.5	17.5	18.5	19.1	44
Q15	20.4	16.8	23	18	17	19.04	56
Q16	26.3	21	17.2	23.6	26.2	22.86	50
Q17	20.4	18.3	19.6	15.4	20.4	18.82	16
Average seagrass cover in transect 1							**28.8235**

H. pinifolia **n= 26**

Transect 2	**1**	**2**	**3**	**4**	**5**	**Ave**	**% Cover**
Q1	14	11.9	15.2	18	17.5	15.32	13
Q2	14	15.5	16.2	16.8	17.8	16.06	25
Q3	10.7	5.2	6.3	5	4.3	6.3	25
Q4	17.5	15.5	17.2	15.1	11	15.26	25
Q5	12.2	22	20.8	21.3	19.8	19.22	21
Q6	12.3	9	18.5	20.7	18.3	15.76	25
Q7	19	13	11.5	13.5	10.2	13.44	25
Q8	11.5	12	15	10	10.5	11.8	25
Q9	6.4	8.2	7	7.5	5	6.82	25
Q10	11	8	13	11.5	13.5	11.4	22
Q11	17.9	10.2	12.5	9.4	13.2	12.64	25
Q12	11.2	11.9	10	14.9	15.5	12.7	25
Q13	19.5	10.5	16.8	12	10	13.76	25
Q14	15.2	12.1	13.4	13	12	13.14	24
Q15	11	20	12.1	14	10.1	13.44	25
Q16	8.5	8.5	10	9.8	15.5	10.46	25

Q17	11	14	12.5	10	5.7	10.64	25
Q18	11.3	13	14	15.5	20.5	14.86	14
Q19	15	13	12.5	14.5	10	13	25
Q20	20.8	25	16.2	14.9	15	18.38	25
Q21	18.3	21	25	23.5	13.5	20.26	25
Q22	18.6	22.1	23.7	22	14.5	20.18	23
Q23	20.4	20	23.5	19.7	19.5	20.62	25
Q24	19.6	18.6	20.7	21.4	18.7	19.8	25
Q25	22.4	21.2	21.4	20.6	21.4	21.4	22
Q26	20.7	19.4	20.6	19.8	22	20.5	2
Average seagrass cover in transect 2							**22.7308**

Plot B - Seagrass sampling site in Macabalan

H. pinifolia **n= 14**

Transect 1	**1**	**2**	**3**	**4**	**5**	**Average**	**% Cover**
Q1	10.2	15.8	21	12	9.5	13.7	18
Q2	13.5	6	15.5	19.5	10	12.9	30
Q3	18.5	17.5	25.5	14.5	12.5	17.7	20
Q4	15.5	17	11.5	14	13.5	14.3	20
Q5	7.5	10.5	9	11	13	10.2	10
Q6	8	11.5	12	9	6.5	9.4	11
Q7	8	13	10.5	15	10.5	11.4	10
Q8	14	8.5	18.3	10	8.5	11.86	13
Q9	6.5	14.5	20.5	24	20	17.1	15
Q10	11	16.3	9	19	13.8	13.82	25
Q11	14.5	18.5	11	10.5	17.2	14.34	80
Q12	18.5	10.5	14.5	10.8	14	13.66	80
Q13	18.3	18.7	15.1	11.2	12	15.06	25
Q14	19	17.6	18.2	10.2	14	15.8	10
Average seagrass cover in transect 1							**26.214**

H. pinifolia **n= 19**

Transect 2	**1**	**2**	**3**	**4**	**5**	**Average**	**% cover**
Q1	23.5	16.5	21.5	34	29	24.9	89
Q2	28	19.5	18	19.6	14.8	19.98	89
Q3	7.5	11	8.5	9.5	13.5	10	13
Q4	16.5	17.5	14.5	17.3	17	16.56	85
Q5	13.5	12.3	11.8	16.5	12.5	13.32	80
Q6	16.5	13	10.8	14	19	14.66	31
Q7	11.5	10.5	11.5	16	12.5	12.4	80
Q8	15.5	15	16	20	13.5	16	63

Q9	14	17	14.5	11.5	12	13.8	11
Q10	12	14	18	17	18	15.8	40
Q11	9	11.5	10.5	8	6.5	9.1	23
Q12	12.5	10.5	13	12	14.3	12.46	25
Q13	15	14	13.2	16	8	13.24	18
Q14	14.5	13	13	11	17	13.7	23
Q15	7	10.3	12	8.3	5.2	8.56	12
Q16	21	11.5	9	12	13.5	13.4	17
Q17	11.5	16.5	11	9.5	13.5	12.4	17
Q18	14.5	12	9.5	11	11.5	11.7	17
Q19	14	12.5	16.5	21	9	14.6	17
Average seagrass cover in transect 2							**39.47368**

Plot C – Seagrass community in Macabalan

Transect 1	1	2	3	4	5	Ave	% cover
Q1 (***C. serrulata)***	22	18	21	24	20	21	1%
Q2	17	22	23	28	25	23	14%
Q3	29	28	30	19	18	24.8	4%
Q4	27	24	16	17	0	16.8	3%
Q5	25	22	17	14	24	20.4	5%
Q6	22	19	26	22	23	22.4	2%
Q7	30	27	27	24	0	21.6	21%
Q8	22	16	30	24	25	23.4	22%
Q9	22	14	20	18	18	18.4	25%
Q10	32	32	24	23	27	27.6	29%
Q11	20	17	19	20	16	18.4	25%
Q12	24	27	28	26	29	26.8	25%
Q13	29	26	28	19	20	24.4	24%
Q14	28	16	23	27	24	23.6	25%
Q15	27	26	31	24	25	26.6	25%
Q16	18	16	16	0	0	10	3%
Average *C. serrulata* cover in transect 1							**16%**

Transect 1 *(H. ovalis)*	1	2	3	4	5	Average	% cover
Q17 ***)***	4	4.5	4	2.5	3.5	3.7	25%
Q18	3.5	4.5	3.5	4	5	4.1	25%
Q19	5	4	5.5	5	5.5	5	25%
Q20	7.5	6	6	5	4.5	5.8	21%
Q21	6	7.5	7	7	1.5	5.8	25%
Q22	6.5	6	7	7	7	6.7	25%
Q23	6	5	6	4	4	5	23%

Q24	6	5	5	5	4.5	5.1	25%
Q25	6	3	5	6.5	6	5.3	25%
Q26	8	5	6	7	5	6.2	10%
Average *H. ovalis* cover in transect 1							**23%**

Plot C

Transect 2	**n=21**						
C. serrulata	**1**	**2**	**3**	**4**	**5**	**Ave**	% cover
Q1	6	5.5	5	6	5	5.5	10%
Q2	4.5	4.5	4.5	4	4.5	4.4	8%
Q3	5.5	5.5	6	5	4	5.2	25%
Q4	3.5	2	2	3	1	2.3	2%
Q5	88	10	108	59	98	72.6	25%
Q6	62	56	63	60	35	55.2	10%
Q13	27	25	23	30	19	24.8	25%
Average *C. serrulata* cover in transect 2							**15%**
Q7 (H. ovalis)	5	4.5	4.5	5	4	4.6	7%
Q8	7	7	6	7.5	7	6.9	15%
Q9	7	5.5	5	6	6	5.9	21%
Q10	8	9	8	8.5	6	7.9	25%
Q11	1.5	3	3.5	3	6	3.4	6%
Q12	3	4	3	3.5	3	3.3	25%
Q14	3.5	3	3	3	4	3.3	24%
Q15	4	3.5	3	4	4	3.7	25%
Q16	25	25	22	21	18	22.2	23%
Q17	19	20	20	18	16	18.6	8%
Q18	4	3	2	2	2.5	2.7	4%
Q19	24	25	25	20	17	22.2	25%
Q20	19	20	19	0	0	11.6	21%
Q21	60	119	106	135	139	111.8	25%
Average *H ovalis* cover in transect 2							**18%**

Left: Gauged rainfall sampling
in Nangka, Libona, Bukidnon
with community participants

Top: Field survey along the
banks of the Cagayan
de Oro River

Top: River water sample collection
at the Taguanao Bridge

Left: River plume sampling along Macabalan coast with the MMC and the ERC staff

Top: Seagrass sampling in Macabalan inshore waters with the MMC staff

Top: Coral sampling in Bonbon coastal waters with the MMC staff

Left: Mangrove field validation
in mudflat area in Bonbon

Top: Rainfall data collection
at the PAGASA station
in Malaybalay City

Top: Weather data collection at the PAGASA
station in El Salvador, Misamis Oriental